MONDAY: energy in and energy out on a global scale

Energy & Radiation, Part II

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

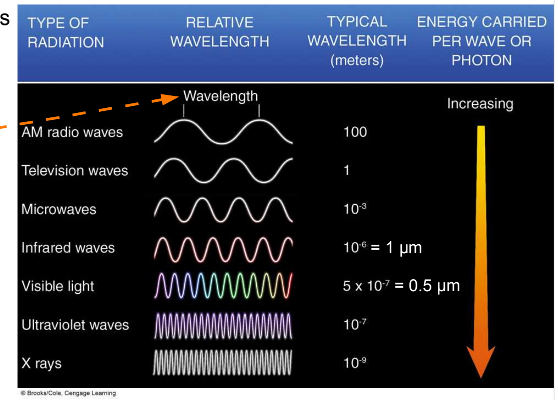
Radiation = Electromagnetic Waves

Any object that has a temperature radiates!

Radiation travels as waves/photons (at the speed of light, c ~ 300,000 km/s ~ 671,000 mph)

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

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



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

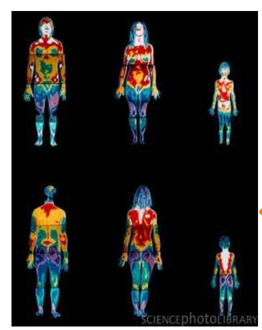
Radiation = Electromagnetic Waves

Any object that has a temperature radiates!

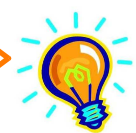
Total possible rate of energy radiation from an object is given by: $E = \sigma T^4$

σ – constant, T – Temperature (K), Units: Watts per m²

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



Human Body: ~ 100 F (~ 310 K)



Light Bulb: ~ 3000 K (~ 5000 F)

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

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Trees emit radiation:

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")**

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")**

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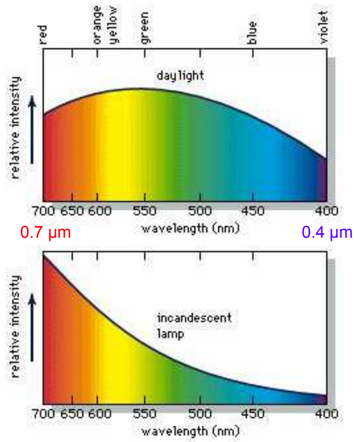
Spectra of visible light from the sun vs that from a conventional (incandescent) light bulb

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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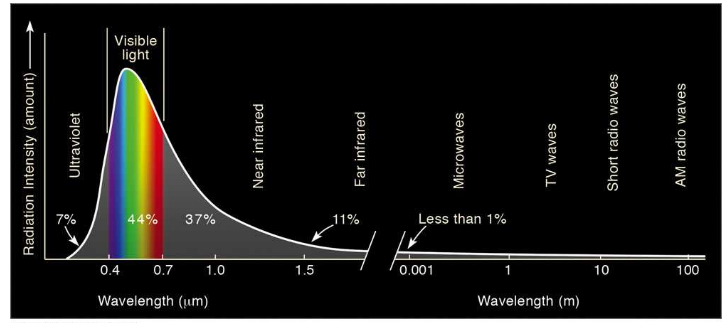
The Sun's Emission Spectrum



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

λ_{max} ~ 0.5 µm → T_{sun} ~ 6000 K

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

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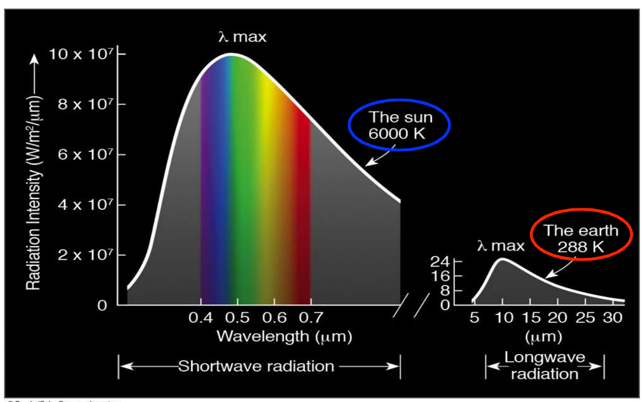
Sun vs Earth Emission Spectra



Sun: "shortwave" radiation Earth: "longwave" radiation

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