Why Quantum Physics?

- "Classical Physics":
  - developed in 15th to 20th century;
  - provides very successful description of "every day, ordinary objects"
    - motion of trains, cars, bullets,….
    - orbit of moon, planets
    - how an engine works,..
  - subfields: mechanics, thermodynamics, electrodynamics,
  - Quantum Physics:
    - developed early 20th century, in response to shortcomings of classical physics in describing certain phenomena (blackbody radiation, photoelectric effect, emission and absorption spectra…)
    - describes "small" objects (e.g. atoms and their constituents)

Some key events/observations that led to the development of quantum mechanics…

- Black body radiation spectrum (Planck, 1901)
- Photoelectric effect (Einstein, 1905)
- Model of the atom (Rutherford, 1911)
- Quantum Theory of Spectra (Bohr, 1913)
- Compton effect (Compton, 1922)
- Exclusion Principle (Pauli, 1922)
- Matter Waves (de Broglie 1925)
- Experimental test of matter waves (Davisson and Germer, 1927)

Thermal radiation

- Hot filament glows.
- Classical physics cant explain the observed wavelength distribution of EM radiation from such a hot object.
- This problem is historically the problem that leads to the rise of quantum physics during the turn of 20^{th} century

Blackbody Radiation

- **An object at any temperature is known to emit thermal radiation**
  - **Characteristics depend on the temperature and surface properties**
  - **The thermal radiation consists of a continuous distribution of wavelengths from all portions of the em spectrum**

- **At room temperature, the wavelengths of the thermal radiation are mainly in the infrared region**

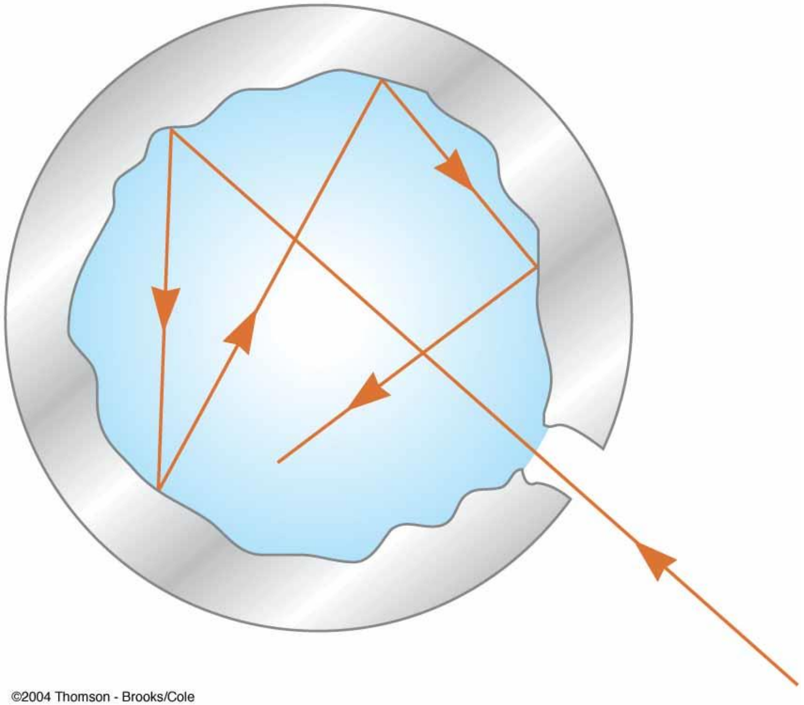
Blackbody Radiation

- As the surface temperature increases, the wavelength changes
  - It will glow red and eventually white
- The basic problem was in understanding the observed distribution in the radiation emitted by a black body
  - Classical physics didn’t adequately describe the observed distribution

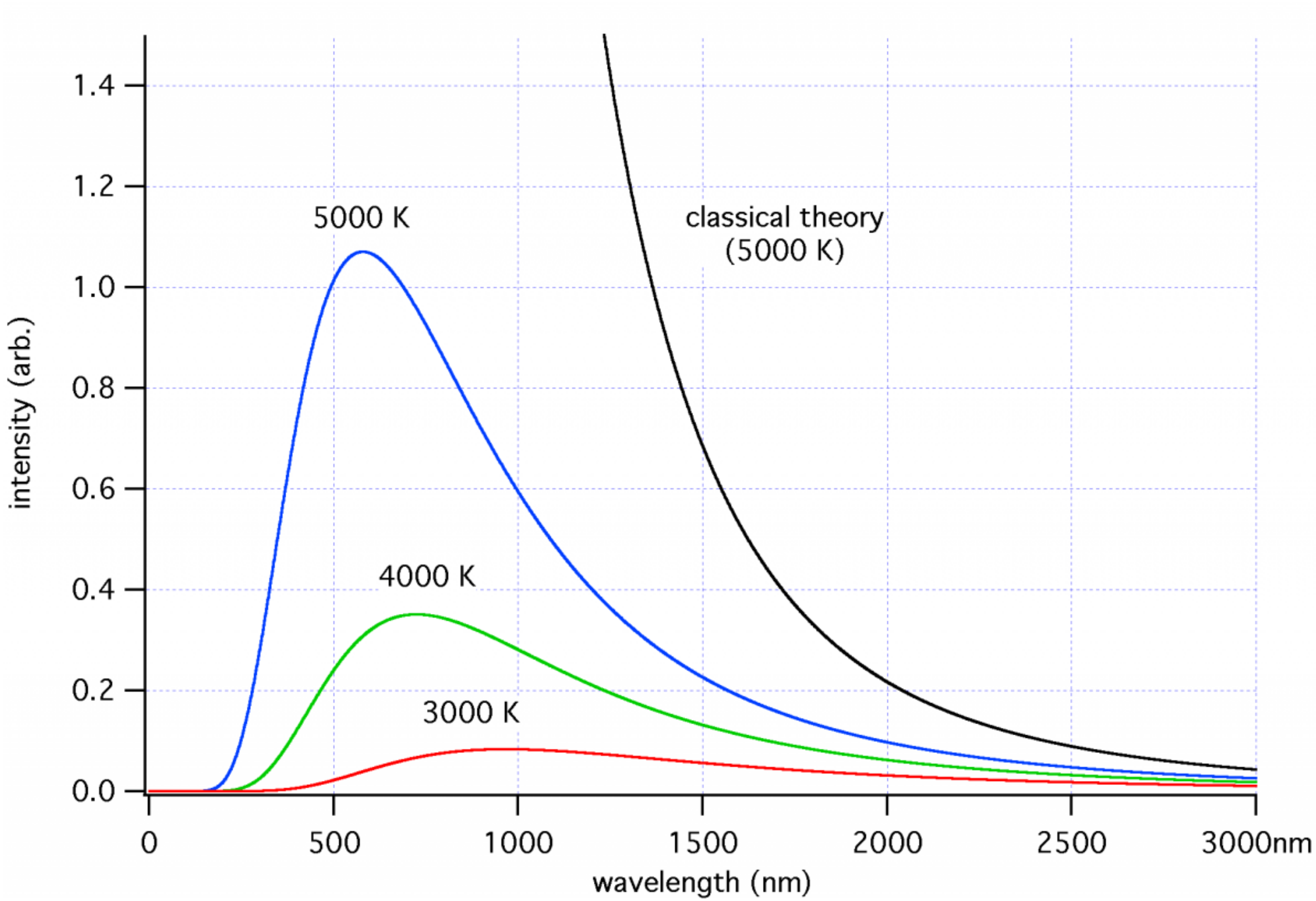
- A black body is an ideal system that absorbs all radiation incident on it
- The electromagnetic radiation emitted by a black body is called blackbody radiation

Blackbody Approximation

- A good approximation of a black body is a small hole leading to the inside of a hollow object
- The hole acts as a perfect absorber
- The nature of the radiation leaving the cavity through the hole depends only on the temperature of the cavity



Blackbody Radiation Spectrum



Wien's displacement law (1893):

the peak of the curve shifts towards longer wavelength as the temperature falls

$$\lambda_{peak} T = b$$

where b is called the **Wein's constant.**

This law is quite useful for measuring the temperature of a blackbody with a very high temperature.

The above laws describes the blackbody radiation very well.

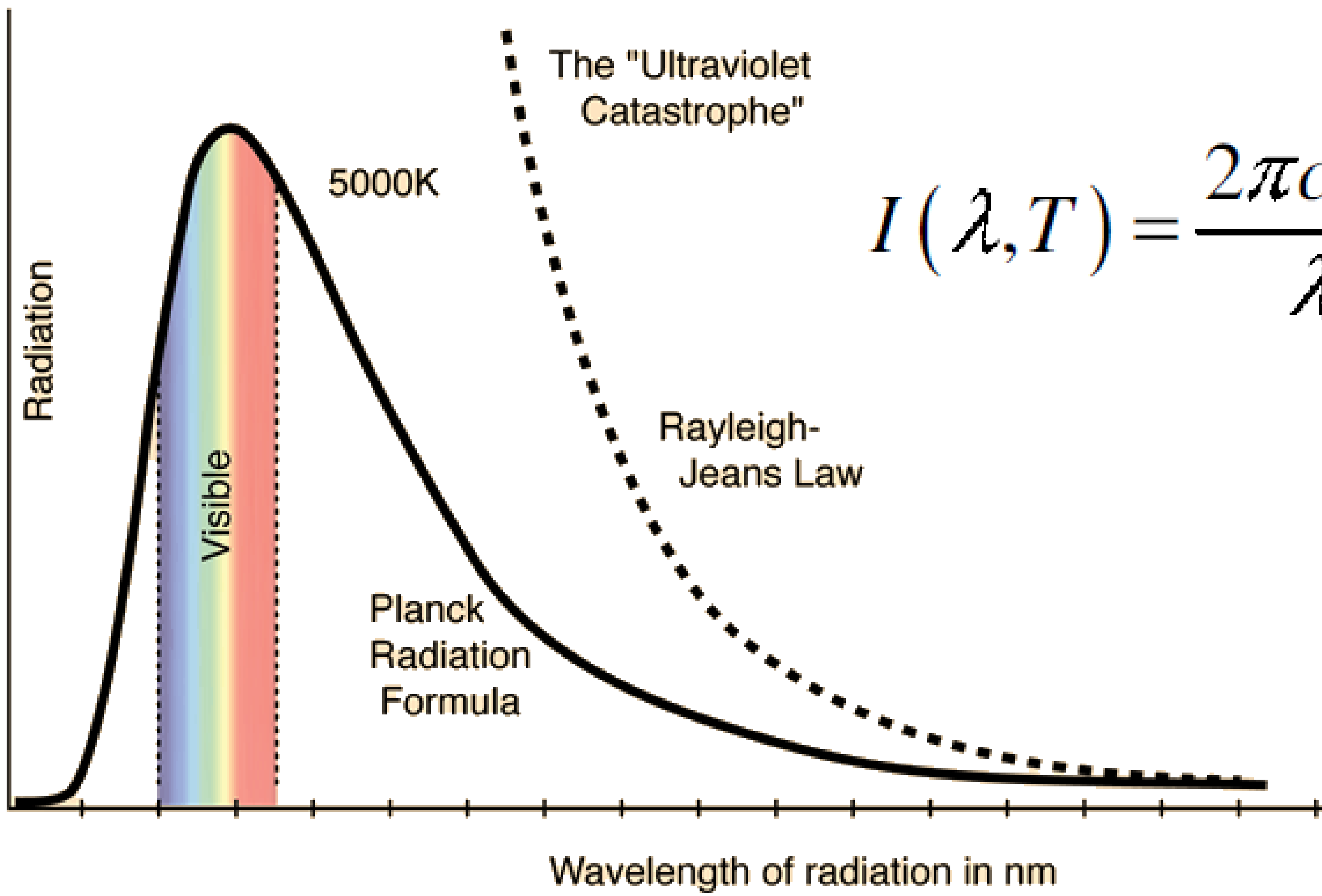
- **Rayleigh and Jeans**

In 1890, Rayleigh and Jeans obtained a formula using the classical electromagnetic (Maxwell) theory and the classical equipartition theorem of energy in thermodynamics .The formula is given by

$$I(\lambda, T) = \frac{2\pi c k_B T}{\lambda^4}$$

Rayleigh-Jeans formula was correct for very long wavelength in the far infrared but hopelessly wrong in the visible light and ultraviolet region.

Ultraviolet catastrophe



$$I(\lambda, T) = \frac{2\pi c k_B T}{\lambda^4}$$

- **Wein's formula:**

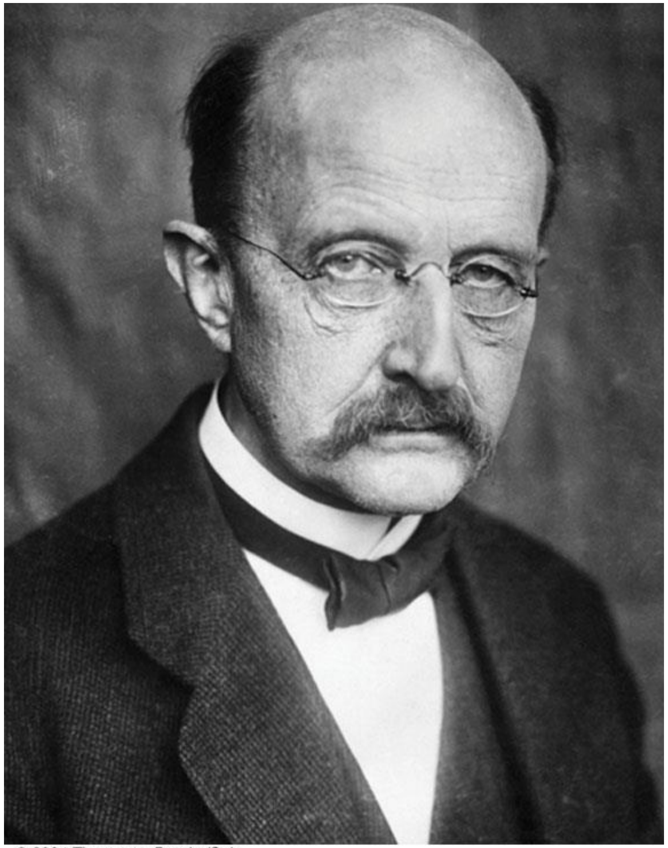
Later on in 1896, Wein derived another important formula using thermodynamics.

$$E_{\lambda}(T) = C_2 \lambda^{-5} e^{-\frac{C_3}{\lambda T}}$$

Unfortunately, this formula is only valid in the region of short wavelengths.

Max Planck

- Introduced the concept of "quantum of action"
- In 1918 he was awarded the Nobel Prize for the discovery of the quantized nature of energy



Planck's radiation law

- Planck assumed that the radiation in the cavity was emitted (and absorbed) by some sort of "oscillators" contained in the walls. He used Boltzman's statistical methods to arrive at the following formula:

$$\boxed{\mathcal{I}(\lambda,T)=\frac{2\pi c^2 h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}}$$

Planck's radiation law

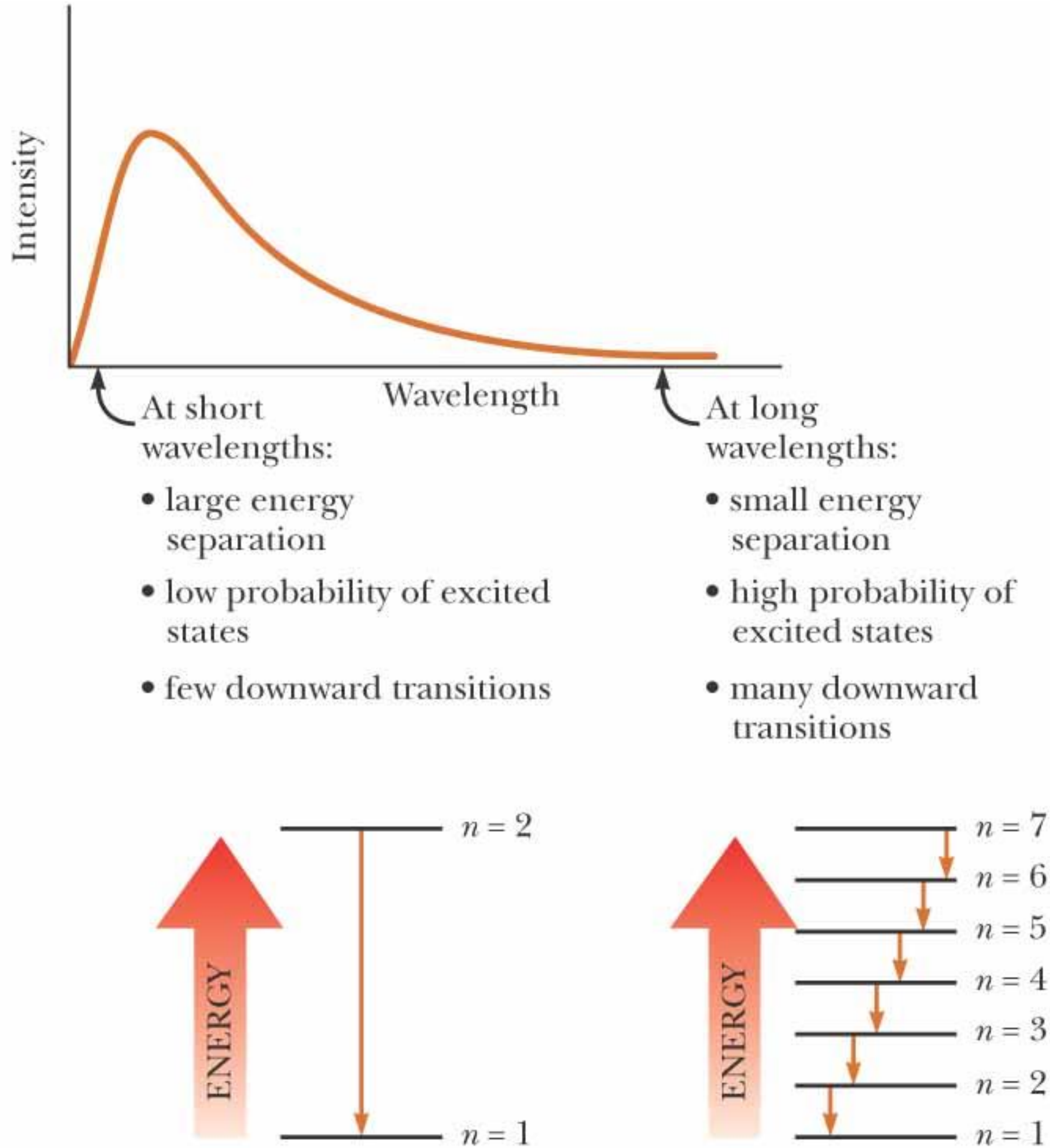
- Planck made two modifications to the classical theory:
  1) The oscillators (of electromagnetic origin) can only have certain discrete energies determined by $E_n = nh\nu$, where n is an integer, ν is the frequency, and h is called Planck's constant.

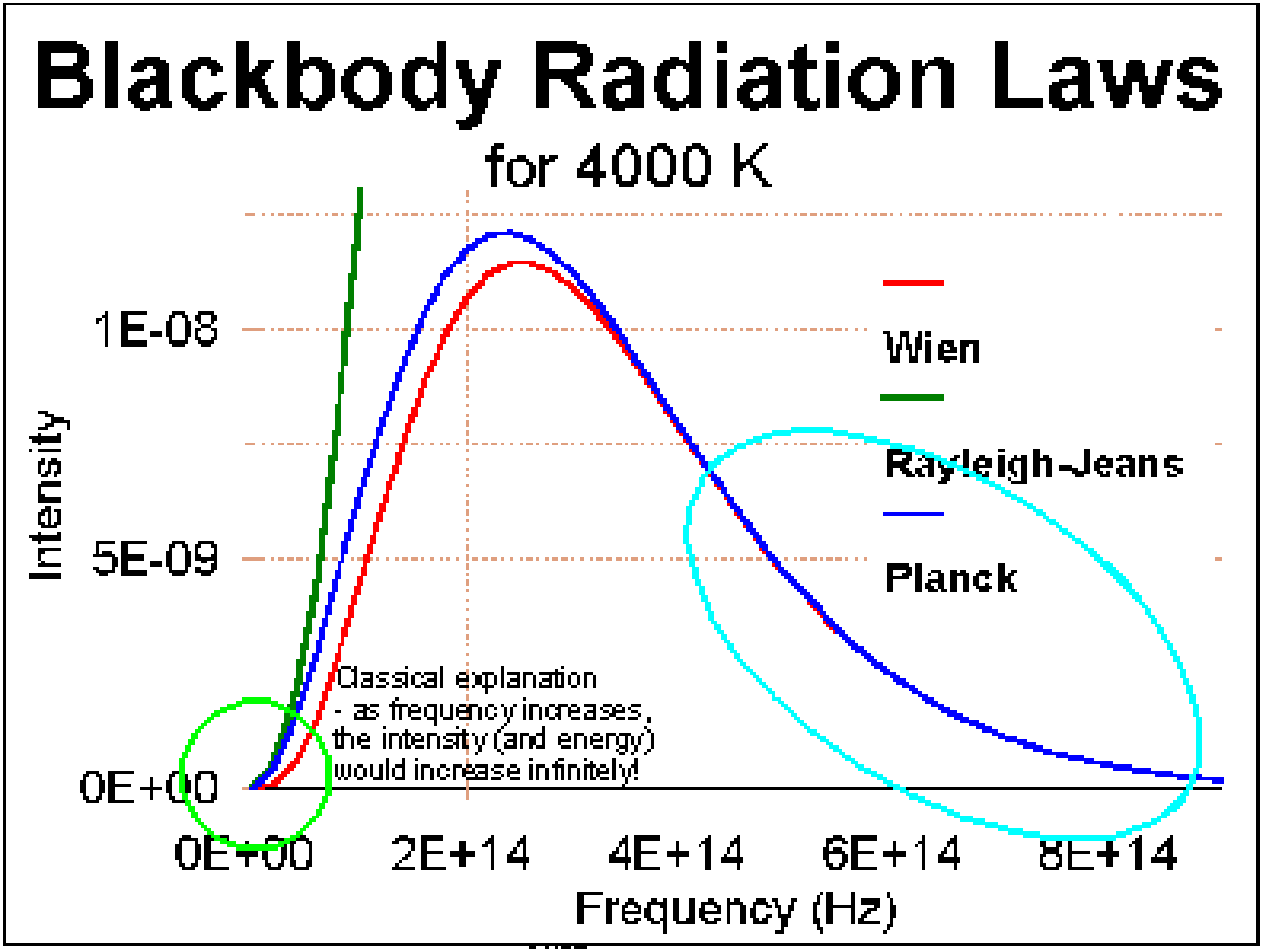
     $h = 6.6261 \times 10^{-34}$ J·s.

  2) The oscillators can absorb or emit energy in discrete multiples of the fundamental quantum of energy given by

     $\Delta E = h\nu$

Planck's Model, Graphs





Blackbody Radiation Laws
for 4000 K
1E-08
5E-09
0E+00
Intensity
0E+00
2E+14
4E+14
6E+14
8E+14
Frequency (Hz)
Wien
Rayleigh-Jeans
Planck
Classical explanation
- as frequency increases,
the intensity (and energy)
would increase infinitely!


"QUANTUM MECHANICS"