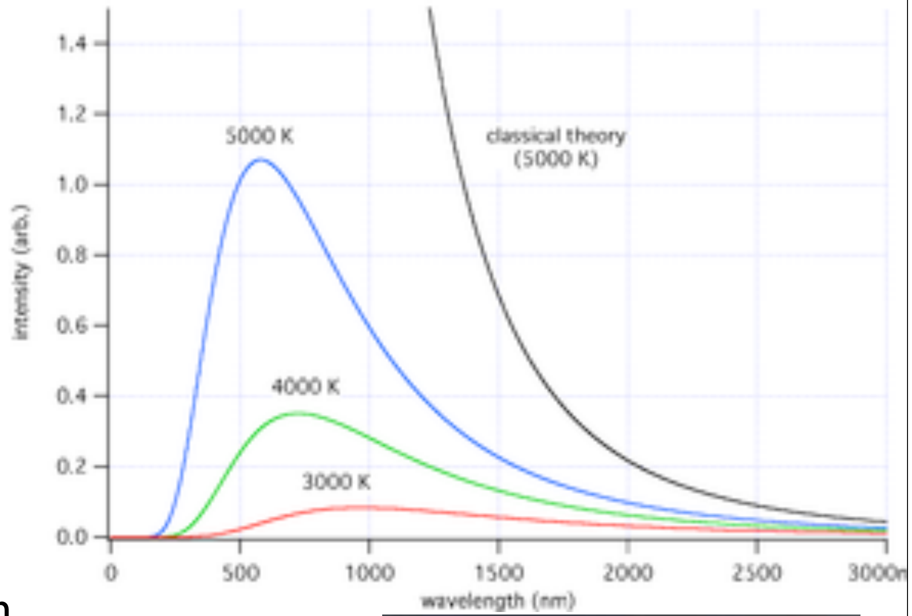
Planck’s Law



Classical physics (statistical thermodynamics) cannot explain the experimentally observed spectra of radiation.

Classical physics assumed that radiation is emitted continuously by the matter with smooth continuous spectrum of all possible energy levels.

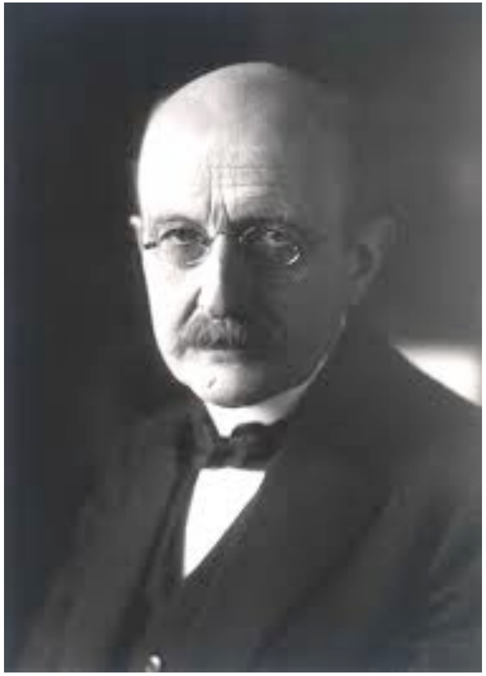
In 1900, Max Planck pustulated that the electromagnetic energy is emitted not continuously (like by vibrating oscillators), but by discrete portions or quants. Quantum mechanics was born! Planck’s Law states that

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{kT\lambda}} - 1}$$

where h=6.62x10^{-34} *Js* is the Planck’s constant.

Light is emitted in quants and can be considered not only as a wave-like entity but also as a particle, or *photon*, with the energy given by the Planck-Einstein relation

$$E = h\nu = \frac{hc}{\lambda}$$



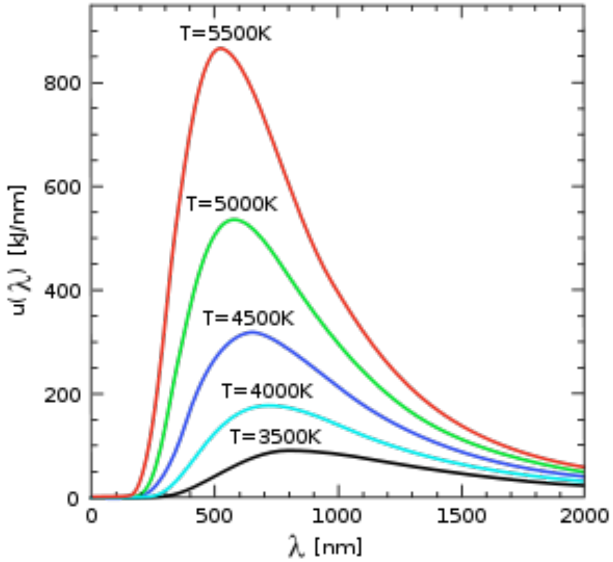
Wien's Displacement Law

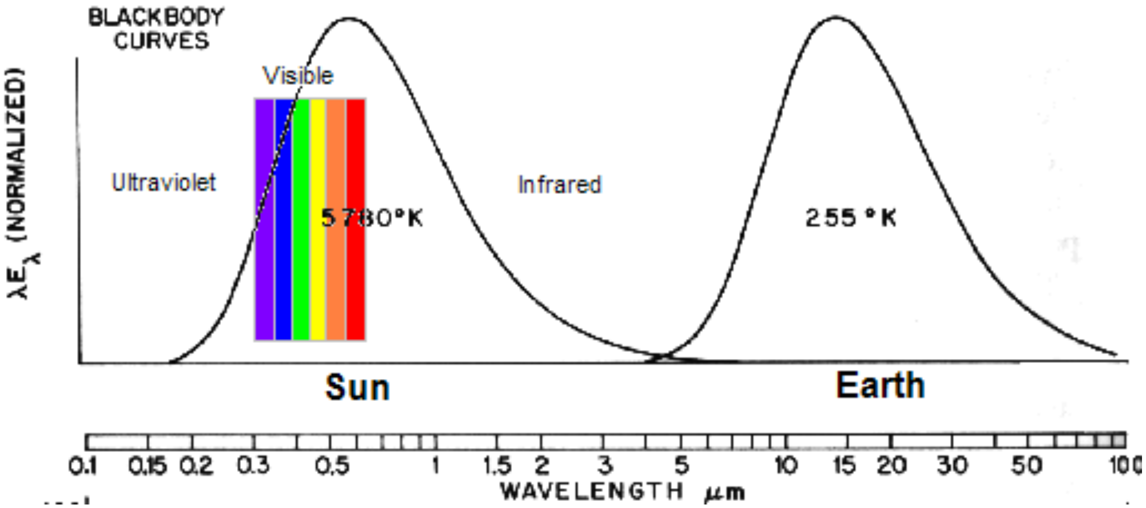
Planck's Law can be used to derive the wavelength of peak emission for a given temperature: $\dfrac{dB_\lambda}{d\lambda} = 0$

$$\lambda_{\max} = \frac{2897}{T}$$

(derived theoretically by Wien in 1893)

where wavelength is in micrometers, and temperature in *K*.





Example: maximum solar emission is observed at $\lambda_{\max} = 0.475\,\mu m$. Form Wien's Law it follows that the Sun's temperature is about 6100 K.

Stefan-Boltzmann Law

The total blackbody emission radiance is proportional the the fourth power of the temperature:

$$B(T) = \int_0^\infty B_\lambda(T)\,d\lambda = \frac{\sigma}{\pi}T^4$$

The total black-body irradiance (flux) is then

$$F_B(T) = \pi B(T) = \sigma T^4$$

where the Stefan-Boltzmann constant is given by $\sigma \approx 5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$

Gray-body radiation

Real objects emit and absorb not quite like blackbodies.

However, the blackbody theory can be used for non-black (or gray) bodies.

It is useful to define the monochromatic emissivity $\varepsilon_\lambda = \frac{I_\lambda}{B_\lambda}$ $0 < \varepsilon_\lambda \le 1$

monochromatic absorptivity: $a_\lambda = \frac{I_\lambda(absorbed)}{I_\lambda(incident)}$

Kirchhoff's Law

For any radiating objects, the emissivity and absorptivity are equal to each other:

$$\varepsilon_\lambda = a_\lambda$$

Typical emissivities: snow 0.8; paper 0.68; wall paint 0.94; steel 0.24-0.34; water 0.95; red brick 0.92