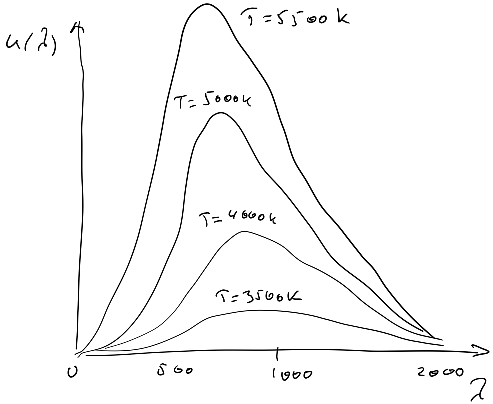
Laws of thermal radiation

At the end of XIX and beginning of XX century there were a lot of experimental activities to measure spectral distribution of energy radiation and radiation capacity.



What were the observations?

1) Integral under the curve increase with temperature. But integral is radiation emissivity.

$f(T)$ increase with T.

2) Wavelength of emission decrease with increase of temperature.

Based on this two laws were formulated.

① Stephan - Boltzmann law

$$f(\omega,T) = \int_0^\infty r_{\omega,T}\, d\omega = \sigma T^4$$

$\sigma = 5.67\cdot 10^{-8}\,\frac{W}{m^2K^4}$ - Stefan - Boltzmann constant

Demonstration

② Wien's displacement law

$$f(\omega,T)=\omega^3 F\left(\frac{\omega}{T}\right)$$

Wien was not actually able to determine function $F\left(\frac{\omega}{T}\right)$, but he realized it depends on $\frac{\omega}{T}$.

λ – wavelength

$$\varphi(\lambda,T)=\frac{2\pi c}{\lambda^2}f(\omega,T)=\frac{2\pi c}{\lambda^2}\left(\frac{2\pi c}{\lambda}\right)^3F\left(\frac{2\pi c}{\lambda T}\right)=\frac{1}{\lambda^5}\psi(\lambda T)$$

Let's find maximum of the radiation:

$$\varphi'(\lambda T)=0$$

$$-\frac{5}{\lambda^6}\psi(\lambda T)+\frac{1}{\lambda^5}\psi'(\lambda T)T=0$$

$$-5\psi(\lambda T)+(\lambda T)\psi'(\lambda T)=0$$

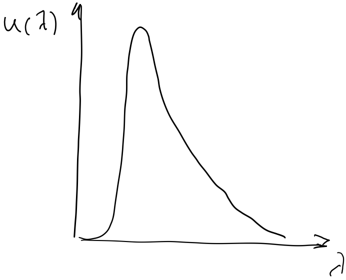
$$\boxed{\lambda_{max}T=b} \longrightarrow$$ Wien's displacement law

$b=2.9\cdot10^3\ m\cdot K$ → Wien's constant

We can easily determine Sun's temperature.

$\lambda_{max}=500\ nm \Rightarrow T=6000\ K$

It was very interesting to try to understand, why energy of ABB is distributed this way.

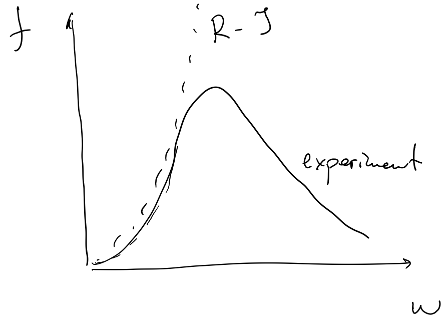


There were many different approaches and tries.

However, most bright effort by Rayleigh and Jeans.

$$f(\omega,T)=\frac{\omega^2}{4\pi^2c^2}kT \qquad f(\nu,T)=\frac{2\pi\nu^2}{c^2}kT$$

They based their theory on e/m nature of light and on thermodynamics laws.



This formula well agrees at small frequencies. At bigger frequencies there are very large discrepancies.

This situation has been called ultraviolet catastrophe. This is paradox, that total power of radiation should infinitly increases with frequency.

UV catastrophe changed a lot of perceptions in physics as it was not possible to explain it with classical approach used before.

Within the frame of classical physics we cannot understand experimental curve of black body radiation. However, this problem was successfully solved by Planck in 1900.

$$\boxed{f(\nu, T) = \frac{a_1 \nu^3}{e^{a_2 \frac{\nu}{T}} - 1}}$$

October 19, 1900

$$a_1 = \frac{2h}{c^2} \qquad a_2 = \frac{h}{k_B}$$

Next morning, Rubens confirmed by experiment.

Next 2 month Planck worked on its physical derivation.

h - hilfskgrosse

New constant → new physics