9.1: Overview

learning objectives

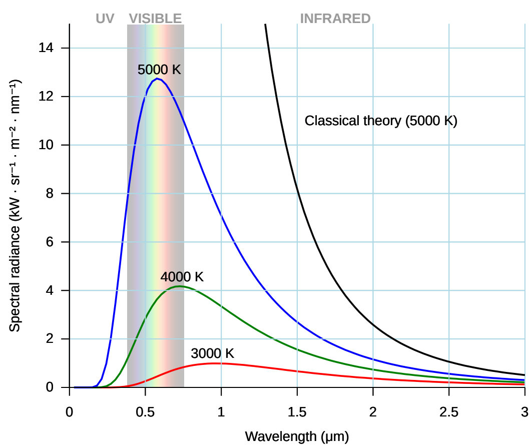
- Identify assumption made by Max Planck to describe the electromagnetic radiation emitted by a black body

A black body in thermal equilibrium (i.e. at a constant temperature) emits electromagnetic radiation called black body radiation. Black body radiation has a characteristic, continuous frequency spectrum that depends only on the body's temperature. Max Planck, in 1901, accurately described the radiation by assuming that electromagnetic radiation was emitted in discrete packets (or quanta). Planck's quantum hypothesis is a pioneering work, heralding advent of a new era of modern physics and quantum theory.

Explaining the properties of black-body radiation was a major challenge in theoretical physics during the late nineteenth century. Predictions based on classical theories failed to explain black body spectra observed experimentally, especially at shorter wavelength. The puzzle was solved in 1901 by Max Planck in the formalism now known as Planck's law of black-body radiation. Contrary to the common belief that electromagnetic radiation can take continuous values of energy, Planck introduced a radical concept that electromagnetic radiation was emitted in discrete packets (or quanta) of energy. Although Planck's derivation is beyond the scope of this section (it will be covered in Quantum Mechanics), Planck's law may be written:

$$B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{bc}{\lambda k_B T}} - 1} \tag{9.1.1}$$

where BB is the spectral radiance of the surface of the black body, TT is its absolute temperature, λλ is wavelength of the radiation, kBkB is the Boltzmann constant, hh is the Planck constant, and cc is the speed of light. This equation explains the black body spectra shown below. Planck's quantum hypothesis is one of the breakthroughs in the modern physics. It is not a surprise that he introduced Planck constant $h = 6.626 \times 10^{-34} J \cdot s$ for the first time in his derivation of the Planck's law.



Black body radiation spectrum: Typical spectrum from a black body at different temperatures (shown in blue, green and red curves). As the temperature decreases, the peak of the black-body radiation curve moves to lower intensities and longer wavelengths. Black line is a prediction of a classical theory for an object at 5,000K, showing catastropic discrepancy at shorter wavelengh.

Note that the spectral radiance depends on two variables, wavelength and temperature. The radiation has a specific spectrum and intensity that depends only on the temperature of the body. Despite its simplicity, Planck's law describes radiation properties of objects (e.g. our body, planets, stars) reasonably well.

Key Points

- A black body in thermal equilibrium emits electromagnetic radiation called black body radiation.
- The radiation has a specific spectrum and intensity that depends only on the temperature of the body.
- Max Planck, in 1901, accurately described the radiation by assuming that electromagnetic radiation was emitted in discrete packets (or quanta). Planck's quantum hypothesis is a pioneering work, heralding advent of a new era of modern physics and quantum theory.

Key Terms

- **spectral radiance**: measures of the quantity of radiation that passes through or is emitted from a surface and falls within a given solid angle in a specified direction.
- **black body**: An idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence. Although black body is a theoretical concept, you can find approximate realizations of black body in nature.
- **Planck constant**: a physical constant that is the quantum of action in quantum mechanics. It has a unit of angular momentum. The Planck constant was first described as the proportionality constant between the energy of a photon (unit of electromagnetic radiation) and the frequency of its associated electromagnetic wave in his derivation of the Planck's law

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