Blackbody Radiation-Section1

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1 Blackbody: What is it?

A blackbody is a physical object that absorbs all the radiations incident on it, and reflects or transmits none, and therefore the surface appears black. Independent of the frequency and angle of incidence, a perfect blackbody absorbs all electromagnetic radiations that fall on it. Practically, a perfect(ideal) blackbody does not exist. However, there are materials which absorb a major portion of the light incident on them. For example, VANTABLACK (**V**ertically

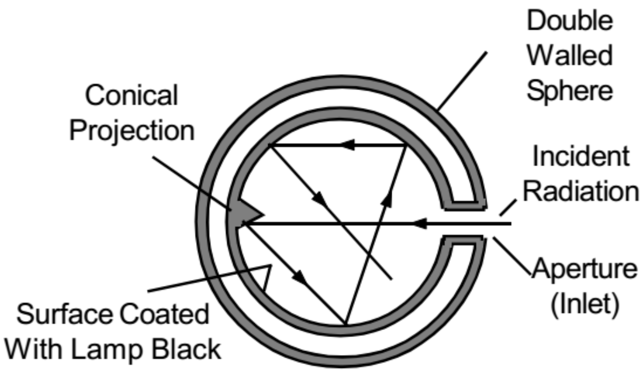

Figure 1: Hole attached to a cavity: An experimental blackbody

Alligned **N**ano**T**ube **A**rrays BLACK), a nanomaterial that can absorb more than 99.9% of the incident visible rays. For better understanding of blackbody, let us consider a double-walled hollow spherical shell with Lamp Black coated on its inner surface (see figure 1). Incident radiation enters into the shell through a small aperture and is completely absorbed at the inner wall of the cavity *via* multiple internal reflections on the inner surface. Incoming radiations that fall on the aperture, therefore, get completely absorbed. So, hole with such a cavity is considered as blackbody good enough for experimental purposes.

2 Radiation form blackbody

Blackbodies do not only absorb electromangetic radiations. At any given temperature, blackbodies also emit electromagnetic radiations. In fact, the rate of emission has to be equal to the rate of absorption for the blackbody to remain at thermal equilibrium. For the case as shown in figure 1, at any temperature, electromagnetic radiations also come out of the small aperture. This is called blackbody radiation. The characteristic of blackbody radiation depends on temperature T of the blackbody, and is independent of the material of the blackbody. So, at a fixed temperature, all the blackbodies will emit same radiation spectrum.

3 Blackbody radiation spectrum

When a blackbody radiates at thermal equilibrium, the radiations contain electromagnetic waves of various wavelengths (therefore, of various frequencies). In fact, blackbody radiation contains a broad wavelength (frequency)

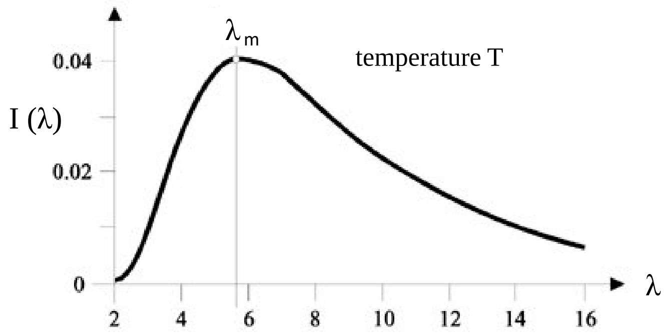

Figure 2: Blackbody radiation: Characteristic spectrum at a fixed temperature T.

range, where each wavelength λ has its own intensity I(λ) [or, each frequency ν has its own intensity I(ν)]. At temperature T of the blackbody, a graphical plot of λ vs I(λ) presents a characteristics blackbody radiation spectrum. Corresponding to wavelength λ_1, λ_2, λ_3...there are intensities I(λ_1), I(λ_2), I(λ_3)...respectively. The λ values are plotted along x-axis and corresponding I(λ) values are plotted along the y-axis. Such a plot is shown in figure 2 for fixed temperature T of the blackbody. At low wavelength range the intensity curve initially increases following power law. The intensity reaches a maximum value $I_m(\lambda)$ and then falls down exponentially as wavelength increases. The wavelength corresponding to $I_m(\lambda)$ is indicated as λ_m. Therefore, λ_m indicates the wavelength corresponding to maximum intensity.

4 Temperature dependence of blackbody radiation: Wien's displacement law

As mentioned earlier, the characteristic blackbody radiation spectrum does not depend on the material properties. Rather, it depends on sample temperature T. A change in T modifies the emission spectrum's wavelength range as well as the emission intensity I(λ) corresponding to each wavelength λ. The whole spectrum, therefore, gets significantly modified. The temperature dependance of the emission spectrum is shown in figure 3. Blackbody

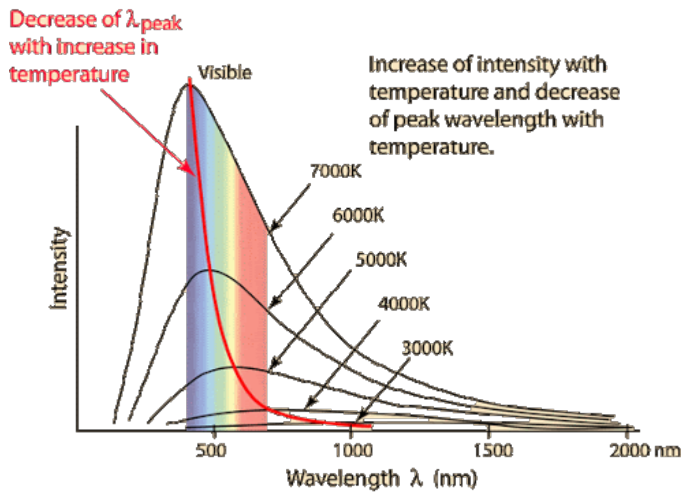

Figure 3: Temperature variation of blackbody radiation characteristic spectra.

radiation spectra are shown for five different temperatures: 3000, 4000, 5000, 6000 and 7000 K, respectively. With increase of blackbody temperature T, the emission intensity increases sharply. Also, the emission spectrum broadens towards the lower wavelength side. The most significant observation is that, the peak intensity shifts towards lower wavelength value with the rise of sample temperature. Therefore, the corresponding wavelength λ_m also shifts towards lower value with increasing temperature T. The displacement of λ_m was correlated to temperature T by Wien.

4.1 Wien's displacement law

The wavelength of the most strongly emitted radiation in the continuous spectrum is inversely proportional to the absolute temperature of the blackbody. i.e.

$$\lambda_m \propto \frac{1}{T}$$

$$\lambda_m T = b \tag{1}$$

Here, b is Wien's constant 2.898×10^{-3} mK. In figure 3, the red curve demonstrates the decrement of λ_m with temperature T.

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[1] Figures are collected from Wikipedia and other online resources.