Seebeck and Peltier Effects

Introduction

Thermal energy is usually a byproduct of other forms of energy such as chemical energy, mechanical energy, and electrical energy. The process in which electrical energy is transformed into thermal energy is called Joule heating. This is what causes wires to heat up when current runs through them, and is the basis for electric stoves, toasters, etc.

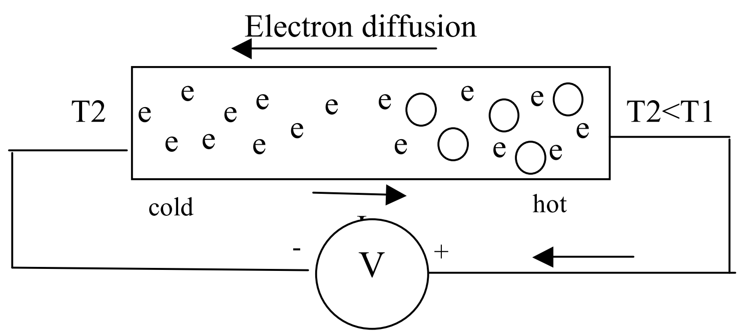


Figure 1: Electrons diffuse from the hot to cold side of the metal (Thompson EMF) or semiconductor leaving holes on the cold side.

I. Seebeck Effect (1821)

When two ends of a conductor are held at different temperatures electrons at the hot junction at higher thermal velocities diffuse to the cold junction. Seebeck discovered that making one end of a metal bar hotter or colder than the other produced an EMF between the two ends. He experimented with junctions (simple mechanical connections) made between different conducting materials. He found that if he created a temperature difference between two electrically connected junctions (e.g., heating one of the junctions and cooling the other) the wire connecting the two junctions would cause a compass needle to deflect. He thought that he had discovered a way to transform thermal energy into a magnetic field. Later it was shown that a the electron diffusion current produced the magnetic field in the circuit a changing emf V (Lenz's Law).

The magnitude of the emf V produced between the two junctions depends on the material and on the temperature ΔT_{12} through the linear relationship defining the Seebeck coefficient S for the material.

$$\Delta V = S \, \Delta T_{12}$$

The Seebeck coefficient can be measured Figure 2, by connecting wire-A in a circuit with 2 wire-Bs. The two junctions (ends of wire-A) are held at two temperatures, and V measured as $T1$ or $T2$ is varied, Diagram of.

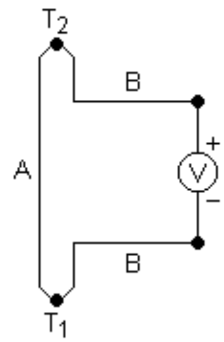


Figure 2: Experimental setup for measuring the Seebeck coefficient *S.*

Only terminals 1 and 2 need be considered if the B-leads at the voltmeter are kept at the same temperature**.** If T1>T2 electrons flow to T1 leaving T2 more positive.

Vb-Va = SA(T2-T)   Vc-Vb= SB(T1-T2)   Vd-Vc= SA(T-T1)

V = (Vb-Va)+ (Vc-Vb) + (Vd-Vc)
V = SA T2 - ~~SA T~~ +SB T1 -SB T2 + ~~SA T~~ - SA T1
V = SA(T2-T1) - SB(T2-T1) = (SA-SB)(T2-T1)
Q = q V = q (SA-SB)(T2-T1)
dQ/dt = I (SA-SB)(T2-T1) = I Π_{12}

We will make a crude measurement of the Seebeck coefficient of Cu and Al while holding the junctions temperature T1 and T2 to 0°C and 100°C respectively.

Our explanation of the Seebeck effect was naïve and further involves the conductivity of electrons and holes in the metal. You will find that Cu ad Al have opposite coefficients?

Procedure

1. Place the Cu or Al sample across the cups and attach the DMM probes.
Measure the voltage difference ΔV at T~24 °C room tempererature.
The DMM should be set to Voltage and Auto-ranging.

2.Fill the cold side cup with ice and add water to make a ice bath.
Measure the temperature with the thermocouple gauge T~0-2 °C.

2. Fill the hot side cup full with water. Begin heating the the AC heater until boiling T~98-100 °C.

3. Measure the ΔV across different materials (Cu, Al) at T1 cools from (100-50) °C for each sample.

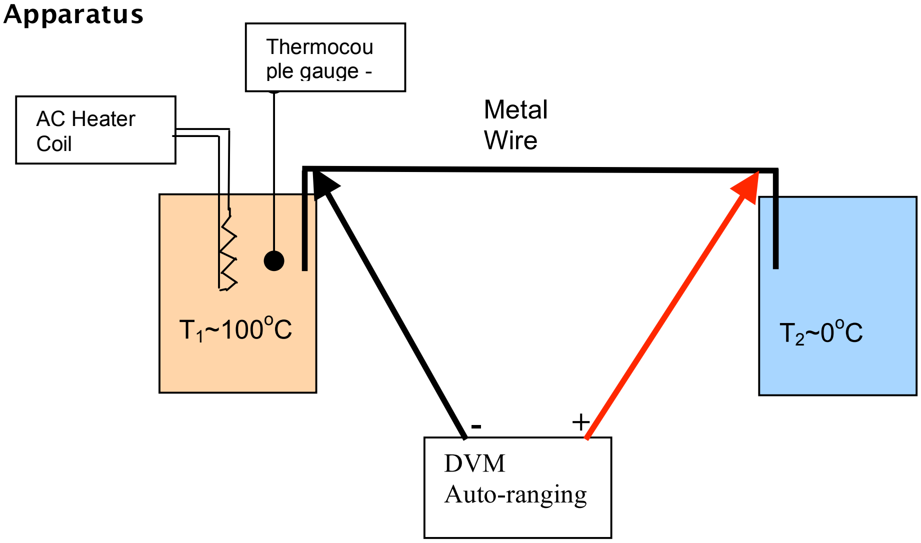
4. The temperature at the probe is about 10% higher or lower than the cup temperature! Should you make this correction?

5. Plot ΔV vs ΔT_{12} and determine the Seebeck Coefficients for Cu and Al.
$S=\Delta V/\Delta T_{12}$ *(Correct for temperature at the probe points.)*

6. Compare the measured coefficients of Cu and Al with standard results.

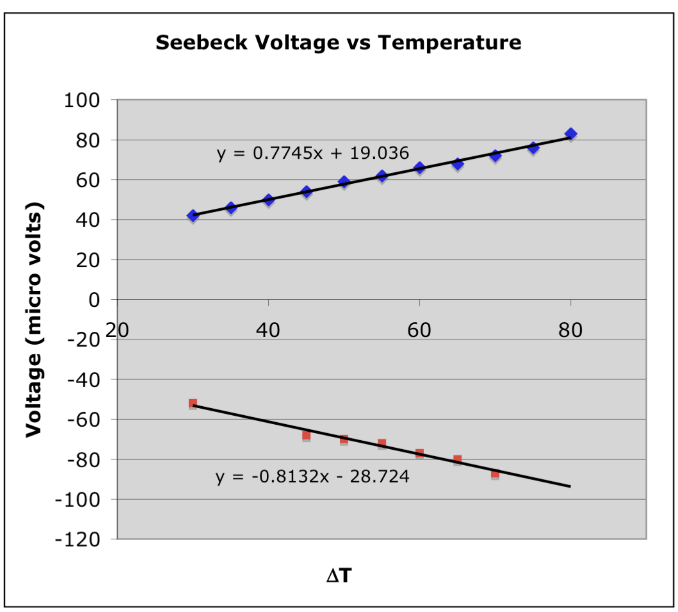
7. Explain why CU ad Al have opposite Seebeck coefficients.

Apparatus



Sample Data

T1	T2	ΔTcorr	ΔV(uV) Cu	ΔV(uV) Al
100	0	80	83	
95	0	75	76	
90	0	70	72	-87
85	0	65	68	-80
80	0	60	66	-77
75	0	55	62	-72
70	0	50	59	-70
65	0	45	54	-68
60	0	40	50	
55	0	35	46	
50	0	30	42	-52



II. Thermocouple

A thermocouple is a temperature measuring device can be made by holding all but one terminal of the Seebeck apparatus (say T1) to the same temperature. We will investigate the thermoelectric potential generated by Al-Cu and chromel-alumel (Type-K thermocouple).

It can be shown that the contact potential between metals $\Delta V_{contact} \sim \phi_1 - \phi_2$ *the difference of work functions.*

Procedure

1. Create a junction between Al-Cu (as shown in Figure 1, by twisting wires firmly together. Next you will use a chromel-alumel pair (provided).

2. Set the DMM to the auto-ranging scale. Measured Voltages range usually between 50 or 200 mV.

3. Attach the voltmeter leads to the two free ends (as shown in Figure 1, above.) The test leads with the clips will be useful for this.

4. Measure and record the voltage with the junction at room temperature.

5. Insert the junction into a cold liquid or place it against an ice block and measure and record the voltage again (leave the other junction at room temperature).

6. Repeat the experiment using the chromel-alumel pair.

8. Make a graph of the voltage vs. temperature for the difference for thechrome alumel chromel-alumel pair by attaching a thermocouple gauge to the wire pair to give the temperature reading. Boiling water(100,90,80,70,60,50,)ºC Ice bath 0ºC

T(0ºC)	100	90	80	70	60	50	0
V(mV)							

9. Which pair of materials gives you the best sensitivity (i.e., highest voltage measured for the same temperature difference)?

10. Does $\Delta V_{contact} \sim \phi_1 - \phi_2$ in each case. Look up workfunctions for Cu-Al, chromel-alumel .

Type K (chromel-alumel) is the most commonly used for general purpose thermocouple. It is inexpensive and, owing to its popularity, available in a wide variety of probes. They are available in the −200 °C to +1350 °C range. The type K was specified at a time when metallurgy was less advanced than it is today and, consequently, characteristics vary considerably between examples. Another potential problem arises in some situations since one of the constituent metals, nickel, is magnetic. One characteristic of thermocouples made with magnetic material is that they undergo a step change when the magnetic material reaches its Curie point. This occurs for this thermocouple at 354 °C. Sensitivity is approximately 41 µV/°C. (Wikipedia)