Building and calibrating a thermocouple

Introduction

Temperature measurements provide information about thermal processes, such as the heat transfer. To measure temperature, a number of detectors can be used: thermometers, thermistors, thermocouples and resistance temperature detectors (RTD). The thermocouple is an example of a transducer which converts a temperature difference into an electromotive force (EMF). Its use as a thermometer is widespread because it is easily constructed and has very little effect on the temperature of a small object to be measured.
The thermocouple consists of two wires of dissimilar metals which are joined at each end. When these two junctions are put into a temperature gradient, the free carriers at the hot end have more kinetic energy and tend to diffuse towards the cold end. The diffusion sets up an electric field which tends to oppose the heat flow $\dot{Q}$. Thus an EMF appears along the conductor, which is proportional to the temperature difference:

$$V = S(T_1 - T_2) \tag{1}$$

The proportionality law between V and $\Delta T = T_1 - T_2$ is called the Seebeck Effect, and S is the Seebeck Coefficient. It depends on the density and mobility of the carriers in the material.

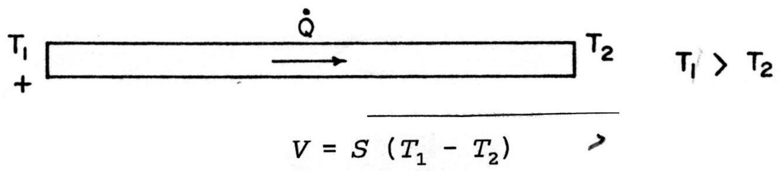

Figure 1: The Seebeck Effect

It is important to note that a thermocouple measures the temperature difference between the two junctions and not the absolute temperature. In order to use the thermocouple as a temperature sensor, one junction has to be maintained at constant temperature, such as an ice bath (the reference junction) while the other is placed in contact with the body or system of unknown temperature (the measurement junction). The thermocouple has to be calibrated against a standard thermometer.

You will make a Copper-Constantan thermocouple (Constantan is a Copper-Nickel alloy). Strip about 1/2 inch from both ends of all three wires. Twist together each end of the Constantan wire to one end of a Copper wire. Form the twisted ends into an oval shape. Solder them. In Figure 2 below, A is Constantan and B is Copper. Using alligator clips, connect the free ends of the B segments to the voltmeter.

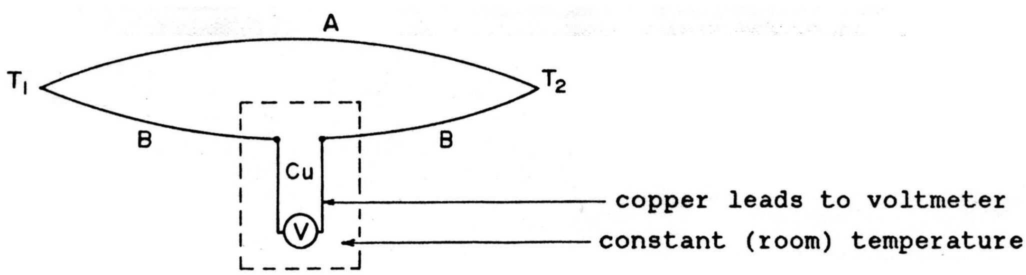

Figure 2: Building the thermocouple

The exercise

You can convince yourself that the $B - Cu$ and $Cu - B$ EMFs will cancel as long as both $B - Cu$ junctions are at the same temperature, even if this isn't the temperature of the voltmeter.
The thermocouple you made has to be calibrated against a standard thermometer before it is used in any experiment. To calibrate it, an ice bath is used as reference temperature for one of the soldered joints. The other joint has to be immersed in:
- boiling water (100^oC)
- crushed ice (0^oC)
- water at 4-5 other temperatures (temperature has to be checked with a thermometer).

To Do

$\Longrightarrow$ Write a program in Python to fit the calibration data with Equation (1). Plot the calibration curve of the thermocouple: EMF(V) vs. T . Estimate the errors. Determine the Seebeck constant of the thermocouple (S_{AB}).
$\Longrightarrow$ Write a Python program using the calibration program and asking the user to give a measured V value. The program will output the cooresponding temperature T.
$\Longrightarrow$ Questions:
1) What is the output resistance of the thermocouple?
2) Suppose we have several thermocouples. Would it be any advantage to connect them in series?

Written by Ruxandra Serbanescu in Dec. 2016