PHY 452/562
Lasers and Modern Optics

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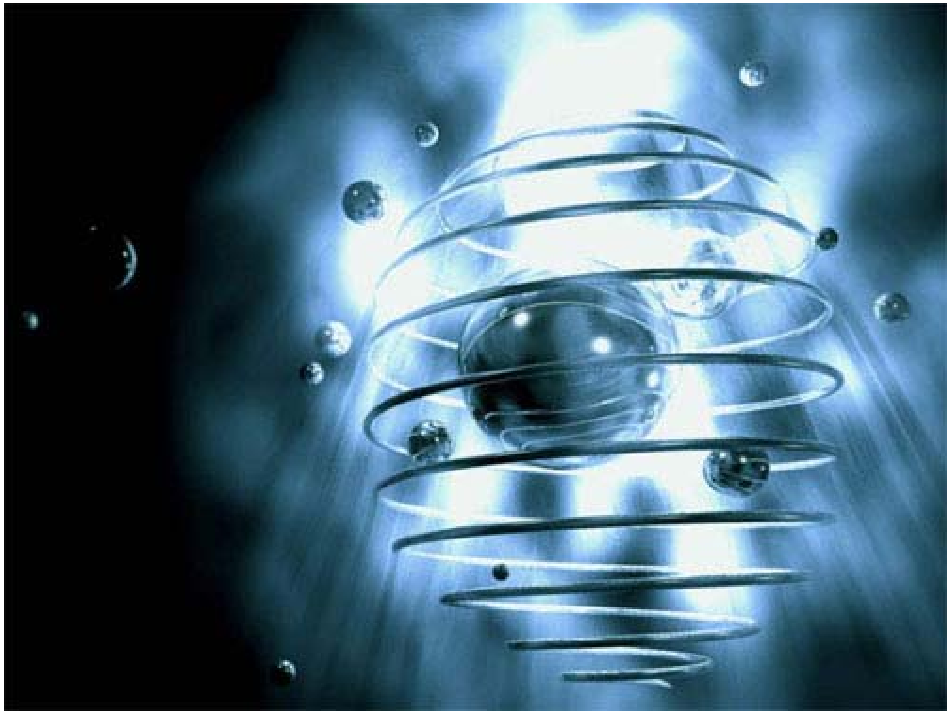
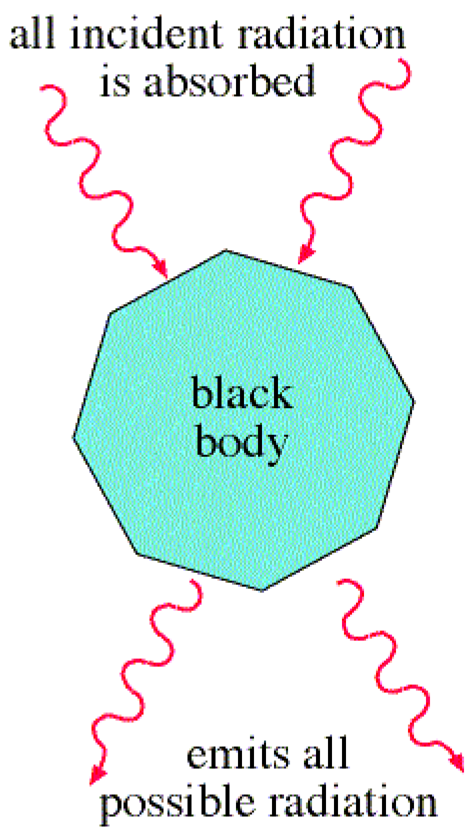
Lecture 6: Quantum Mechanics I

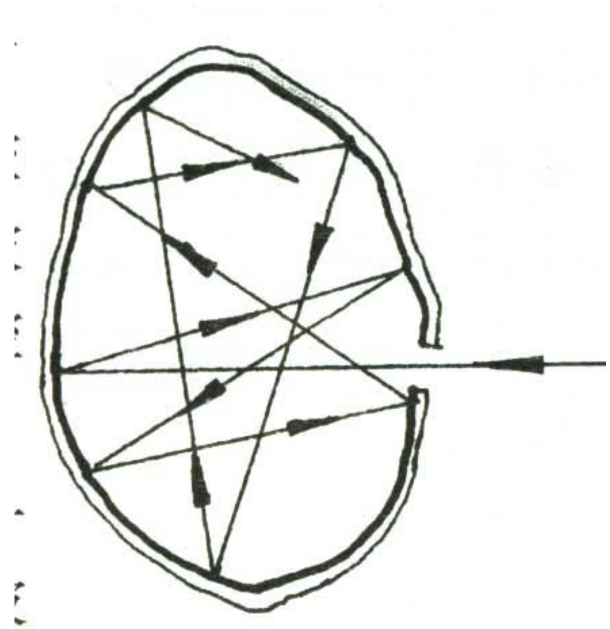
Stony Brook University

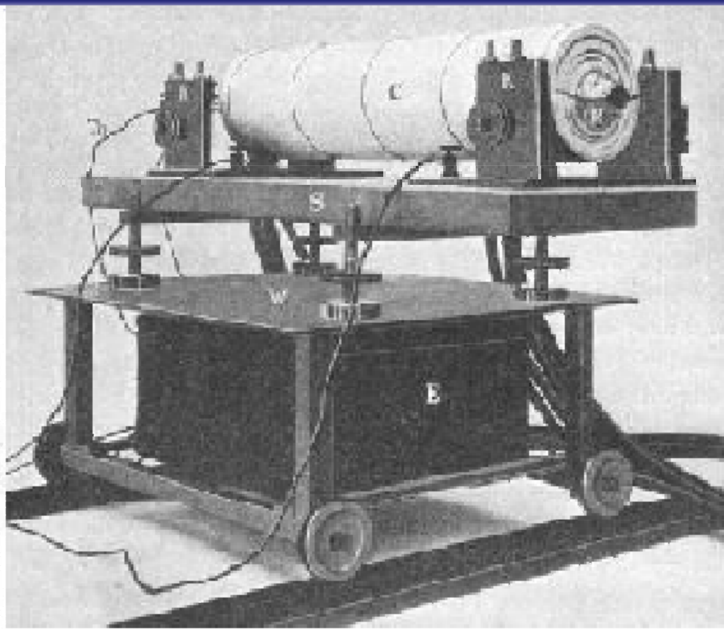
- Black body radiation.
- Quantization a la Planck.



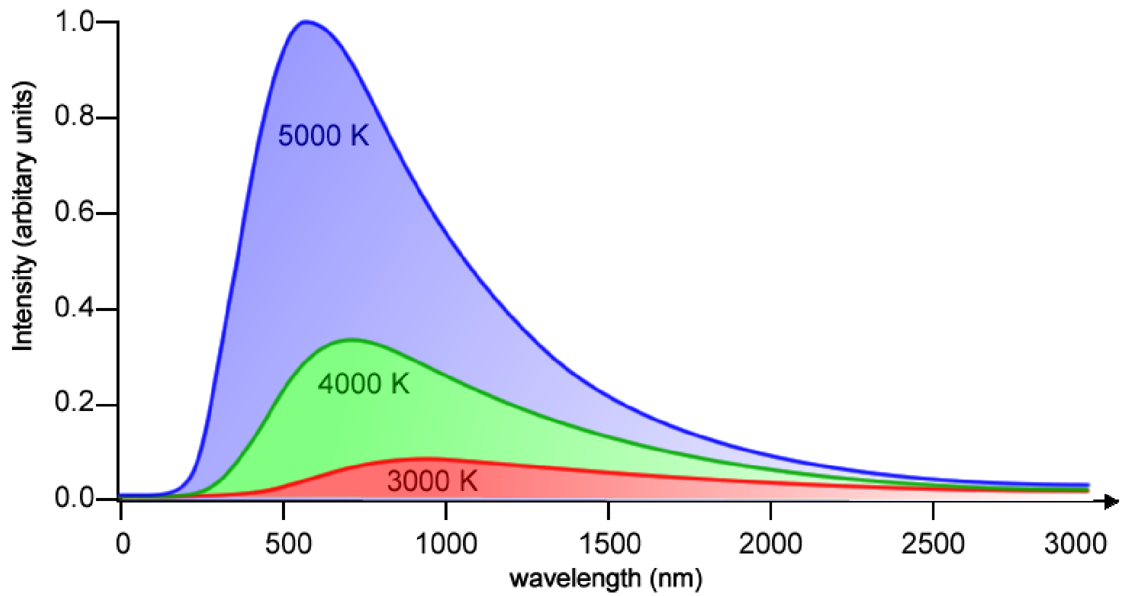
• Blackbody is defined as the body which can absorb all energies. A large cavity with a small hole on its wall can be taken as a blackbody.



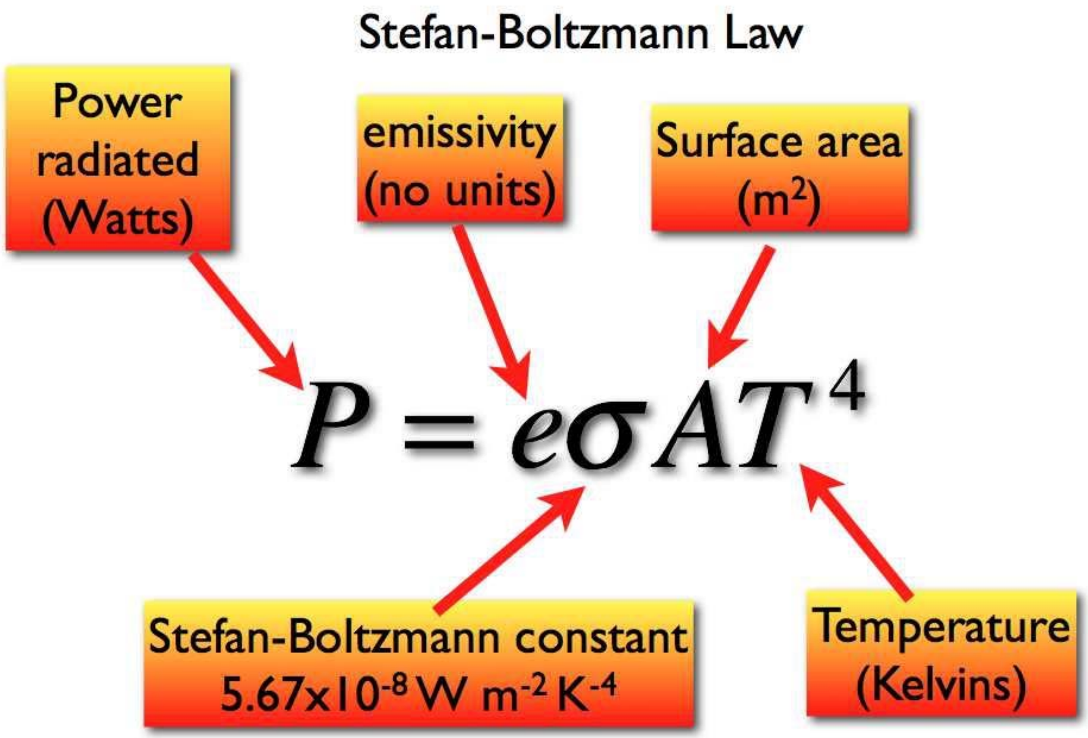


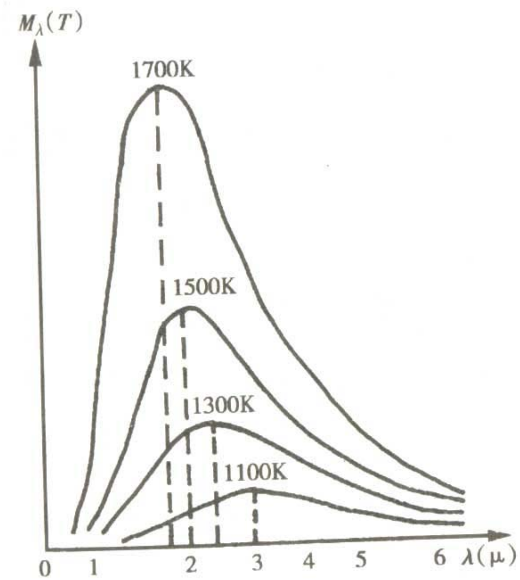


Lummer and Kurlbaum's black-body experiment from 1898



Stefan and Boltzmann's law: the radiation energy is proportional to the fourth power of the associated temperature.



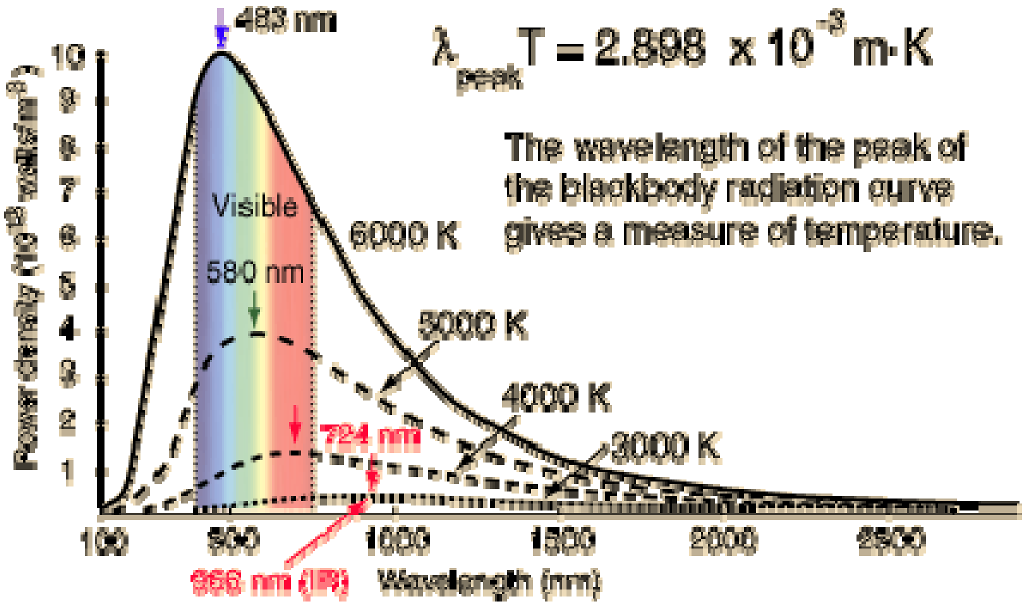


Blackbody radiation of spectra for four different temperatures.

Wien's displacement law: the peak of the curve shifts towards longer wavelength as the temperature falls and it satisfies

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

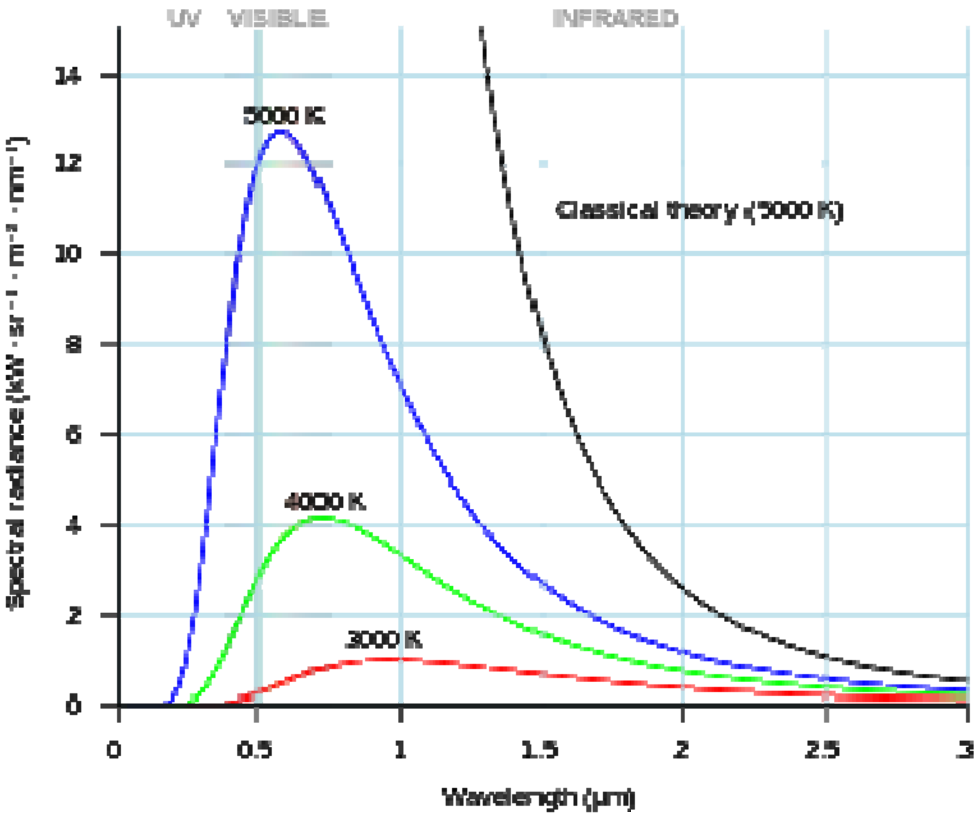
where b is called the **Wein's constant**.



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

Rayleigh and Jeans theory

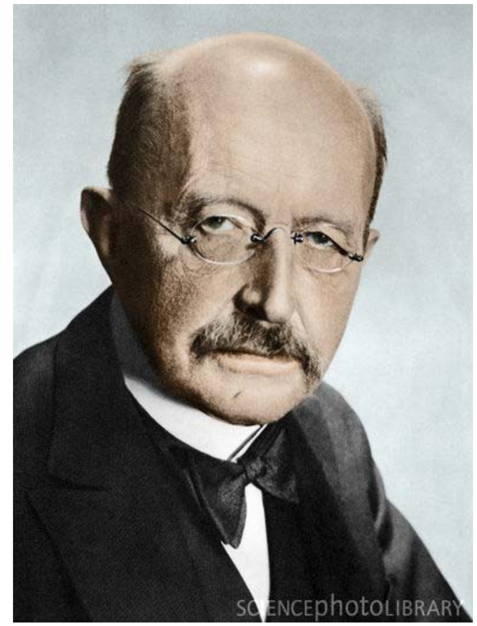
In 1890, Rayleigh and Jeans obtained a formula using the classical electromagnetic (Maxwell) theory and the classical equipartition theorem of energy:



$$M_\lambda(T) = C_1 \lambda^{-4} T$$

Planck's formula

In 1900, after studying the above two formulas carefully, Planck proposed an empirical formula.



$$M_{\lambda}(T) = 2\pi hc^2 \lambda^{-5} \frac{1}{e^{\frac{hc}{k\lambda T}} - 1}$$

Where *c* is the speed of light, *k* is Boltzmann's constant, *h* is Planck's constant and *e* is the base of natural logarithm.

The formula can describe the curve of blackbody radiation exactly for all wavelengths.

- For very large wavelength, the Rayleigh-Jeans formula can be obtained from Planck's formula;

$$\frac{hc}{k\lambda T} << 1$$

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$$e^{\frac{hc}{k\lambda T}} = 1 + \frac{hc}{k\lambda T} + \frac{1}{2}\left(\frac{hc}{k\lambda T}\right)^2 + \cdots$$

Drop the second order and higher order terms, and RJ formula could be obtained.

For smaller wavelength of blackbody radiation, the Wein's formula can be achieved also from Planck's formula;

$$\frac{1}{e^{\frac{hc}{k\lambda T}}-1} \approx e^{-\frac{hc}{k\lambda T}}$$

Integrating Planck's formula with respect to wavelength, the Stefan and Boltzmann's law can be obtained as well.

$$M(T) = \int_0^\infty M_\lambda(T)\,d\lambda = \sigma T^4$$

Planck's Hypotheses:

- The molecules and atoms composing the blackbody can be regarded as the linear harmonic oscillator with electrical charge;

- **The oscillators can only be in a special energy state. All these energies must be the integer multiples of a smallest energy (ε_0 = hν). Therefore the energies of the oscillators are $E = n\,h\nu$ with n = 1, 2, 3, …**