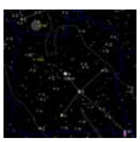
PHYS 2380 Quantum Physics 1

Lecture 3 – Light – Introduction to Blackbody radiation

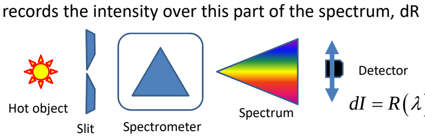
Outline

- Empirical observations of black body radiation
- Rayleigh-Jeans theory and its failure
- Planck theory for black body radiation




Black body radiation

- Radiation emitted by all objects as a result of their non-zero temperature: Black body radiation video
- The detector intercepts part of the spectrum from λ to λ+dλ and records the intensity over this part of the spectrum, dR

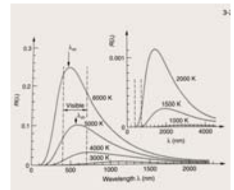


$$dI = R(\lambda)\, d\lambda$$

- Where R(λ) is called the radiancy or intensity per unit wavelength, or spectral distribution

Black body spectrum

- The spectrum depends only on the temperature of the body
- The peak of the distribution, λ_m shifts as the temperature changes.
- The total intensity, R, is the area under the R(λ) curve
- These are summarized by:
- The Wien displacement law
- The Stefan-Boltzmann law
- σ = 5.6703 x 10^{-8} W/m^2K^4



$$\lambda_m T = 2.898\times10^{-3}\, m\bullet K$$

$$R = \int_{over\ all\ \lambda} R(\lambda)\, d\lambda = \sigma T^4$$

Application to our sun

- λ_m for sunlight is approximately 500 nm
  - What is the surface temperature of the sun?
  - How much thermal energy is being radiated by the sun every second?
  - If a similar sized star emits 10 times this amount of energy what would the λ_m for that star be?
- Surface temperature of the sun:

$$\lambda_m T = 2.898\times10^{-3}\ mK$$

$$T = \frac{2.898\times10^{-3}\ mK}{\lambda_m} = \frac{2.898\times10^{-3}\ mK}{5.00\times10^{-7}\, m}$$

$$= 5796\, K$$

Application to our sun

- Thermal energy radiated by the sun:
- Energy radiated per unit area:

$$R = \sigma T^4 = \left(5.67\times10^{-8}\, W/m^2K^4\right)\left(5796\, K\right)^4$$

$$= 6.40\times10^{7}\, W/m^2$$

- Surface area of the sun: $A = 4\pi r_{sun}^2 = 4\pi\left(6.95\times10^{8}\, m\right)^2 = 6.070\times10^{18}\, m^2$
- Total energy radiated:

$$P = AR = \left(6.40\times10^{7}\, W/m^2\right)\left(6.070\times10^{18}\, m^2\right)$$

$$= 3.885\times10^{26}\, W$$

Application to another star

– If a similar sized star emits 10 times this amount of energy what would the λ_m for that star be?

$$T \propto \frac{1}{\lambda_m};\ R \propto T^4 \Rightarrow R \propto \frac{1}{\lambda_m^4};$$

$$\therefore \frac{R_1}{R_2} = \frac{\lambda_{m2}^4}{\lambda_{m1}^4} \Rightarrow \frac{\lambda_{m2}}{\lambda_{m1}} = \sqrt[4]{\frac{R_1}{R_2}} = \sqrt[4]{\frac{1}{10}} = \frac{1}{1.78}$$

$$\lambda_{m2} = \frac{\lambda_{m1}}{1.78} = \frac{500\,nm}{1.78} = 281\,nm$$

Application to the human body

- The human body has a temperature of 37 C.
  – How much thermal energy does it radiate?
  – How much energy does it have to produce to maintain this temperature?

$$37C \Rightarrow (273+37)K = 310K$$

$$R = \sigma T^4 = (5.67\times10^{-8}\,W/m^2K^4)(310\,K)^4$$

$$= 524W/m^2$$

$$P = AR = (1.73\,m^2)(524W/m^2) = 907W$$

Google says that on the average the human body has a surface area, A, of 1.73 m^2

Application to the human body

– How much energy does it have to produce to maintain this temperature?

- The body also absorbs energy from its surroundings. Assuming a temperature of 300 K for the surroundings:

$$R_{abs} = \sigma T_{sur}^4 = 459W/m^2$$

$$\Delta R = R_{emit} - R_{abs} = 524W/m^2 - 459W/m^2$$

$$\Delta R = 64.4W/m^2$$

$$\Delta P_{tot} = \Delta R\,A = (64.4W/m^2)(1.73\,m^2) = 111.4W$$

– I calorie = 4.18 Joules; 1 Calorie = 1000calories
– 111.4 W = 26.7 cal/s = 95,953 cal/hr = 96 Cal/hr
– Or 2300 Cal/day (255 Cal in one glazed donut)