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Blackbody Radiation

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Abstract:

This article is about the spectral distribution of blackbody radiation.

What is a blackbody?

By definition, a blackbody is one that absorbs all the radiations incident on it. Conversely if a blackbody is heated to a temperature T, it would emit radiations of all frequencies.

The spectral distribution in a blackbody radiation depends only upon the temperature of the radiating body.

Classical approach:

Based on classical wave theory and thermodynamics, Rayleigh derived an equation for the spectral distribution of blackbody radiation. The equation, known as Rayleigh-Jeans law, is

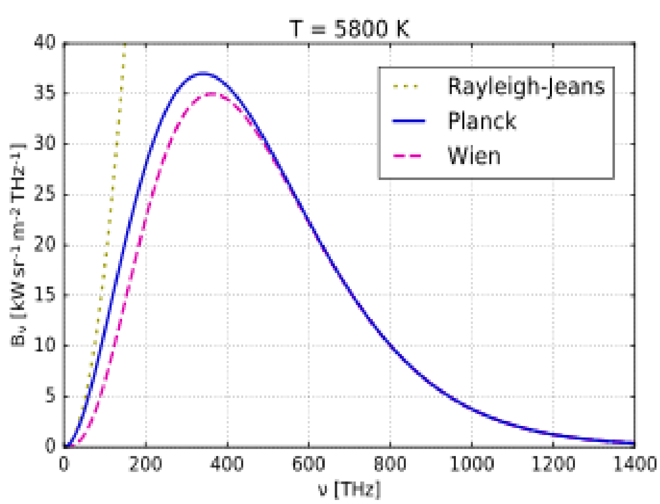
$u_\lambda = 8\pi kT/\lambda^4$

where u_λ is the spectral energy density, T is the temperature in Kelvin and k is the Boltzmann constant. The spectral energy density is defined as the radiation

Energy per unit volume in the wavelength range λ to $\lambda+d\lambda$. It has been experimentally confirmed that u_λ is only a function of the wavelength of the radiation and the temperature of the blackbody.

The Rayleigh-Jeans law of spectral distribution agreed well with the experimental curve only at low frequencies. The law predicts rapidly increasing u_λ as one decreases λ, but that is not the actual case. This failure was known as the ultraviolet catastrophe.

Experimentally, the spectral distribution has a maximum at some wavelength λ_m and decreases on both side of it.



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This image shows the plot between energy density and frequency.

Quantum approach:

Max Planck put forward an empirical formula and searched for its theoretical basis. He assumed (i) the atoms of the walls of the blackbody are like tiny electromagnetic oscillators, each having a characteristic frequency of vibration and (ii) the oscillator of a given frequency emits and absorbs electromagnetic radiation of the same frequency.

In case of light the energy can be absorbed or emitted in packets of size ε,

$$u_\lambda(T) = \frac{8\pi hc}{\lambda^5}\frac{1}{e^{hc/\lambda k_B T} - 1}.$$

2ε, 3ε,...etc with ε=hυ , where h is the planck's constant. Such packets are termed as quanta.

Using this hypothesis he derived the following equation for spectral distribution

This equation matches extremely well with the experimental results in the entire range of wavelength, when the value of h is 6.6×10^{-34} . For large wavelengths the equation approaches Rayleigh-Jeans law which was why it

was successful at large wavelengths. For smaller wavelengths the equation approaches Wein's law.

References:

Modern atomic and nuclear physics- AB Gupta
Quantum physics- HC Verma
Image: Wikipedia