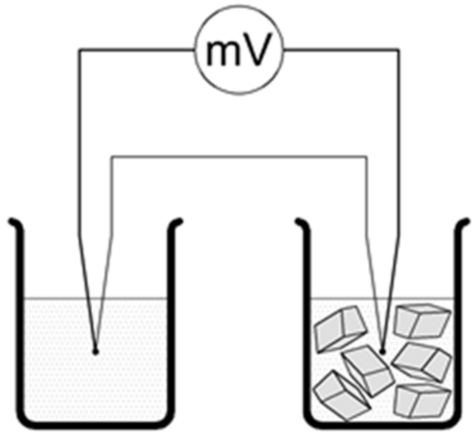
Experiment Nr. 19

Calibration of electrical thermometers

Theoretical part

Thermocouples and resistance thermometers belong to a group of electrical thermometers; thus, we use an electrical quantity measured on these thermometers being dependent on temperature. A thermocouple is based on thermoelectric effect (Seebeck effect). Thermocouples are made of two different metal conductors that are welded at the ends. This junction is called hot junction and here, the temperature is to be measured. The materials of the metal conductors must be appropriately selected for a specific range of temperatures to be measured. For more accurate measurements, the thermocouple arrangement consists of two wire junctions – hot junction and cold junction. The cold junction is considered as the reference junction in the thermocouple arrangement, with a reference or known temperature, typically 0 °C. The typical arrangement is shown in the following figure:



If the junctions are at different temperatures, a thermoelectric voltage could be measured (in the range of mV), that is a function of the temperature difference. The relationship between the thermoelectric voltage and the temperature difference is usually approximated by a quadratic relationship as follows:

$$\mathcal{E} = a + b\left(t_2 - t_1\right) + c\left(t_2 - t_1\right)^2$$

For a particular wires' materials and small temperature differences, the function becomes linear. The resulting thermoelectric voltage must be measured with a sensitive millivoltmeter. For highly precise measurements, the compensation method of voltage measurement is used.

The advantage of thermocouples is a small heat capacity. Due to this, thermocouples only slightly affect the real temperature of the investigated matter and they also show very small thermal inertia.

Resistance thermometers are based on the change of electrical resistance principle of metals or semiconductors with temperature. To a first approximation, the dependence of the electrical resistance R of a resistance thermometer on temperature could be considered as linear. Therefore, the relation is as follows:

$$R = R_0\left(1 + \alpha t\right),$$

where R_0 is the resistance at 0 °C and α is the temperature coefficient of resistance (TCR). For metals, the temperature TCR is positive (PTC sensors), for semiconductors (thermistors) is negative (NTC sensors). There is usually a quadratic relationship between electrical resistance and temperature for metals, for a smaller temperature range the relationship could be considered as linear. For NTC thermistors, the situation is more complicated, because the relationship between electrical resistance and temperature is exponential.

Platinum is often used as the material of a resistance thermometer due to its chemical inertness, high melting point and relatively large temperature range, in which the electrical resistance of a platinum thermometer is linearly dependent on temperature. The electrical resistance of a platinum thermometer at 0 °C is typically 100 Ω (Pt100).

The advantages of electrical thermometers, thermocouples and resistance thermometers include, among others, that they allow temperature measurement even in hard-to-reach places and their output as an electrical signal can be used in computer-controlled systems.

Theory of the measurement principle and measurement procedure

Calibration of a thermocouple means assigning temperature values to the measured values of thermoelectric voltage. The measurement scheme is shown in the Theoretical part afore. The cold junction is kept at a constant reference temperature during the measurement. Very often, the temperature of a mixture of melting ice and water is selected as the reference. However, the temperature of the cold junction must be kept constant, for example by placing the mixture in a Dewar flask.

Calibration of a resistance thermometer means assigning temperature values to measured values of resistance.

Both electrical thermometers are placed in the calibration furnace and the selected values of the temperature are set on the furnace control panel. For a precise temperature setting, a calibration furnace with an accuracy lower than 0.1 °C should be used.

Measurement objectives

1. Prepare a mixture of melting ice and cold water to be used as a reference bath for the thermocouple cold junction. Check the temperature of the bath.

2. On the furnace control panel set the temperature to 0 °C and check the reference values for both thermocouple and resistance thermometer.

3. Determine the voltage and resistance values for about 12 – 15 values of temperature. Use a step of about 3 – 4 °C.

4. Plot the calibration curves (lines) for the thermocouple and for the resistance thermometer. Use linear regression to prove function linearity. Determine the calibration constants.

Comments

Ad 1. Prepare about 300 ml of the mixture and pour it into the Dewar flask. Place the cold junction of the thermocouple into the mixture. Both the thermocouple hot junction and the resistance thermometer should be already placed in the calibration holes of the furnace.

Ad 2 + 3. For every temperature value wait until the furnace reaches the desired value. Then wait about 5 minutes and read the values of voltage and resistance. Use highly sensitive multimeter for determination of the measured values.

Ad 4. Use the linear function $y = ax + b$ for both calibration lines. Determine the constants a and b. Calculate the voltage and resistance values for the ambient room temperature.

Uncertainty calculation notes

The temperature accuracy of the calibration furnace is lower than 0.1 °C. Considering all uncertainty sources, the combined relative uncertainty of the calibration values should be lower than 1 %. Check the relative uncertainties given by the linear regression calculation and discus on the results.