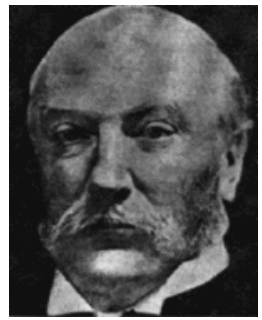
History: some troubling experiments

Around the turn of the century (last century, 1900), there were a series of experiments that were not consistent with the laws of classical physics. Finding a way to explain these observations lead to the birth of Quantum Mechanics.

- Blackbody Radiation
  - Stefan-Boltzmann and Wien displacement Law
  - Rayleigh-Jeans Law (ultraviolet catastrophe)
  - Planck's quantum hypothesis
- Atomic Hydrogen Spectrum
  - Bohr model of the hydrogen atom
- Photoelectric Effect
  - Threshold energy
  - Instantaneous character – no time delays
  - Independent of intensity

Blackbody: Rayleigh-Jeans

Rayleigh and Jeans used classical mechanics and derived the wavelength dependence of the emitted light,



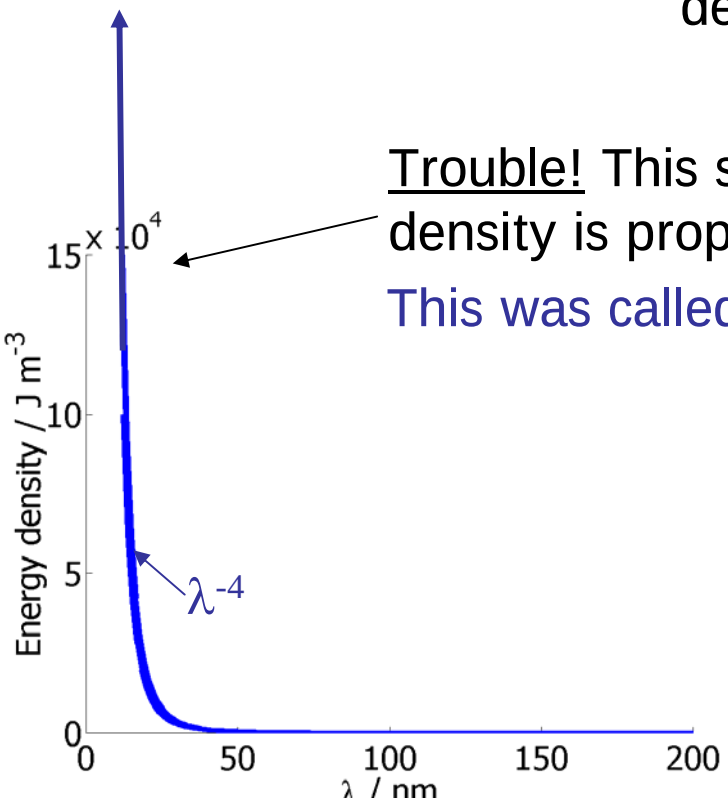
Lord Rayleigh

Rayleigh-Jeans law: $d\varepsilon = \rho\, d\lambda$

Energy density $\left(\mathbf{J \cdot m^{-3}}\right)$

$\rho = \frac{8\pi kT}{\lambda^4}$

wavelength: $\lambda = \frac{c}{\nu}$

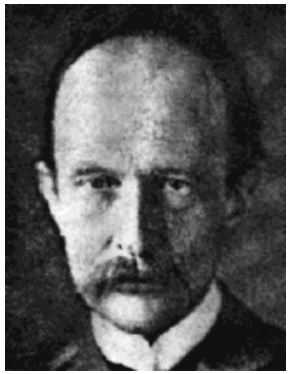


Trouble! This says the energy density is proportional to λ^{-4}

This was called the **ultraviolet catastrophe**

Classical mechanics says that even at low temperatures there should be huge amount of energy emitted at short wavelengths!?

Blackbody: Planck



Planck (1900)

wavelength: $\nu\lambda = c$

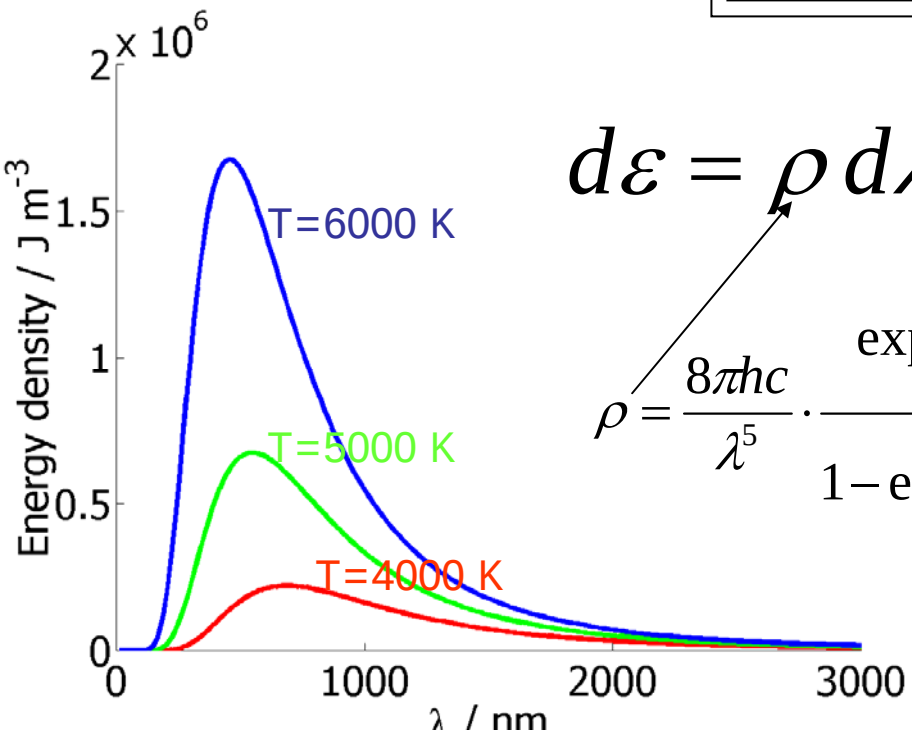
The BIG CONTRIBUTION!

Planck suggests that radiation can only come in packets that are the size of $h\nu$. This is equivalent to quantization of the field.

Planck's constant

$$E = h\nu$$

$$h = 6.626\times10^{-34}\ \mathbf{J\cdot s}$$



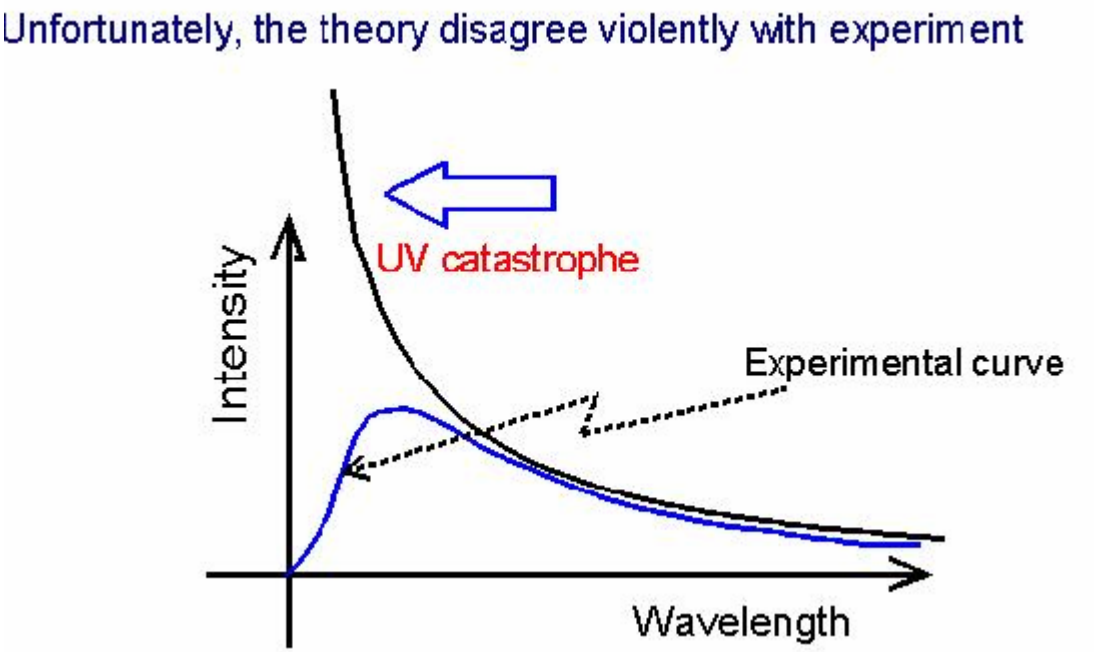
$$d\varepsilon = \rho\, d\lambda$$

$$\rho = \frac{8\pi hc}{\lambda^5}\cdot\frac{\exp\left(\frac{-hc}{\lambda kT}\right)}{1-\exp\left(\frac{-hc}{\lambda kT}\right)}$$

-By requiring a minimum amount of energy to excite a given frequency, $E=h\nu$, the catastrophe is avoided:

$$\lambda \to 0 \quad d\varepsilon \to 0$$

- A black body absorbs and emits all frequencies of radiation without favor.
- Blackbody radiation is the radiation emitted at different wavelengths by a heated black body, for a series of temperatures.

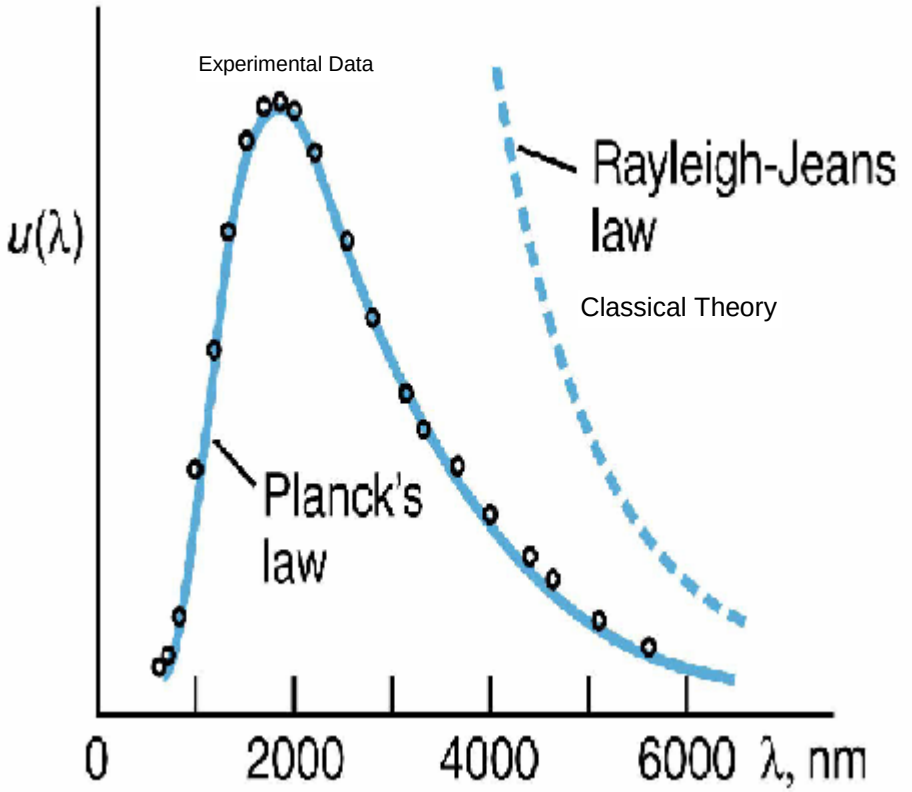


The ultraviolet catastrophe is the classical prediction that any black body at any temperature should emit intense ultraviolet radiation. If this were the case, Earth would be uninhabitable.

Rayleigh-Jeans used the assumptions of classical mechanics and derived an exact equation for the spectral distribution assuming that the radiating hot body is made up of a large number of tiny oscillators. Their equation is :

$$\rho d\upsilon = \frac{8\pi\upsilon^{0}\mathrm{KT}}{\mathrm{C}^{2}} d\upsilon$$

Where $\rho d\upsilon$ is the radiation intensity between frequencies υ and $\upsilon+d\upsilon$ at absolute temperature. The equation predicts the Intensity to increase continuously as The square of the frequency which is Proved to be correct at the longer wavelength (IR) but completely wrong at the shorter Wavelength (UV), this phenomena is Known as UV-Catastrophe, as in the figure. It shows the Planck'slaw (experimental data) And Raylieh-Jeans law (classical theory), and Because $\lambda=C/\upsilon$ the classical theory predict that As $\lambda=0$ (high frequency) the radiation intensity $\rho d\upsilon =$ infinity oops!



Max-Planck

was able to explain the experimental results of Raylieh and Jeans by assuming that the vibrating constituents of a hot body could only emits energy in a discrete amounts called **quanta** and that the energy of each quantum was equal to $h\upsilon$ where υ was the frequency of the oscillator and h is the now famous Planck's constant, so with Planck's assumption The idea of the existence of discrete energy state in matter was born. From Planck assumption if λ=0 (high frequency) the radiation intensity $\rho d\upsilon = 0$ thus UV catastrophe is history.