XXI Studencka Sesja Plakatowa

Black-Body Radiation – checking the Stefan-Boltzmann and the Planck's law

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30

Abstract

Our purpose in this experiment is to study the black-body radiation. As the emitter we use an incandescent lamp treated as an approximated black body. From the total power of our emitter we derive the approximated dependence of the radiant flux on temperature. Using a prism spectrometer and a pyrometer we measure the spectral radiance as a function of temperature. Obtained results are in agreement with theoretical formulae describing the black-body radiation.

Experiment

At the first stage, we built a simple circuit (Fig. 1, upper), which enables us to supply the electric power to the lamp and to measure the current and voltage on the lamp. With Ohm's law and Joule's law, we can convert these values into the power and the resistance of our lamp. At the second stage, we combine the lamp with a monochromator (to select a light of the given wavelength), a photomultiplier (to measure the photon flux) and a pyrometer (to measure the emitter temperature), as shown in Fig. 1 (lower).

Theoretical Equations

Black bodies are ideal physical objects that behave as both perfect emitters and absorbers of radiation [2]. Its radiant emittance (roughly, total radiated power) is described by the Stefan-Boltzmann formula:

$$P = \sigma T^4$$

On the other hand, black-body spectral radiance (roughly, intensity of the emitted radiation) is accurately given by Planck's law. For a certain value of frequency, and suitably grouping all the constants, we may write:

$$B_\nu(T) = \frac{C_1}{e^{C_2 \frac{\nu}{T}} - 1}$$

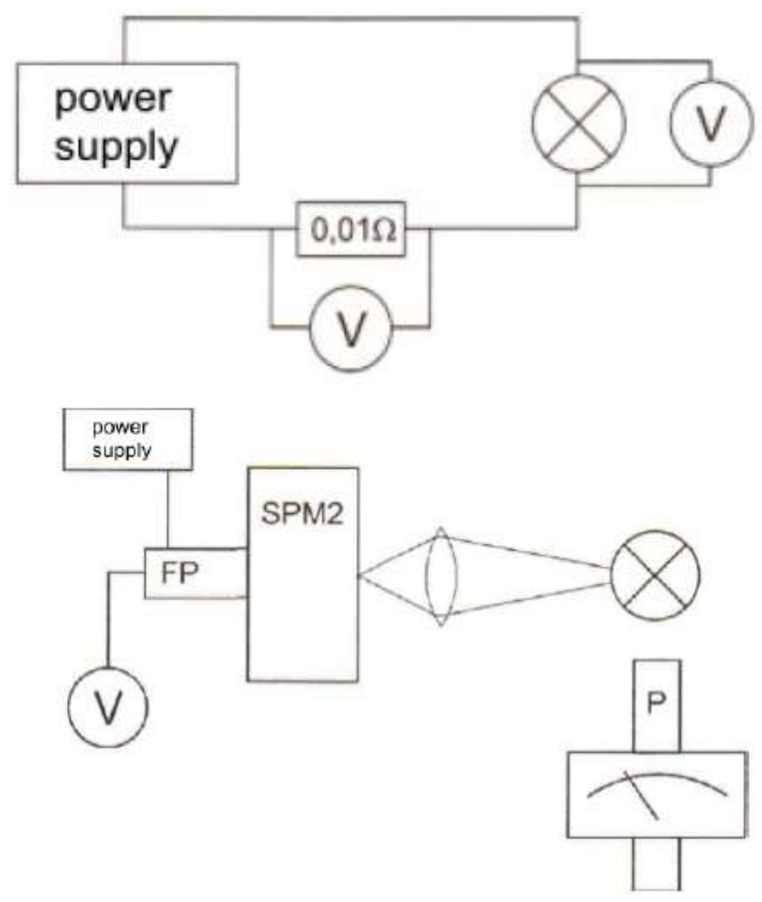

Figure 1. Experimental setup of both stages [3]

Data Analysis

From the obtained dependence of the total power emitted by the bulb and its resistance (first stage, Fig. 2), we observed a certain linear region for low resistance, corresponding to thermal conductivity. This region was fitted to a straight line, which was then subtracted to all the values of total power. In such a way, we obtained a relation between radiated power and resistance. Besides, it is known that increasing thermal vibrations (T) also rises resistance (R), and a linear relation between T and R is in general a good approximation [1]. Thus, we could fit the data to the Stefan-Boltzmann formula with variable exponent (Fig. 3). The estimation was close to the theoretical value:

$$N = 4.132 \pm 0.031$$

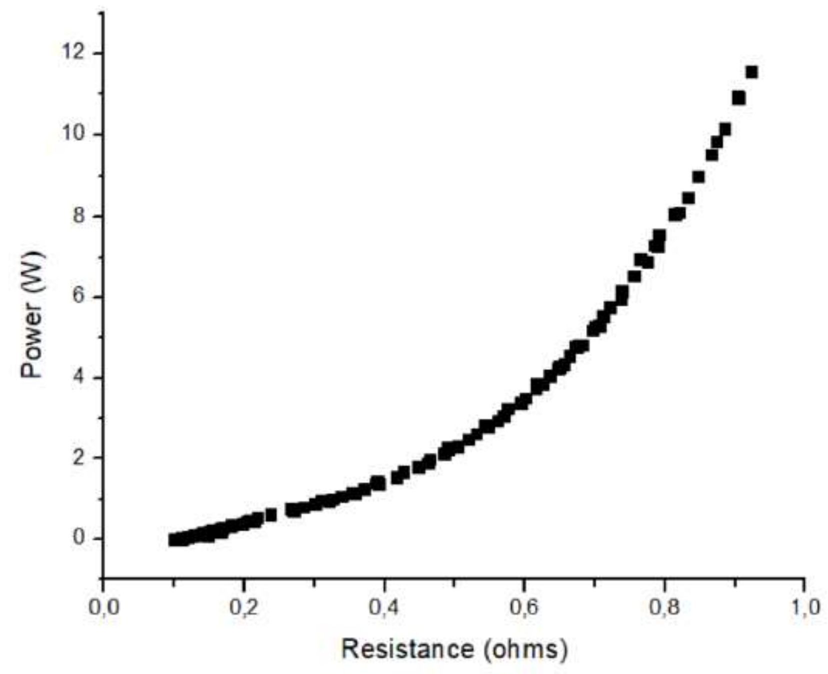

Figure 2. Dependence of the total power of the bulb versus bulb resistance. We can observe a linear region for low resistance, corresponding to thermal conductivity (dominant for low temperatures), while radiated power dominates for high temperatures.

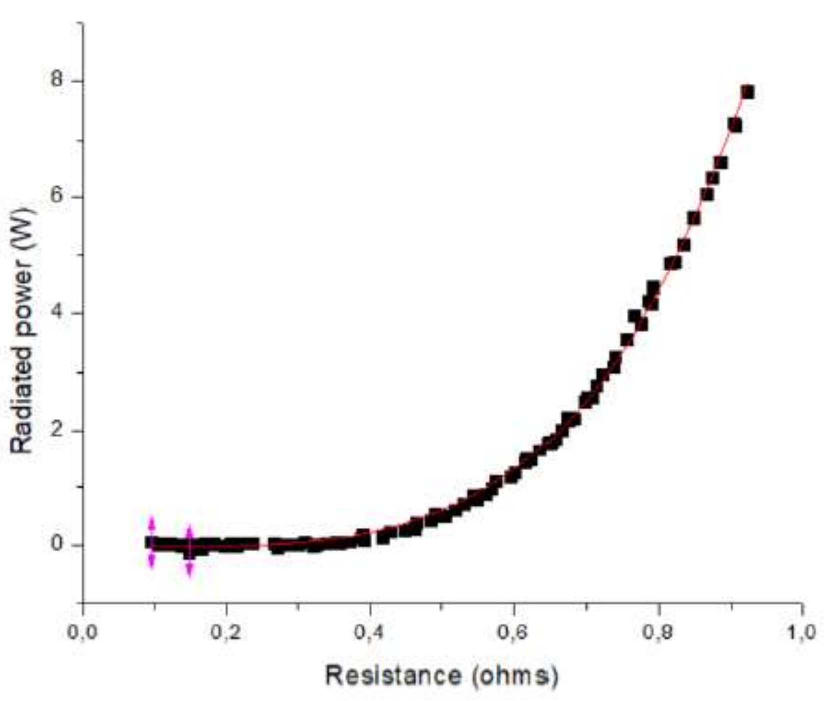

Figure 3. Fitting to Stefan-Boltzmann formula with variable exponent $P_R = A \bullet R^N + C$

As for the second stage, the photomultiplier signal (V) was proportional to the photon flux through the slit. Besides, by the experimental geometry, it was decided that we were measuring the radiance of the central part of our emitter into the cone defined by the emission point and the lens. Therefore, we could plot the dependence of voltage on temperature and fit the Planck's law to this dependence, for a frequency set with the monochromator (example: Fig. 4 for red colour). We produced three estimations of C2, which were also consistent with the reference value h/k=4.79924466 $\bullet 10^{-11}$ s $\bullet$K [1]. The three estimated values were:

$$C_{2,red} = (5.061 \pm 0.095) \cdot 10^{-11} \; s \cdot K$$

$$C_{2,gre} = (4.537 \pm 0.089) \cdot 10^{-11} \; s \cdot K$$

$$C_{2,vio} = (4.612 \pm 0.074) \cdot 10^{-11} \; s \cdot K$$

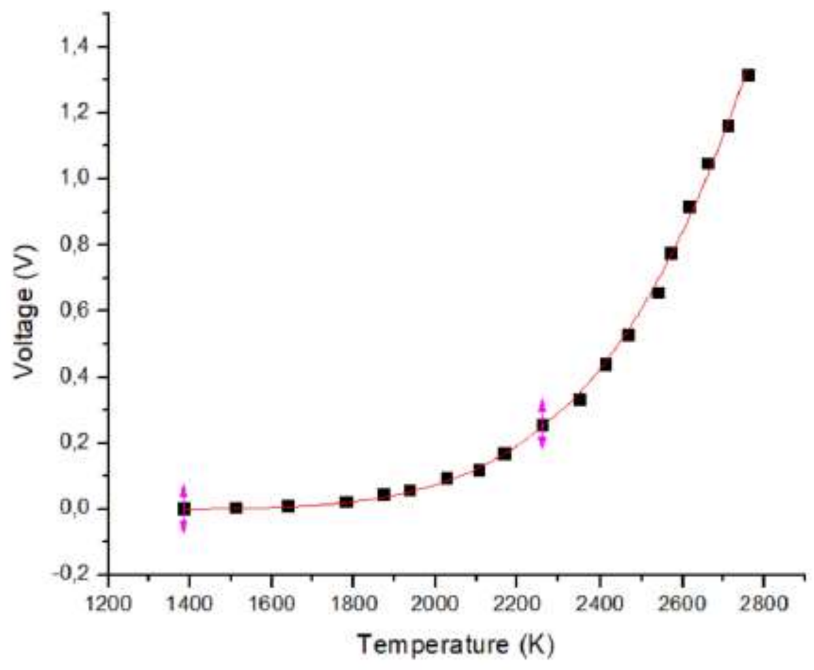

Figure 4. Fitting to Planck's law for red colour

References

[1] Eisberg, R. and Resnick, R. (1985). Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles. 2nd ed. United States of America: John Wiley & Sons.
[2] Feynman, R. P., Leighton, R. B. and Sands, M. (1963). The Feynman Lectures on Physics, Volume 1. United States of America: Addison-Wesley.
[3] Z11 experiment manual. Available at http://www.2pf.if.uj.edu.pl/.