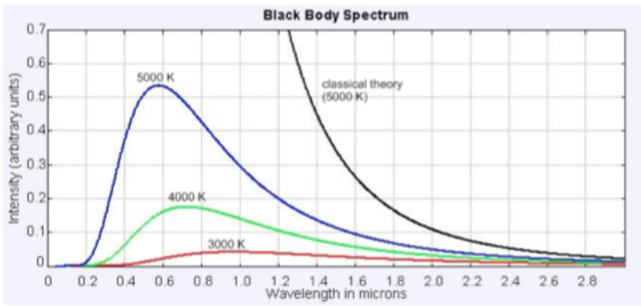
CH 27-1 – Photon

Important Ideas

- An object like a hot piece of metal or a ball of gas like a star emits light, simply as a result of having temperature and being in thermal equilibrium with its surroundings. This radiation is called *black-body radiation*. A graph of intensity as a function of wavelength is shown below.



  The data could not be explained by the laws of electricity and magnetism. Max Planck came up with a "mathematical trick" (so he thought) that would give a curve that fit the theory. With this trick, he assumed that light could only be emitted with energies that were integer multiples of hf. So, $E = nhf$ where h is a constant to fit the data and f is the frequency of the light. h is Planck's constant and is

$$\begin{aligned} h &= 6.626 \times 10^{-34}\ \mathrm{J \cdot s} \\ &= 4.136 \times 10^{-15}\ \mathrm{eV \cdot s} \end{aligned}$$

  This was a revolutionary idea and was the first to suggest that energies of physical systems could be discrete (i.e. not continuous). Planck called these energies *quanta*, and the energy is said to be *quantized*.

  One of the features that Planck explained theoretically was Wien's law

$$\lambda_{max} T = 2.90 \times 10^{-3} \mathrm{K \cdot m}$$

  where λ_{max} is the wavelength where the maximum occurs in the blackbody curve. Thus, hotter objects have peaks at shorter wavelengths (in the blue region of the visible spectrum for a hotter star) and cooler objects have peaks at longer wavelengths (in the red region of the visible spectrum for a cooler star). Living things, like people, have peaks at wavelengths in the IR part of the spectrum. The Universe (interstellar space) is very cold. Its peak is at 160 GHz, which is in the microwave region of the spectrum. Thus it is called the Cosmic Microwave Background (CMB).

- Einstein explained an experiment called the photoelectric effect by treating light as a particle with energy $E = hf$. This particle became known as a *photon*.

$$\begin{aligned} E_{photon} &= hf \\ &= \frac{hc}{\lambda} \end{aligned}$$

  The constant $hc = 1240\ \mathrm{eV \cdot nm}$.

Examples

1. The spectrum of the light from Star A has a peak at 500 nm. The spectrum of the light from Star B has a peak at 600 nm. Which star is hotter?
   (a) Star A
   (b) Star B
   (c) Neither; they have the same temperature.
   (d) There's not enough information to determine the star's temperature.
2. What color of the spectrum does the peak for each star in the previous question correspond to?
3. What color is each of the stars in the previous question?
4. What is the temperature of the Universe?
5. The light from the Sun has a peak at 502 nm. What is the temperature of the Sun (the temperature of its photosphere)?
6. What is the peak wavelength for radiation emitted by a normal human body? In what region is this?
7. Bulb A's filament is reddish yellow. Bulb B's filament is white. Which bulbs filament has a greater temperature?
   (a) Bulb A
   (b) Bulb B
   (c) Neither; they have the same temperature.
8. As a star like the Sun ages, it also cools. The wavelength of the peak of its blackbody radiation curve as it cools will shift toward the
   (a) red end of the spectrum.
   (b) blue end of the spectrum.
   (c) Neither; because it will remain the same.
9. What is the energy of a photon of wavelength 400 nm?
10. What is the energy of a photon of wavelength 700 nm?
11. A typical red laser pointer has a power of about 1 mW. How many photons per second are emitted by the laser?
12. If you have a green laser pointer of the same power (1 mW), does it emit more or less photons per second than the red laser pointer?