Phys 301 Class 14
Blackbody Radiation
(Maybe Compton Effect)

What is a "Blackbody"?

- Theoretical object
- Perfectly absorbs all electromagnetic radiation.
- Emits radiation at same rate absorbed.
- Our model: stars

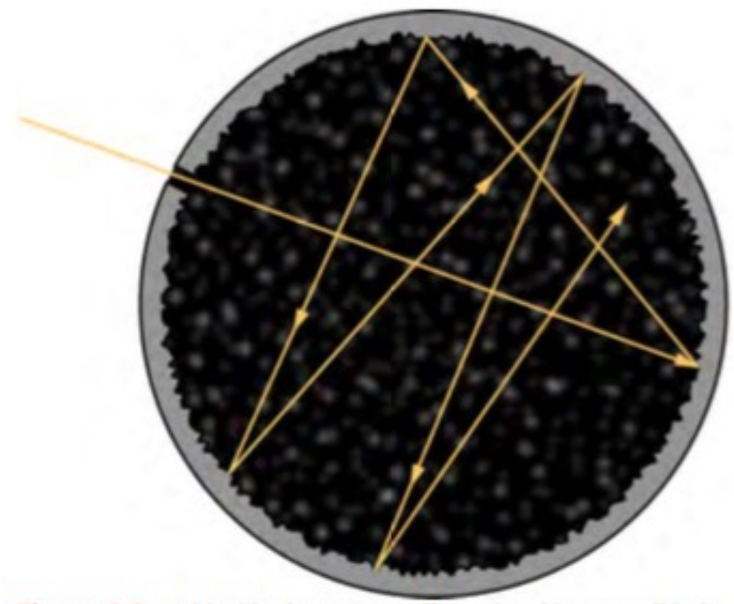


Figure 6.2 A blackbody is physically realized by a small hole in the wall of a cavity radiator.

Alberio: A Famous Double Star

Handout Part I

Summary

- As temperature increases…
- Peak wavelength decreased (peak frequency increases)
  - Wien's Law: $\lambda_{\mathrm{peak}} T = 2.898 \times 10^{-3} \mathrm{m} \cdot \mathrm{K}$
- Total power radiated increases (integral)
  - Stefan's Law: $P(T) = \sigma A T^4$
  - Stefan-Boltzman Constant: $\sigma = 5.670 \times 10^{-8} \frac{\mathrm{W}}{\mathrm{m}^2 \mathrm{K}^4}$

The Planck Function

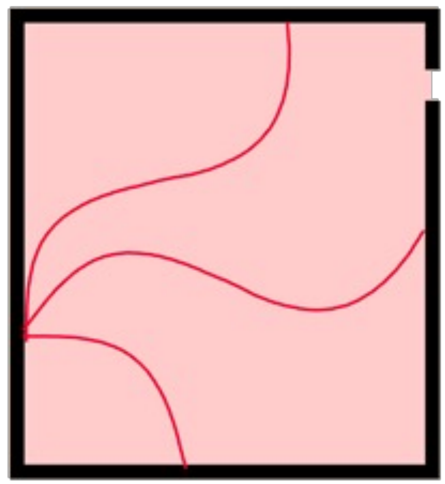
$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda kT} - 1}$$

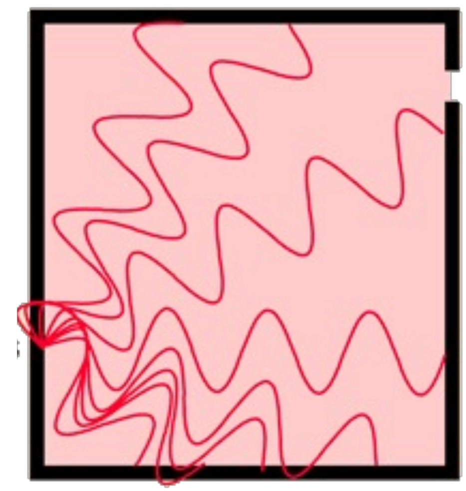
Experimentally determined by 1900s – but why this shape?

Some factors of π? Differences between power per area per solid angle…

Back to the "Blackbody"

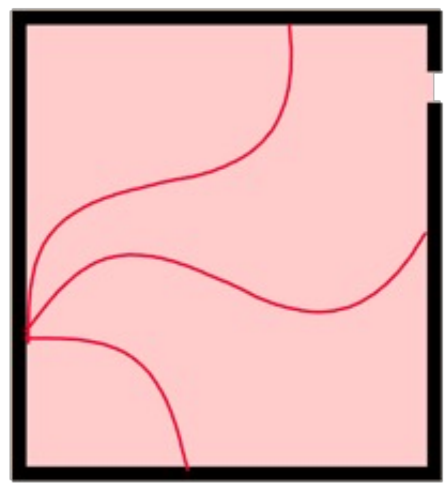
- If light is a wave, reflecting off of sides. Boundary conditions (*E*-field = 0 at the wall) Standing waves!
- Number of modes proportional to frequency squared.

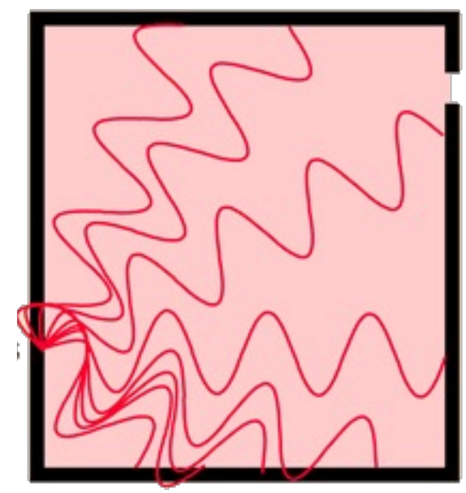




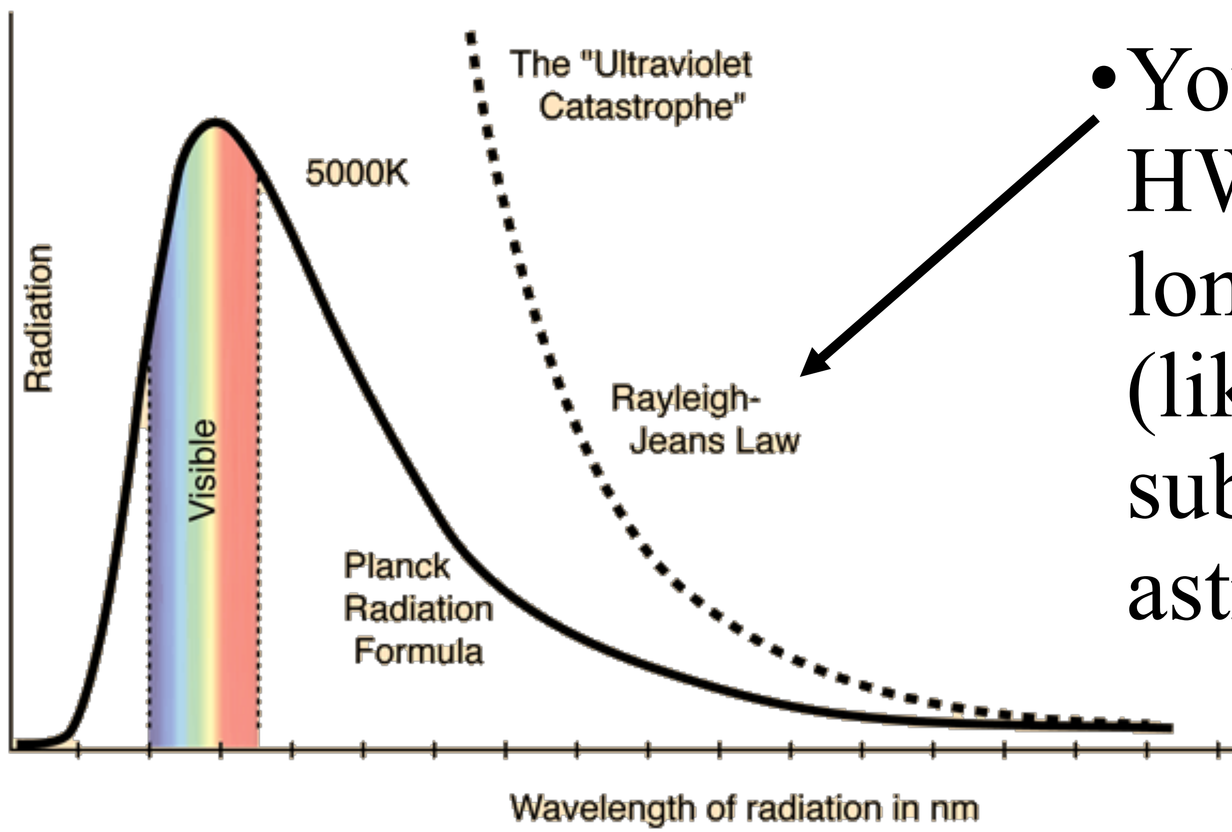
Back to the "Blackbody"

- If any energy possible… and all equally likely ("equipartition theorem" from classical physics)...
- Unlimited energy!



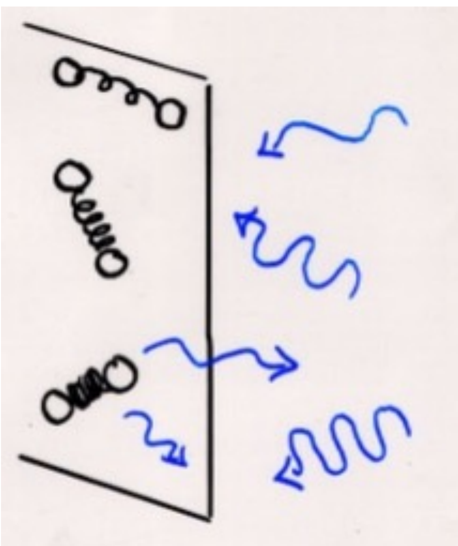


Ultraviolet Catastrophe



- You'll derive in HW: works fine for long wavelengths (like awesome submillimeter astronomy).

How to Resolve? 1900, Max Planck



- Wall is composed of little oscillators.
- Oscillators absorb and emit radiation.
- Vibrate at frequency *f*, absorb and emit at frequency *f*.
- If all *f* allowed, most oscillators will have high *f*, UV dominates.

Quantization

- Every oscillator can ONLY have energy which is an INTEGER multiple of some tiny tiny value ϵ.
- Allowed: $\epsilon, 2\epsilon, 3\epsilon, \cdots, n\epsilon$
- Forbidden: $\frac{1}{2}\epsilon, 3.7\epsilon, \sqrt{2}\epsilon$
- Planck puts the "*quanta*" in *quantum mechanics*.

If so…

- Relative probability that oscillator has energy ϵ while in thermal contact with walls of temperature *T*:

$$\text{Rel Prob}\ (\epsilon) = \frac{1}{e^{(\epsilon/kT)} - 1}$$

- Result: Unlikely for any oscillator to have large energy. Unlikely to emit a large amount of energy.

Energy and Frequency Related for an oscillator.

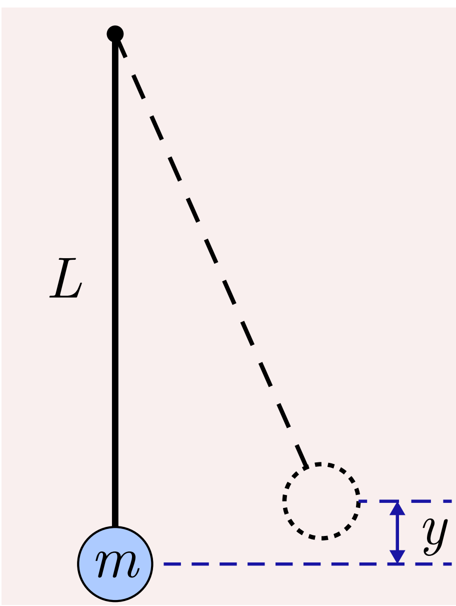
$$E_n = n\epsilon$$

$$E_n = nhf = n\frac{hc}{\lambda}$$

$$h = 6.626 \times 10^{-34} \mathrm{J} \cdot \mathrm{s}$$

Planck's Constant

How is Energy Quantized in "Real World"? Why did no one notice?



- Pendulum $L = 25$ cm, $m = 0.01$ kg
- Swings with frequency $f = 1$ Hz.
- $E = mgy$

$$E_1 = 1hf = mgy_1$$
$$E_2 = 2hf = mgy_2$$

$$\Delta E = (2hf - 1hf) = mgy_2 - mgy_1$$
$$hf = mg\Delta y$$

$$\frac{hf}{mg} = \Delta y \quad = \frac{(6.626 \times 10^{-34}\mathrm{J \cdot s})(1\ \mathrm{Hz})}{(0.01\ \mathrm{kg})\left(9.8\,\frac{\mathrm{N}}{\mathrm{kg}}\right)}$$
$$= 6.76 \times 10^{-33}\mathrm{m}$$

What Have We Learned?

- Young's Double Slit Experiment
  - Light acts like a wave.
- Blackbody Radiation, Planck Function
  - Energy is quantized.
- Compton Scattering and Photoelectric Effect
  - Light acts like a particle.
- Compton Scattering handout