Lecture 33, Dec 1, 2022

Thermal Radiation

- Consider an enclosure at temperature T_{surr} filled with vacuum, containing an object of temperature T_s
  - $T_s = T_{surr}$ at equilibrium
- Thermal radiation is energy emitted by matter as a result of its finite temperature
  - Radiation has wave patterns (EM waves)
  - Thermal radiation typically has wavelengths of 0.1 to 100µm
    * UV is 0.1 to 0.4µm
    * Visible radiation is 0.4 to 0.7µm
    * IR radiation is 0.7 to 100µm
- Radiation is released with energy level changes from an excited state
  - When radiation is absorbed we go from lower to higher energy states, similar to spectroscopy
  - For infrared radiation this corresponds to vibrational energy levels
  - Visible radiation corresponds to electronic energy levels (typically outer electrons)
- Radiation is a volumetric phenomenon, but most solids are "opaque", so emissions from within the object will just be immediately reabsorbed
  - This is why we usually consider it a surface property
- A blackbody is a perfect emitter and absorber of radiation
  - At a given temperature, no surface can emit more energy than a blackbody
  - It also emits radiation equally in all directions ("diffuse" emission)
- Stefan-Boltzmann Law: The radiation energy emitted by a blackbody per unit time per unit area is given by $E_b = \sigma T^4$ for the Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}\,\mathrm{W/m^2\,K^4}$
  - E_b is the blackbody emissive power
- A blackbody is a theoretical object, but some things come close:
  - Black paint
  - Isothermal cavity (e.g. a box with a very small hole, the hole is a blackbody)
- The spectral distribution of blackbody radiation has the form $\dfrac{c_1}{\lambda^5 \exp\left(\frac{c_2}{\lambda T}\right) - 1}$
- In a real body, the radiation emission and absorption are dependent on wavelength and direction
  - e.g. CO_2's absorption spectrum absorbs more in the region of sunlight reflected by Earth's surface, which causes the greenhouse effect
  - Real surfaces can emit more in certain directions
  - Real surfaces also never have the same overall emission power as a blackbody
- We can define the emissivity: $\varepsilon(T) = \dfrac{E(T)}{E_b(T)}$
  - This is integrated over all directions and wavelengths
  - To simplify calculations, we assume ε is independent of λ (gray surface) and θ (diffuse surface)
  - This gives us the formula we already know: $E(T) \approx \varepsilon\sigma T^4$
- Consider a surface with some incident radiation G; some will be reflected, G_{ref}; some will be absorbed, G_{abs}; some will be transmitted, G_{tran}
  - Define the absorptivity $\alpha = \dfrac{G_{abs}}{G}$, the reflectivity $\rho = \dfrac{G_{ref}}{g}$, and the transmittivity $\tau = \dfrac{G_{tran}}{G}$
  - For a general material these have to sum to 1; for an opaque material $\tau = 0$, so $\alpha + \rho = 1$
  - A blackbody has $\rho = 0$ and so $\alpha = 1$
  - We assume a gray body, where α, ρ, τ are independent of λ, and diffuse, where α, ρ, τ are independent of θ