MONDAY AM
Radiation, Atmospheric Greenhouse Effect

Radiation

- Heat Transfer – Radiation
- Understanding the *Electromagnetic Spectrum & Energy Balance*

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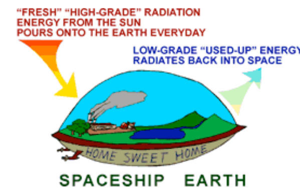
It all starts with the Sun

- Nuclear fusion in the Sun powers all changes on the Earth!
- Solar energy heats the air, lifts it, blows it around, evaporates water, makes snowstorms ...
- Conversion of solar energy and downhill dissipation as heat energy drive all weather and climate phenomena

Energy comes in hot, and goes out cold (at 342 W / m²)



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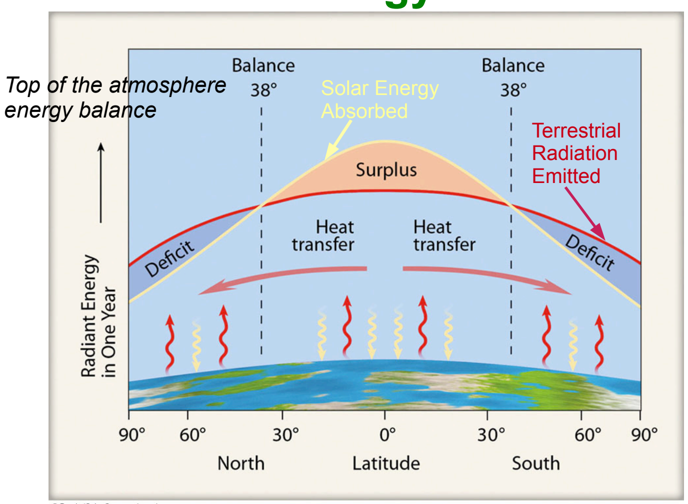
Earth's Energy Balance



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Heat Transfer Processes

- *Conduction:* molecules transfer (kinetic) energy by colliding with one another and imparting their momentum
- *Convection:* fluid moves from one place to another carrying it's heat energy with it
  - In atmospheric science, convection is conventionally associated with vertical movement of the fluid (air or water), whereas advection is used for the horizontal movement
- ***Radiation:*** transfer of heat between objects without requiring contact or fluid in between

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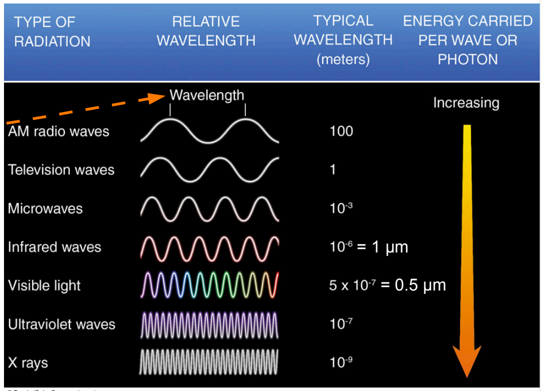
Radiation = Electromagnetic Waves

Any object that has a temperature radiates!

Radiation travels as waves/photons (at the speed of light, c ~ 300,000 km/s ~ 186,000 mi/s)

Wavelength (λ) conveniently measured in micrometers: 1 μm = 10^{-6} m

Electromagnetic Waves do **not** require a medium (such as air) to propagate



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frequency (f) = c / λ and Energy ~ f ~ 1 / λ

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: λ ≤ 3 micrometers
  - long wave radiation: λ > 3 micrometers

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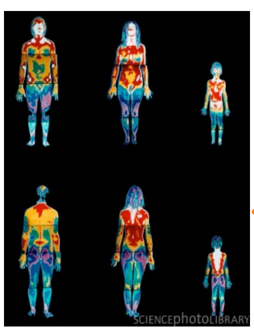
Radiation = Electromagnetic Waves

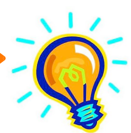
Any object that has a temperature radiates!

Total possible rate of energy radiation from an object is given by: $E = \sigma T^4$

σ – constant, T – Temperature (K), Units: Watts per m^2

Doubling temperature = increasing intensity of radiation by factor of 16!





Light Bulb: ~ 3000 K (~ 5000 F)

Human Body: ~ 100 F (~ 310 K)

light bulb radiates 10,000 times as strongly as human body

Trees emit radiation:

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Temperature vs Wave Type

- Hotter objects emit electromagnetic waves (radiation) with more energy than colder objects
- Waves with more energy have shorter wavelengths (e.g. ultraviolet radiation is more likely to burn your skin than visible radiation)
- The wavelength at which an object emits its maximum amount of radiation is inversely proportional to the object's temperature:

$$\lambda_{max} = \frac{3000}{T}$$

T – Temperature in K, λ_{max} – wavelength at maximum radiation in µm = 10^{-6} m (micrometers)

⇨ **Wien's Law (pronounce "Veen")**

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Higher Temperature → Smaller Wavelength

- Human body: 310 K (100 F) → peak wavelength of emission ~ 10 µm (mid-infrared)
- (conventional) Light bulb: 3000 K (5000 F) → peak wavelength of emission ~ 1 µm (near-infrared, compare visible light: 0.4–0.7 µm)
- higher temperature → smaller wavelength

$$\lambda_{max} = \frac{3000}{T}$$

T – Temperature in K, λ_{max} – wavelength at maximum radiation in µm = 10^{-6} m (micrometers)

⇨ **Wien's Law (pronounce "Veen")**

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Basic Radiation Laws

- Stefan-Boltzmann law:
  - ($E = \sigma * T^4$) (energy flux in Watts / m^2)
  - As T increases, E increases by a power of 4. If T doubles, E increases by 16 times!
- Wien's law:
  - $\lambda_{max} = 3000 / T$, λ_{max} is in µm 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

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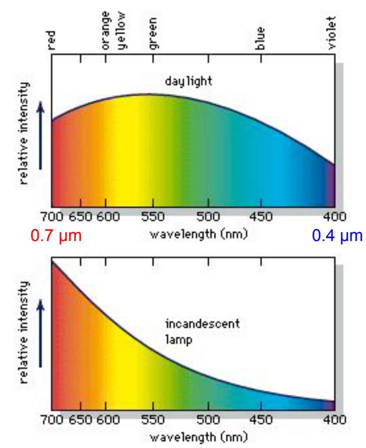
Spectra of visible light from the sun vs that from a conventional (incandescent) light bulb

Recall the light bulb's maximum intensity is around 1 µm, i.e. to the left of the graph



1 µm = 1000 nm

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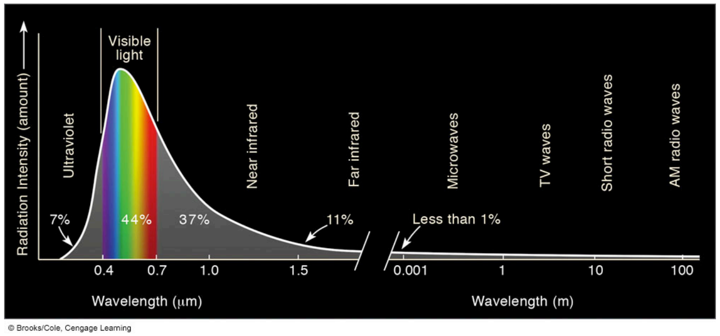
The Sun's Emission Spectrum

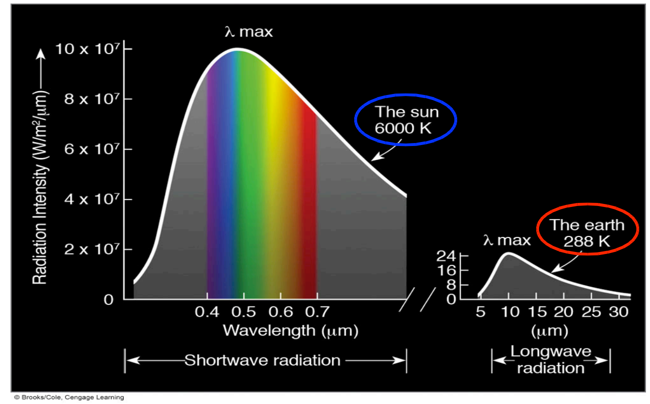


$$\lambda_{max} = \frac{3000}{T}$$

λ_{max} ~ 0.5 μm → T_{sun} ~ 6000 K

Our eyes have adapted to wavelengths corresponding to peak radiation by the sun

Sun vs Earth Emission Spectra



Sun: "shortwave" radiation

Earth: "longwave" radiation

Black Body Radiators

- Hypothetical objects that absorb all of the radiation that strikes them
- They also emit radiation at a maximum rate for their given temperature
- Black body radiators are not necessarily black!
- Sun and Earth are approximately black body radiators (snow is in the infrared!)
- The energy emission rate is given by:
  - Stefan-Boltzmann law (total emission)
  - Wien's law (peak emission wavelength)
  - Planck's law (wavelength dependent emission)