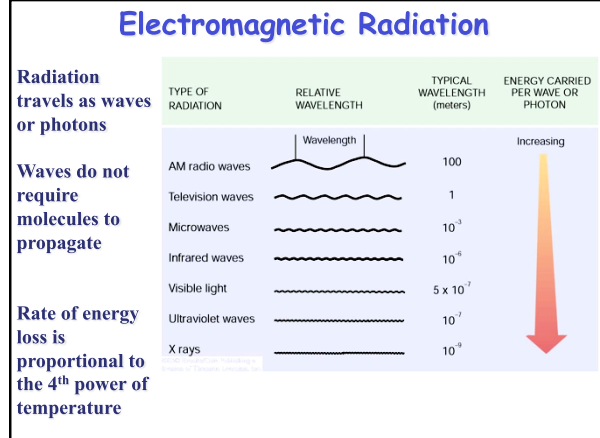


## Atmospheric Radiation



## Ways to label radiation

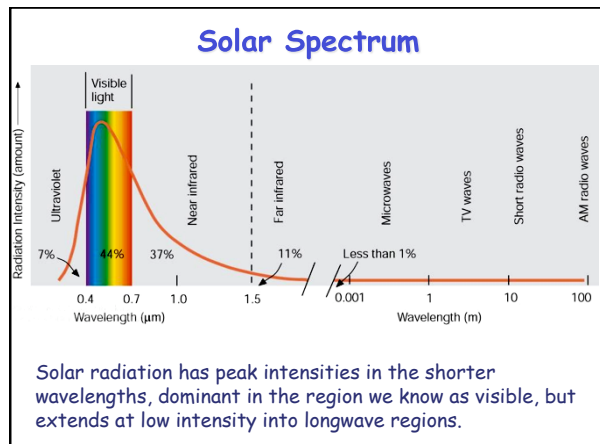
- By its **source**
  - Solar radiation - originating from the sun
  - Terrestrial radiation - originating from the earth
- By its **name**
  - ultra violet, visible, near infrared, infrared, microwave, etc....
- By its **wavelength**
  - short wave radiation < 3 micrometers
  - long wave radiation > 3 micrometers

## Black Body Radiators

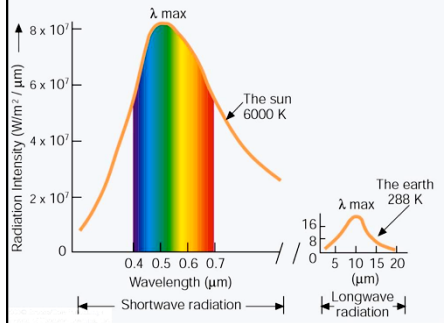
- Hypothetical objects that **absorb all of the radiation that strikes them**. They also emit radiation at a maximum rate for its given temperature.
  - Does not have to be black!
- The energy emission rate is given by
  - Stefan Boltzmann law (total energy)
  - Wien's law (peak emission wavelength)
  - Planck's law (wavelength dependent emission)

## Basic Radiation Laws

- **Stefan-Boltzmann law:**
  - ( $E = \sigma T^4$ ) (energy flux in Watts/m<sup>2</sup>)
  - As T increases, E increases by a power of 4. If T doubles, E increases by 16 times!
- **Wien's law:**
  - $\lambda_{max} \sim 3000/T$  ( $\lambda_{max}$  is in  $\mu\text{m}$  and T is in Kelvin)
  - Wavelength of peak radiation emitted by an object is inversely related to temperature
- **Planck's law:**
  - Describes the emission of radiation in each wavelength, as a function of temperature



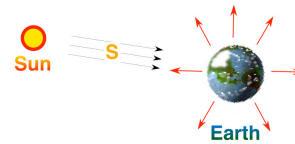
## Shortwave and Longwave Radiation



The hot sun radiates at shorter wavelengths that carry more energy.

Energy absorbed by the cooler earth is then re-radiated at longer wavelengths, as predicted by Wein's law.

## Earth Radiation Balance



Incoming Energy = Outgoing Energy

$$(\text{absorbed sunshine})(\text{area}) = (\text{thermal loss})(\text{area})$$

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

If the earth always radiates energy, why doesn't it cool?

*It is in a state of radiative equilibrium.*

Incoming radiation is balanced by outgoing radiation.

At what temperature is this equilibrium reached for the earth system? 255 K.

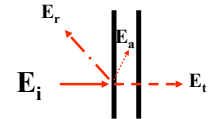
- Radiative equilibrium predicts surface temperature of about 255 K (or about  $-18^\circ\text{C}$ )
- But, the earth's observed average surface temperature is  $\sim 15^\circ\text{C}$ .

Why? The answer lies in an understanding of absorption, reflection, transmission of radiation.

## Conservation of Energy

- Radiation incident upon a medium can be:
  - Absorbed
  - Reflected
  - Transmitted

$$E_i = E_a + E_r + E_t$$



## Short Wave (Solar) Radiation

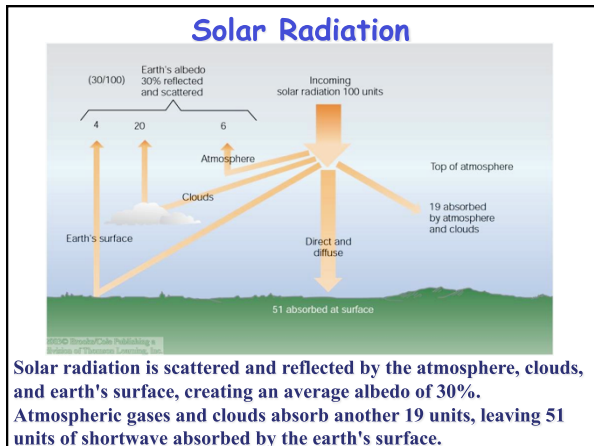
- **Absorbed** by the atmosphere
- **Reflected** by clouds, particles and air molecules back to space
- **Transmitted** to the surface
  - where it is
    - absorbed
    - reflected back upward into the atmosphere
      - some of this may be absorbed by the atmosphere
      - some may be transmitted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

## Reflection

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

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.



### Scattering: Why is the sky blue?

- Sunlight is *scattered* by air molecules
- Air molecules are much smaller than the light's wavelength
- 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 wavelengths 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 wavelengths are also scattered
  - Sun appears red/orange

### Atmosphere is Warmed from Below

Latent heat released

Convection

Conduction

Absorption and emission of infrared radiation by H<sub>2</sub>O and CO<sub>2</sub>

**Solar radiation passes first through the upper atmosphere, but only after absorption by earth's surface does it generate sensible heat to warm the ground and generate longwave energy. This heat and energy at the surface then warms the atmosphere from below.**

### Long Wave (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 LW emission upward joins that from the surface escaping to space, thus cooling the planet.

### 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

Day

Warm

Asphalt Road  
(warms due to solar radiation)

Night

Cool

Asphalt Road  
(cools by IR radiation)



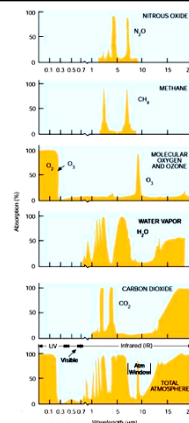
## Atmospheric Absorption

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<sub>2</sub>
- O<sub>3</sub>
- Clouds



## Molecular Absorbers/Emitters

Molecule	Arrangement	Persistent Dipole Moment
N <sub>2</sub>		No
O <sub>2</sub>		No
CO		Yes
CO <sub>2</sub>		No
N <sub>2</sub> O		Yes
H <sub>2</sub> O		Yes
O <sub>3</sub>		Yes
CH <sub>4</sub>		No

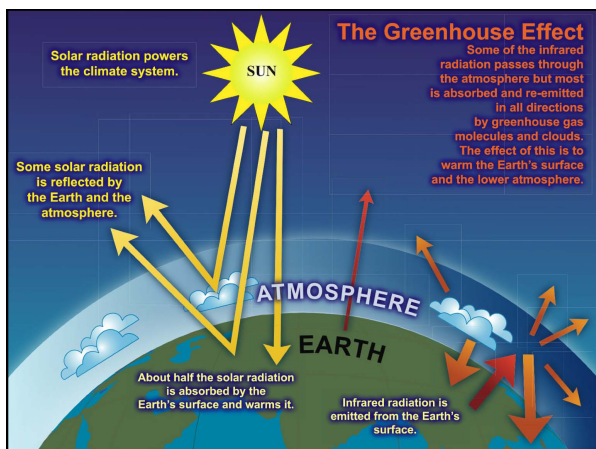
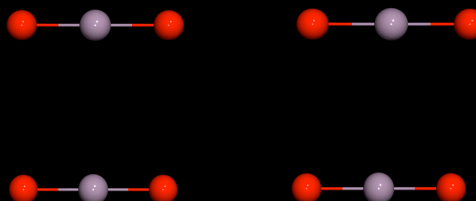
Diatomic Structures	
N <sub>2</sub> , O <sub>2</sub> , CO	

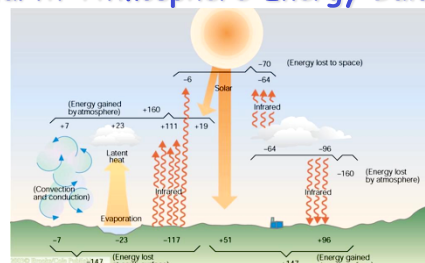
Triatomic Structures	
CO <sub>2</sub> , N <sub>2</sub> O	
H <sub>2</sub> O, O <sub>3</sub>	

- 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
- Different **molecular structures produce wavelength-dependent absorptivity/emissivity**

## CO<sub>2</sub> Vibration Modes



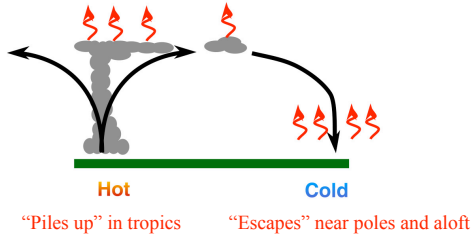
## Earth-Atmosphere Energy Balance



Earth's surface absorbs the 51 units of shortwave and 96 more of longwave energy units from atmospheric gases and clouds. These 147 units gained by earth are due to shortwave and longwave greenhouse gas absorption and emittance. Earth's surface loses these 147 units through convection, evaporation, and radiation.

## The Job of the Atmosphere

is to let the energy out!



*The movement of the air (and oceans) allows energy to be transported to its "escape zones!"*