THERMOMETRY
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The electrical characteristics of two different thermometers, a thermocouple and a thermistor, are measured as a function of temperature between 0°C and 100°C. The calibration curves are described mathematically.

I. INTRODUCTION

Thermometers are devices which have a measurable physical property X, whose value is an accurately known function of temperature, i.e. $X = X(T)$. There is a wide variety of these thermometric properties; the length of a liquid column, the pressure of a gas at constant volume, the electrical potential difference between two junctions of different metals, the magnetic moment of a spin system, are all used for thermometers. The choice of which thermometer to use for a particular measurement depends on sensor accuracy, measurement range, response time, sensor size, environment of the sensor, and the cost of the temperature sensor and its support equipment. Some of the most convenient thermometers are those whose thermometric properties are electrical characteristics, such as capacitance, current, resistance or emf. In this lab we shall consider two such extensively used thermometers.

Thermistors are semiconductor devices whose electrical resistance varies with temperature. Early thermistors were typically made from metal oxides such as manganese, nickel, or cobalt. Modern thermistors are often fabricated from boron-doped silicon, with much-improved characteristics and stability over the earlier versions. The empirical resistance-temperature relationship for a thermistor is generally of the form,

$$R(T) = R_0 \exp\left(\frac{b}{T} - \frac{b}{T_0}\right), \tag{1}$$

where R is the resistance at absolute temperature T, R_0 is the resistance at absolute temperature T_0 and the coeficient b depends on the particular thermistor material.[1,2] In contrast to metals, the temperature coefficient of resistance, defined as

$$\alpha = \frac{1}{R}\frac{dR}{dT}, \tag{2}$$

is negative and relatively large for thermistors. Typical values[2] for thermistors are $\alpha \approx -0.05/K$, whereas for a platinum-metal resistance thermometer, the coefficient is $+0.005/K$ at 0°C. The users of thermistors must be aware that by measuring resistance, power is being dissipated in the thermistor due to Joule self-heating, which can cause an erroneous temperature reading. Thus the current used in measuring the resistance should be kept to a minimum.

In 1822, J. T. Seebeck discovered that an emf is generated when junctions of dissimilar metals are maintained at different temperatures. This effect provides the basis for a very useful device to measure temperature known as the thermocouple. The typical thermocouple geometry, displayed in Fig.1, consists of two junctions of dissimilar metals connected in series, with one junction held at a fixed reference temperature and the other junction in the environment whose temperature is to be measured.

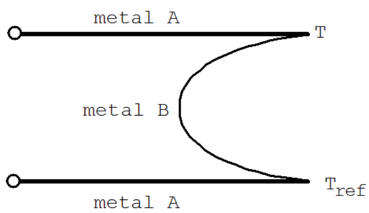

FIG. 1: The emf is a function of the temperature difference $T - T_{ref}$. A cold-juction compensator is often used to electronically simulate T_{ref}.

II. PROCEDURE

You should first prepare an ice-water bath for the thermometers. Use the mercury thermometer to check that the bath temperature is at 0°C. Measure the emf of the thermocouple when it is inserted into the ice-water bath. If it is not exactly zero then check any zero-offset knob. Also be sure that the ohmeter reads zero when the two leads are shorted together before measuring the resistance of the thermistor. Now slowly increase the hot plate heater current until the bath temperature, as measured by the mercury thermometer, is about 10°C. Patience is the key here, since all of the thermometers must come into thermal equilibrium with the water bath and hence with each other. You may want to take the temperature measurements *on the fly*. As a first guess for the hot plate setting, estimate the power required to raise the temperature of your water bath by 100°C in about 1 hour. Record the emf of the thermocouple, the thermistor resistance and the temperature from the mercury thermometer. Periodically check for any zero-drift problems in the meters. Continue to record the two temperature transducer characteristics and the temperature at about 10°C increments until you reach 100°C. Use the thermocouple to measure the temperature of liquid nitrogen. Wear safety glasses and gloves when you do this. Insert the bare thermocouple slowly to avoid thermal shock. Record the emf at the 77.4 K temperature of liquid nitrogen.

III. DATA ANALYSIS

Plot the resistance of the thermistor as a function of $1/T - 1/T_0$ on a semi-log graph. Choose T_0 to be the temperature at the ice point so that R_0 should be close to the resistance at that temperature. Find values for b and R_0 from a fit to the data on your semi-log graph. Comment on how well Eq.(1) fits the data and any discrepancies. Calculate the root-mean-square (rms) deviation

$$\sigma = \sqrt{\frac{1}{N}\sum_i (R_i - R(T_i))^2}, \tag{3}$$

where R_i is the measured resistance at temperature T_i and $R(T_i)$ is the resistance calculated from Eq.(1). **Show that** the coefficient α defined in Eq. (2) is equal to $-b/T^2$. Compare this to α extracted directly from your measuments.

Graph the thermocouple emf as a function of $t = T - T_{ref}$. The linear function $\mathscr{E} = mt$ is often used to approximate or interpolate thermocouple measurements over a limited temperature range. Fit the data to a straight line and discuss the slope and intercept parameters. Use your fitting function to extrapolate to the emf at $t = 77.4\,\mathrm{K} - T_{ref}$. Compare this to your measured emf at the temperature of liquid nitrogen. Discuss the success in extrapolating values far outside of the limited range over which the linear approximation is valid.

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[1] Specifying Temperature Measuring Systems, Application Note #401, Keithley Instruments Inc.

[2] Temperature Measurement Handbook and Encyclopedia, Omega Engineering Inc.