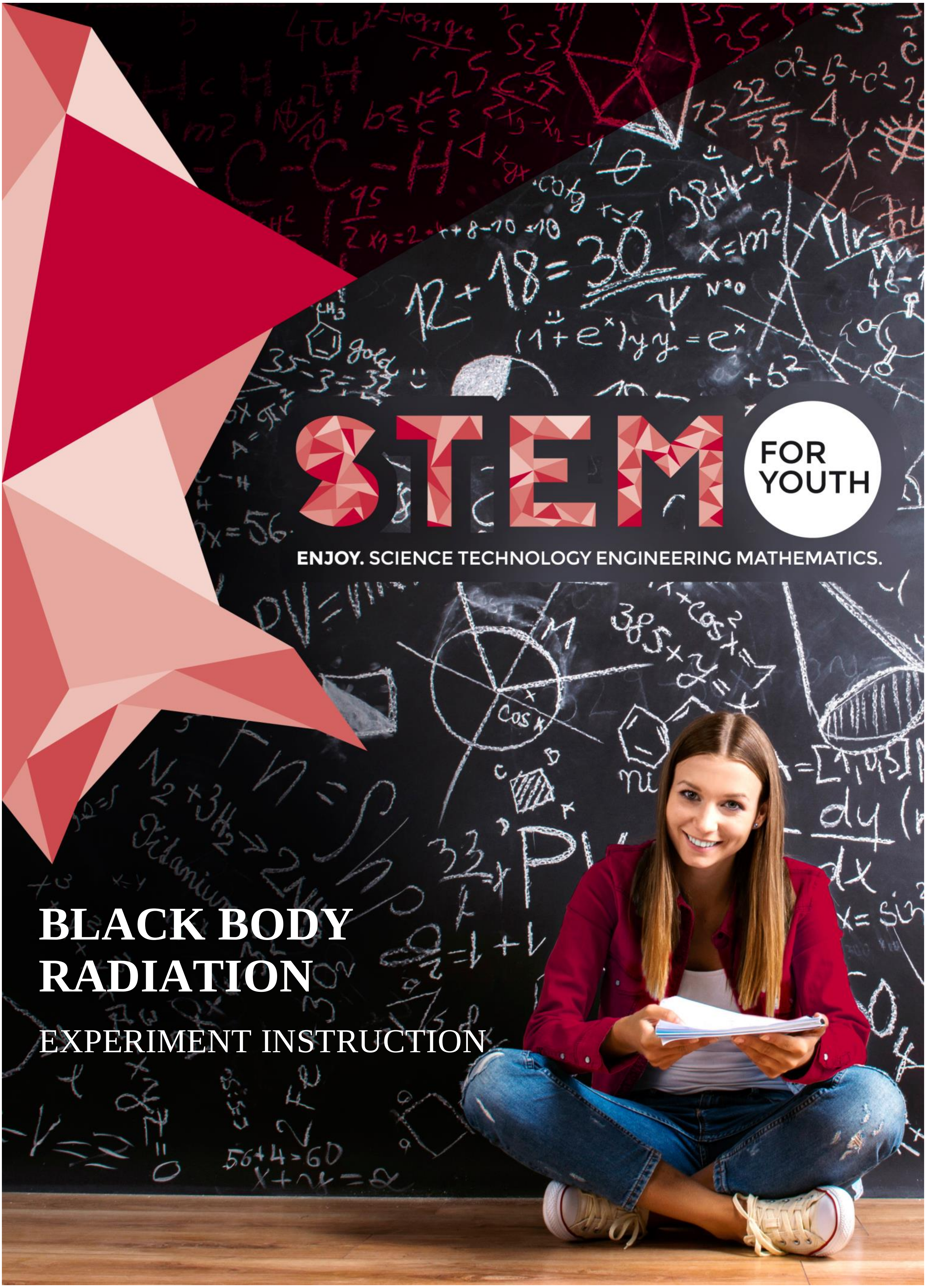

BLACK BODY RADIATION

EXPERIMENT INSTRUCTION

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Black body radiation

Purpose

The purpose of this exercise is to study is to study the spectra (distributions) of the power of the black body radiation.

Introduction

In accordance with the law of conservation of energy, charged particles, must absorb or give away energy to the environment when they change their speed. At a temperature higher than the absolute zero, atoms and particles (protons and electrons) in any material vibrate, so each body radiates and absorbs energy. For a given frequency, the radiated energy has a certain distribution which depends on the body temperature. The nature of such dependence was one of the mysteries of the late nineteenth century. There were several theories that tried to describe these relationships, but until Maxwell's time, none of them could describe the measurement results well in the entire frequency range.
An idealized black body, i.e. a body that absorbs any incident radiation is a model for studying the dependence of radiated power on its wavelength.
It can be imagined as an empty box, with a small hole through which radiation can enter or leave the box. It can be assumed that the internal walls of such a body are in thermal equilibrium with radiation inside the body, so the distribution of energy radiated by through the hole corresponds to the energy radiated by its walls. The classic theory of Rayleigh-Jeans described well the results of measurements for low radiation frequencies (large wavelength). Unfortunately led to a "catastrophe" in large frequencies (small wavelength), so-called ultraviolet catastrophe. Similarly, Wien's law described well the results for high frequencies but fails badly for small ones (see Fig. 1).

Max Planck was the first who found empirical the correct formula for a density of radiated energy as a function of radiation frequency, which he later justified theoretically by introducing the concept of a quantum of radiation. Explanation of this dependence contributed to the revolutionization of the foundations of physics and brought Planck the Nobel Prize.

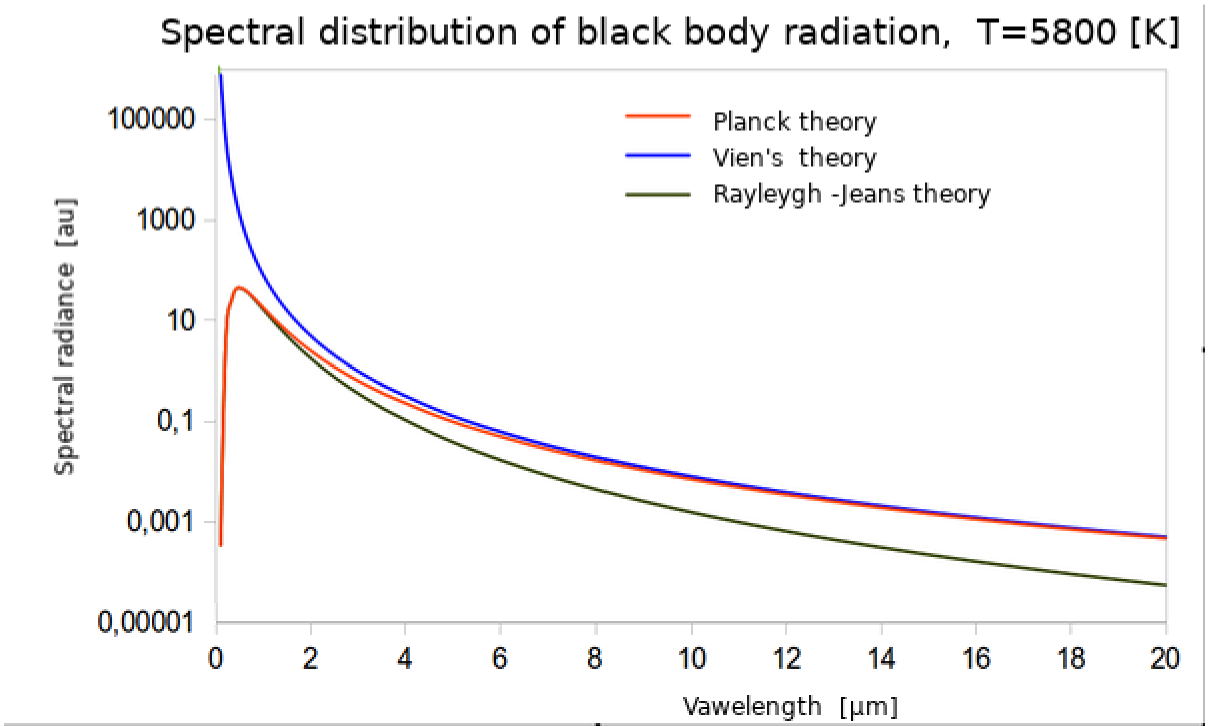

Figure 1: Comparison of Wien's, Rayleigh–Jeans' and Plank's theories for distribution of radiation power as a function of radiation wavelength.

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Figure 1 presents a comparison of the theories of spectral power distributions for a body with a temperate of the surface of the sun. Figure 2 presents a comparison of such distributions calculated according to Planck's law for different temperatures.

If one calculates the total power radiated by the body (area under the power distribution curve), then it turns out that this value is proportional to the fourth power of the temperature of the body. This is the essence of Stefan-Boltzmann law:

$$\Phi = \sigma T^4$$

where:
Φ - total energy emitted per unit surface area of a black body [Wm^{-2}]
σ - Stefan-Boltzmann constant $=5.67 \cdot 10^{-8}$[$Wm^{-2}K^{-4}$]
T - temperature [K].

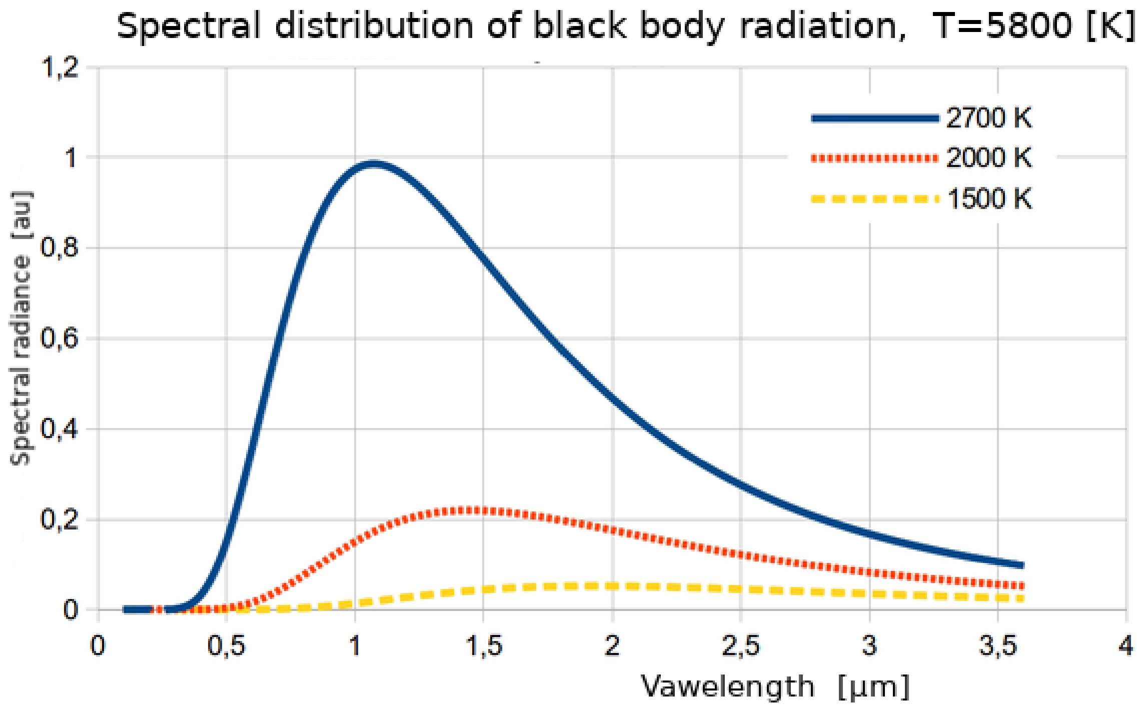

Figure 2: Distribution of radiation power as a function of wavelength for different temperatures.

Figure 2 shows that the location of the maximum of the spectral distribution depends on the temperature. The higher the temperature, the larger the radiated power ("brighter light"), but also the smaller the wavelength corresponding to the maximum of the distribution (which is related to the observed color of light).

The Wien law describes this dependence:

$$\lambda_{max} = C / T$$

were:
λ_{max} - wavelength corresponding to the maximum of the radiation power distribution [µm]
C - Wien's displacement constant = $2.9 \cdot 10^3$ [µmK]
T - temperature [K]

The study of the spectral distribution of the radiating bodies is used for contactless measurement of their temperature, e.g. for testing the temperature of pig iron in furnaces, star temperature or human temperature. Studies on the distribution of radiation coming from space in the microwave spectrum confirmed the Big Bang model of the origin of the Universe.

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Experimental setup

The experimental setup consists of a radiation source, a focusing mirror, a glass prism, a thermocouple, a power supply and a voltage meter. The diagrams of the measurement system is shown in Fig. 3.

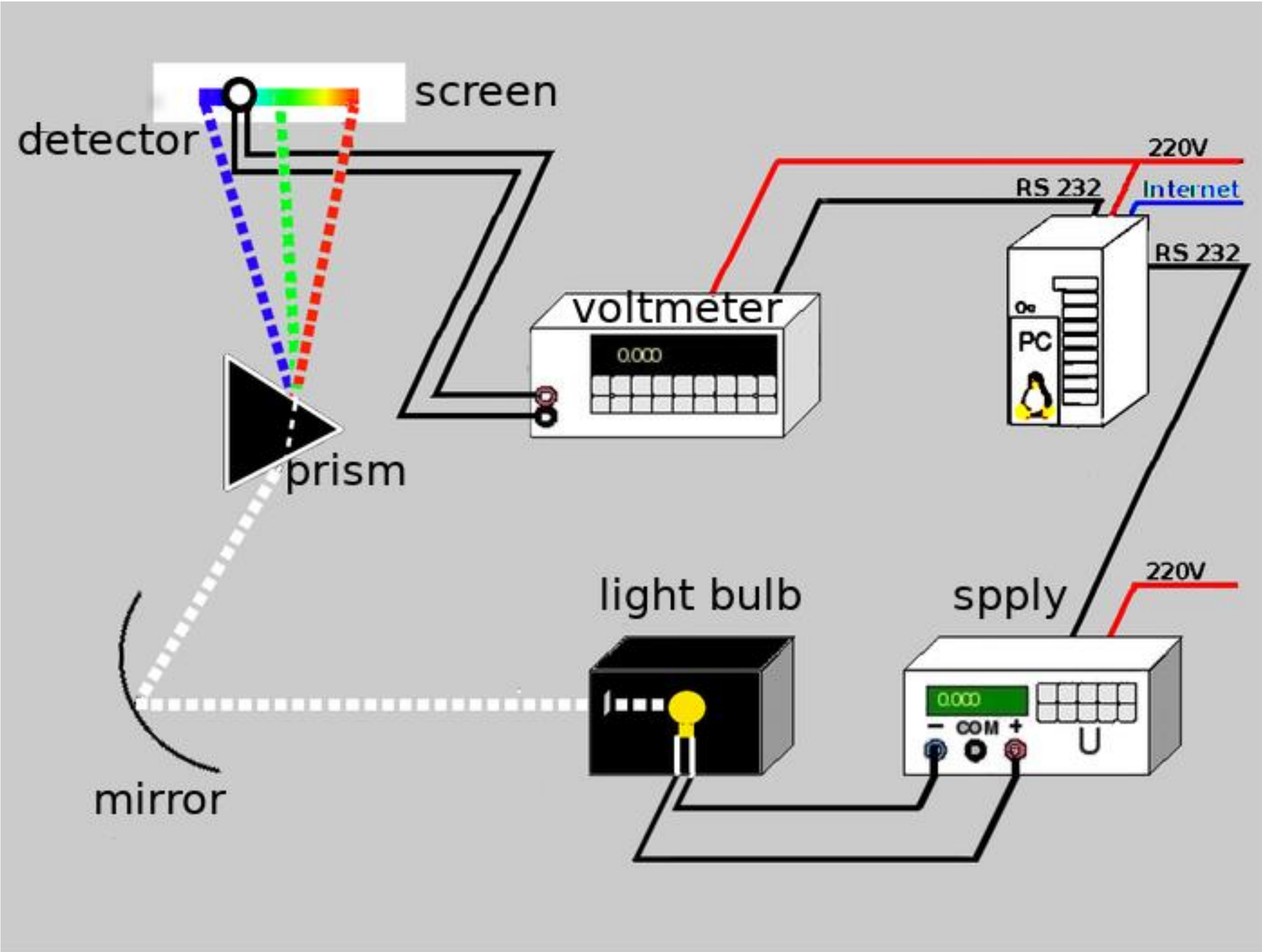

Figure 3: Diagram of the system for measuring the power of electromagnetic radiation.

The source of heat is a bulb with a tungsten filament (a radiant element) heated to a maximum temperature of 2700 K, placed in a container air-cooled by means of a fan.

The light bulb is powered by an adjustable DC voltage from a programmable HESEK PR82116A power supply controlled by a computer through the RS232 serial port. The filament temperature is determined by measuring the resistance of the bulb and using the tungsten resistance dependence on the temperature. The light of the bulb, after passing through the slit, falls on the concave mirror, which directs the beam of radiation on the prism made of quartz glass. The prism bends the radiation beam with different wavelengths in a different way, which leads to separation of white light into the color spectrum that can be seen on the screen. The radiation power detector is a thermocouple (Dexter ST60) connected to a multimeter (Rigol DM3061). A thermocouple is a device that absorbs the radiation falling on it, which means that one of the connectors is heated, which leads to the creation of a voltage difference at both ends. The value of this voltage is a measure of the absorbed power. The position of the thermocouple is determined by a mechanism with a stepper motor controlled by a computer. The picture of the measuring system is shown in Fig. 4.

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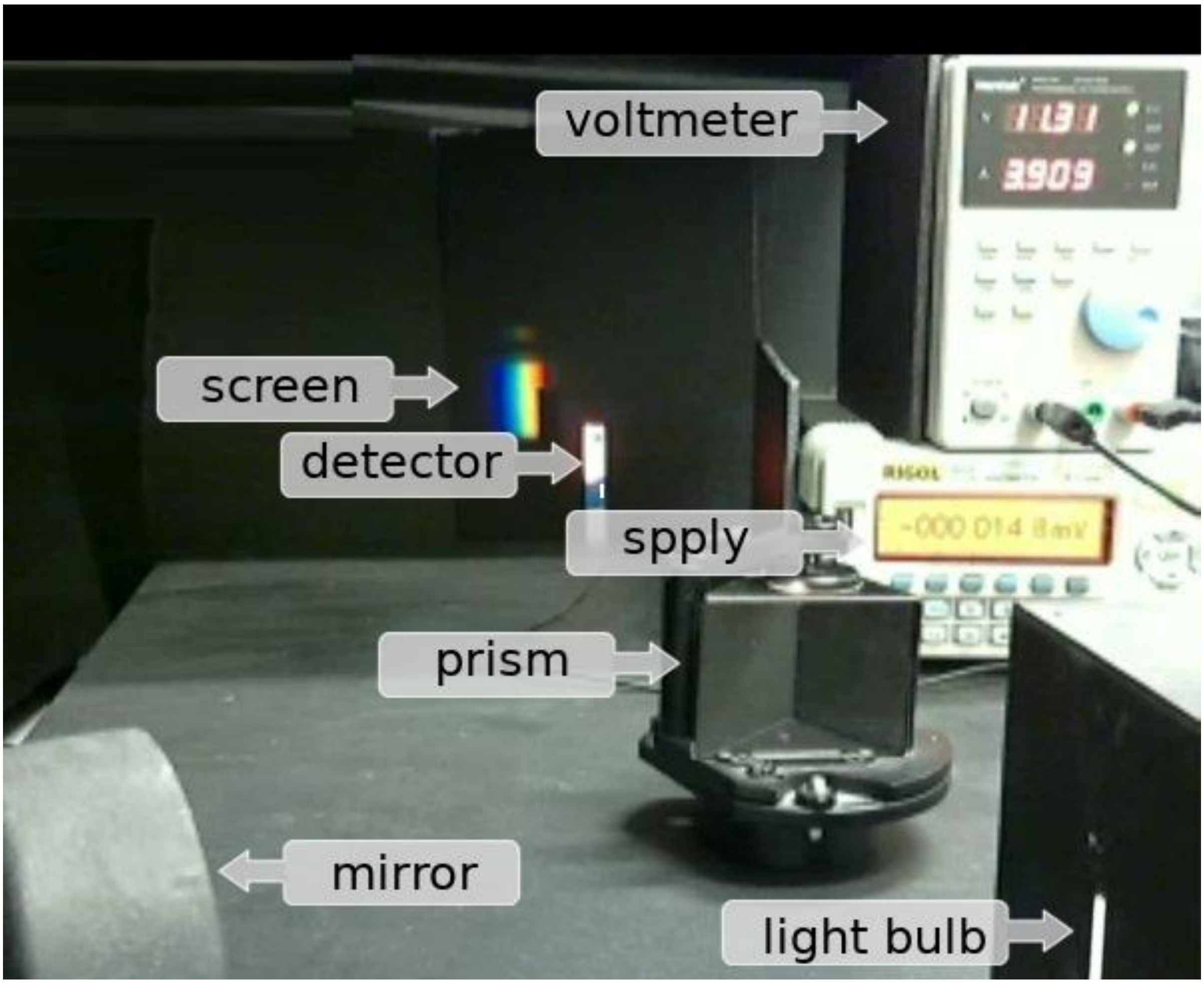

Fig. 4: A photo of the measurement system.

Measurements

After logging in to the Laboratory with the Connect button, select the measurement parameters by setting the expected value in the appropriate window.

Set:

- The temperature of the bulb filament
- The start wavelength
- The final wavelength
- The number of measuring points.

The choice of the number of points and the time of counts depends on the accuracy that we intend to obtain and on the time we can devote to the measurement of the characteristics. Pres the Start button, to start the measurement cycle. The control computer sets the initial wavelength and measures the voltage on the thermocouple. In the next step, it increases the wavelength with a step defined by the division of the difference between the set final and the starting wavelength by the selected number of measurement points. The measurement results are successively sent to the user's computer via the internet connection and displayed on the screen in the form of a graph of voltage on the thermocouple as a function of the radiation wavelength. You

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can stop the measurement at any time, save the data to the disk, change the parameters and restart the measurements. Make measurements for several bulb temperatures.

Data analysis

Make graphs of radiation power as a function on the wavelength for different temperatures of the source. In the graphs, find the maximum of power for each temperature and read the corresponding wavelength λ_{max}. Make a graph of the dependence of λ_{max} on the T^{-1}. The Wien law shows that this relationship should be a linear function. Determine the Wien's displacement constant C from the slope of the line.

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