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Experiment 8

Planck's Constant–Method 1

Introduction

The constant h ($= 6.62559 \times 10^{-34}$Js) was introduced by Planck in 1900 when he provided the first satisfactory theoretical basis for the temperature and wavelength dependence of the radiation from a black body. A black body, by definition, absorbs all the radiation that falls upon it. The rate of energy emission by the body summed over all wavelengths is proportional to the fourth power of the thermodynamic temperature T. The spectral distribution of the radiation depends on the temperature. There is a maximum in the emission versus wavelength curve so that the product of the wavelength of the maximum emission and the temperature is a constant. These relations are known as Stefan's Law and Wien's Law, respectively. In 1893, W. Wien showed from thermodynamic considerations that the form of the radiation curve was given by

$$E_\lambda = \frac{1}{\lambda^5} \cdot f\left(\frac{1}{\lambda T}\right)$$

where E_λ is the energy emitted in range $d\lambda$ at wavelength λ and f is some function to be determined. The experimental data were obtained by Coblentz, who examined the spectral distribution of the body maintained at temperature T. Such a system provides an excellent approximation to a black body because radiation that enters the hole from outside has an exceedingly small chance to escape before it is absorbed at the walls of the cavity. The form of the radiation curve is shown in Figure 8.1. The curves are independent of the nature of the material that forms the walls of the cavity. Today, for convenience, the cavity is a hollow metal cylinder, blackened inside, and completely closed except for a narrow slit in one end. At the temperatures available in the laboratory the shortest wavelength radiation of measurable intensity is in the near ultra-violet.

In 1900, Planck introduced the assumption that each mode of vibration of frequency ν of the electromagnetic field in the cavity could change its energy by a definite amount $h\nu$ (where h was a constant to be determined) rather than by continuously variable amounts. He was then able to derive the explicit form of the radiation curve and to show that Stefan's Law and the Wien Law followed from his form. Moreover, the form was identical to that determined by Coblentz if the constant h was given a value close to that quoted above. Planck's assumption was the first use of the idea of quantization in the radiation field and, later, in the interaction of radiation with atoms.

Some years later, Einstein introduced the idea of light quanta in the explanation of the photo electric effect. The electromagnetic wave of frequency ν that is the light beam gives energy to the electrons in the material in units of $h\nu$. The kinetic energy of the emitted electron is $h\nu - W$, where W is the energy required to remove the electron from the material.

The constant h appeared again in the Bohr theory of the hydrogen atom in 1912 and eventually became an essential part of modern quantum mechanics. Its value is important and much effort

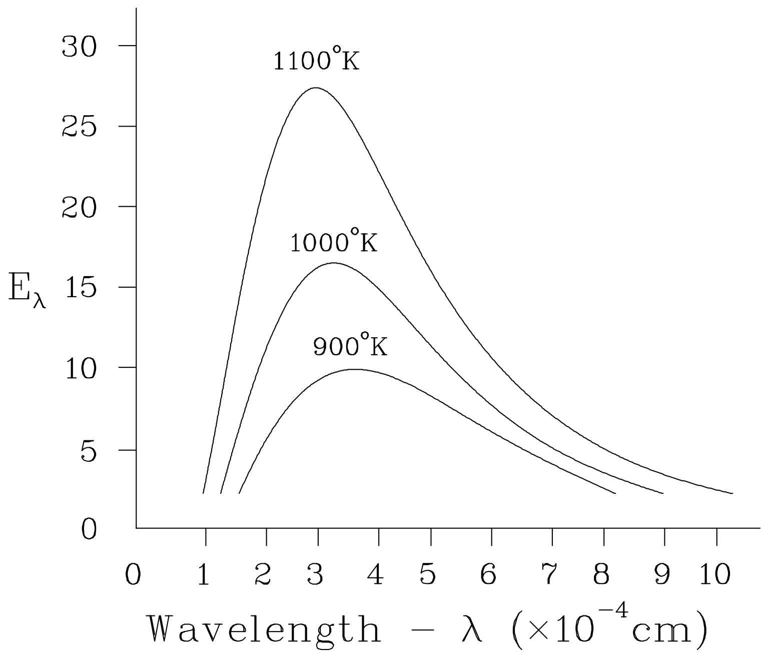

Figure 8.1: Temperature dependent energy emission by a blackbody

has been devoted to the measurement. In two experiments you will obtain estimates for h. The first method is based on the black body radiation curve. The second is a direct experimental examination of Einstein's photo electric equation introduced above.

Method

Planck's formula for the power radiated by a black body at frequency and temperature T is

$$P = 2\pi \left(\frac{\nu}{c}\right)^2 \left(\frac{h\nu}{\exp\left(\frac{h\nu}{kT}\right) - 1}\right)$$

where P is the energy radiated per unit area of surface per second per unit frequency range at frequency ν, k is Boltzmann's constant and c is the velocity of light. If a body is not a black body radiator, so that it does not absorb all radiation that falls upon it, the power radiated is less than the formula value. If the absorption coefficient at ν is independent of the temperature P will be reduced by a constant factor for all temperatures. If the frequency and temperature are such that $\exp(h\nu/kT) \gg 1$ then P is proportional to

$$\exp\left(-\frac{h\nu}{kT}\right).$$

Thus a graph of $\ln P$ versus $1/T$ should be a straight line of slope $h\nu/k$. The frequency is determined by the experimental conditions and k is known independently of this experiment. Thus a value of h can be obtained.

In the experiment we use an oven cavity as a black body radation source which uses $MoSi_2$ as a heater element. This oven can reach temperature as high as $1500°C$. The Temperature of the oven will be measured using two different methods. In the first method the temperature is measured directly using S-type thermocouple inside the oven. In the second method you use the Infra red technique to measure the temperature of the oven.

Determination of h Increase the current to the oven heater until a noticeable light output P is registered on the detector output meter. Measure and record the temperature of the oven when it is stable as well as the light output power P. Correct, if necessary, P for the zero-light-output, and plot $\ln P$ versus $1/T$.

Repeat at ten different temperatures, by increasing current to the oven. The data points $(\ln P, 1/T)$ should fall on a straight line, with slope $h\nu/k$. Calculate h from the slope; the Fabry-Perot filter passes only wavelengths in a narrow band at $\lambda = 650$ nm or as indicated by the instrument.