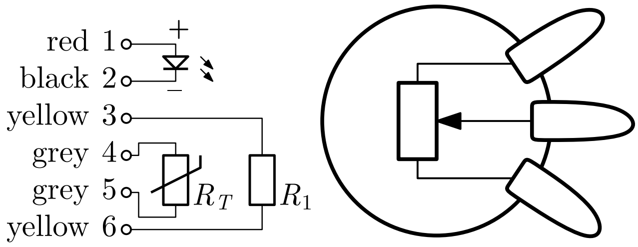
1 Light-emitting diode

Light Emitting Diodes (LEDs) are the most efficient light sources. During recent years, the cheap, powerful and reliable LED light bulbs appeared on the market. This is making a true revolution worldwide, as other electrical lighting tools (e.g. incandescent, halogen and fluorescent) in homes and offices are being replaced with LED lighting.

In this experiment, we will analyse thermal and electrical properties of the light emitting diodes.

You do not need to estimate any uncertainties, but the accuracy of your methods and results is important and will be graded. Always draw the measurement setup you use! When appropriate, use graphs for determining required quantities.

Equipment: 2 identical circuit boards with a LED, resistor and a temperature sensor on them; 2 transparent bottles, 2 airtight caps, 2 tubes, water, syringe, 3 multimeters (the multimeter labelled as "voltage-only" is to be used only for voltage measurements), 2 potentiometers, power supply, cables, stand, stripes of graph paper with millimeter scale.



The schematic and connections of the circuit board (left) and the potentiometer (right) are in the figure. The resistor R_1 may be used for heating the board near the LED. The temperature sensor (thermistor) R_T is another resistor whose resistance depends strongly on the absolute temperature T:

$$T = 2.254\,\mathrm{K}\left(\ln\frac{R_T}{1\,\mathrm{k\Omega}}\right)^2 - 32.46\,\mathrm{K}\ln\frac{R_T}{1\,\mathrm{k\Omega}} + 361.09\,\mathrm{K}.$$

Warning! Apply voltage to the LED only with the polarity shown! The red lead of the power supply is "+" (and should be connected to the red connector of the LED) and the black lead is "−".

The multimeter has a mode marked "⊣▶⊢" that acts as a source of an approximately constant small current, when a diode is connected between the "mAVΩ" (supplies "+") and "COM" ("−") terminals. In this mode the multimeter shows the voltage across the diode in volts, while supplying about 0.33 mA (you may assume the current stays fixed).

In a simplified theory, the diode current I_d, voltage drop V at the junction inside the LED where light is emitted, and absolute temperature T of the junction obey

$$I_d = Ae^{-V_{G0}/(nV_T)}\left(e^{V/(nV_T)} - 1\right) \text{ with } V_T = \frac{k}{q}T,$$

Boltzmann constant $k = 1.381 \times 10^{-23}$ J/K and elementary charge $q = 1.602 \times 10^{-19}$ C. The variable V_T is called the thermal voltage. The parameters V_{G0} and n depend on the materials of the LED; the parameter A depends also on the construction of the LED. The parameter n is called the ideality factor and usually $1 < n < 2$. The parameter V_{G0} is called the nominal bandgap voltage of the semiconductor material.

The voltage across a physical diode $V' = V + I_d R_s$ has also contribution from a parasitic series resistance R_s which is of the order of 1 Ω. **Hint:** estimate the magnitudes in the expression above and simplify your calculations accordingly!

1. Measure and plot the voltage–temperature graph of the LED at a constant current (your current should be small enough so that the voltage drop on R_s can be neglected).

   Find V_{G0}.

   Find the parameters n and A by making additional measurements and a suitable plot.

   At larger currents, the series resistance R_s becomes noticeable. Measure this R_s.

2. Define the efficiency of the LED as the ratio between the power radiated as light and the consumed electrical power. Measure a value of the efficiency η of the LED without using the temperature sensor.

3. The LED also behaves as a solar cell (or a photodiode). The photocurrent I_p generated by light does not depend on the voltage and is proportional to the light intensity; it is subtracted from the diode current ($I = I_d - I_p$). The photocurrent from the ambient light was low enough not to affect previous measurements.

   Place two LEDs directly opposite to each other at $d = 3.0$ cm distance, and supply one of them with $I_1 = 0.50$ A. Determine the maximum electrical power $P_{\max}$ that can be harvested from the LED in this lighting setup at room temperature.

   Determine the corresponding photoefficiency η_p — electrical power output divided by the power of the light absorbed by the active area of the LED. This area is $S = 1.56\,\mathrm{mm}^2$. Assume that the LED radiates uniformly into $\alpha = 33\%$ of the sphere.