Lecture 5

September 5, 2003

1 Black Body Radiation

The beginnings of Quantum Mechanics can be found in understanding the physics of black-body radiation in the mid nineteenth century. The works of Gustav Kirchoff,Ludwig Boltzmann, Josef Stefan, Wilhelm Wien,Lord Raleigh, James Jeans and Max Plank all together lead to a clear understanding that classical physics was not complete!

It was discovered that when E-M waves fell on materials the materials can absorb some wavelengths of the light. Example: The dark-D lines of solar radiation. Similarly materials also emitted radiation when heated to a given temperature. Now consider a cavity made up of some material. Let us assume that there are electromagnetic waves inside the cavity. Since E-M waves carry energy it is useful to understand how this energy is distributed among waves with different wavelengths. Let us assume that the intensity distribution of the E-M wave with wave lengths λ and $\lambda+d\lambda$ is given by $K(\lambda,T)$ where T is the temperature of the cavity.

The second law of thermodynamics tells us that $K(\lambda,T)$ must be the same for all types of cavities! Otherwise we can connect two cavities with the same temperature and different K's and transfer energy from one to the other.

Let e_λ be the emissivity of the walls of the cavity; e_λ is the rate of radiation emitted by a unit area of the walls. Then we must have

$$\int e_\lambda d\lambda = \int a_\lambda K(\lambda) d\lambda \tag{1}$$

where a_λ is called the coefficient of absorption. For a blackbody $a_\lambda = 1$. Assuming that the above relation holds for each wavelength, then for a blackbody at a given temperature

$$e_\lambda = K(\lambda, T) \tag{2}$$

Thus the radiation coming from a blackbody is universal!

Example: The microwave background radiation.

It is possible to experimentally determine $K(\lambda,T)$. We find

$$K(\lambda,T) = \frac{b}{\lambda^5}\frac{1}{\exp(a/\lambda T)-1}. \tag{3}$$

When this was discovered, it was impossible to "derive" this formula from any classical physics. The small wavelength region was describable by a statistical mechanics of particles while the large region description was describable by wave mechanics. But it was impossible to understand the intermediate region.

To describe the whole spectrum Plank assumed that the materials absorbed or emitted E-M waves with quantized units of energy:

$$E = hf = \hbar\omega \tag{4}$$

where $h = 2\pi\hbar = 6.63\times10^{-34} Js$ is called the Plank's constant. The constant $\hbar = h/2\pi = 1.05\times10^{-34} J.s.$ Einstein later made this unit of energy as the unit of energy of a particle which the light is actually made up of. This lead him to his Nobel prize winning article on "Photo-Electric Effect". We will discuss this later. Compton called the particle "Photon".

Read pages 101-107 of the textbook in order to obtain more details (historical and otherwise).