Lebanese University
Faculty of Science II

SCIENTIFIC REPORT

Thermodynamics lab P3303

Experiment IV: Thermoelectric Couple

By

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Oct 14, 2025
Fall Semester 2025

I. Abstract

This report presents the measurement of the thermoelectric electromotive force (emf) of a copper(A)/constantan(B) thermoelectric couple as a function of temperature(θ). One junction was kept at $0\,^{\circ}\mathrm{C}$ (ice bath) while the other was heated in paraffin oil and measured from low to high temperatures. The emf (e) was recorded and fitted by the expression $e(\theta) = a + b\theta$.Finally to deduce the thermoelectric power $\mathrm{d}e/\mathrm{d}\theta$.

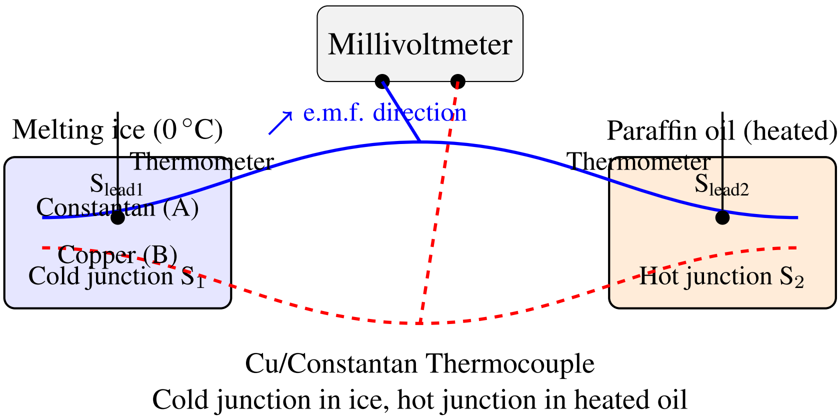
key words: temperature, e.m.f, thermocouple

II. Introduction

A thermoelectric couple (thermocouple) produces an e.m.f when its two junctions are at different temperatures. This effect arises from the combination of contact (Peltier) and temperature (Thomson) effects. For many practical metal couples the open-circuit e.m.f can be reasonably approximated over a limited range by a quadratic equation **but** for the studied range, a linear fitting will be used.

$$e = a + b\theta \tag{1}$$

The derivative $\frac{de}{d\theta}$ (thermoelectric power) is an important quantity known as the **Seebeck** coefficient which can be used to determine the emf or temperature difference and help determine what the materials used in a thermocouple



DiagramI: Sketch of thermoelectric experiment showing Cu(A)/Constantan(B) thermocouple, cold (S_1) and hot (S_2) junctions, and millivoltmeter measurement.

III.Procedure

1. Prepare a melting ice bath (ice + distilled water) and a paraffin oil bath. Place one junction (S_1) of the Cu/Constantan couple in the ice bath and the other junction (S_2) in the oil.

2. Insert calibrated thermometers: one reads the ice bath (verify $0\,°C$) and the other reads the oil temperature (range up to $200\,°C$).

3. Connect the open-circuit ends of the couple to a millivoltmeter.

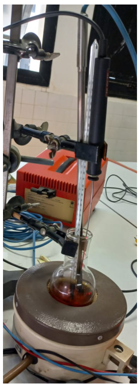
4. Slowly increase the oil temperature using the heater. Wait at each step until temperature stabilizes (repeat reading for every $5\,°C$) increase to check stability).

5. Record (θ, e) pairs where θ is temperature of S_2 (S_1 is $0\,°C$) and e is the millivoltmeter reading in mV.

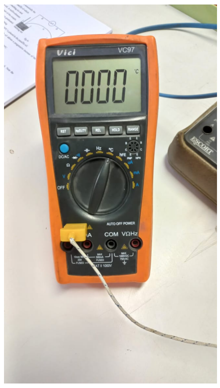
6. Repeat measurements covering the instrument range (25–200 °C).

Below are pictures of a few intruments used and a table including the measured data.

Ice bath



Paraffin oil bath



Multimeter

Figure 1: Some instruments used in the experiment.

Table 1: Measured emf (mV) vs temperature for the Cu / Constantan couple

Temperature (°C)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
Millivoltmeter (e) [mV]	-0.43	-0.41	-0.36	-0.30	-0.22	-0.17	-0.09	-0.01	0.05	0.19	0.28	0.41	0.52	0.63	0.74	0.84	0.95	1.08	1.18	1.30

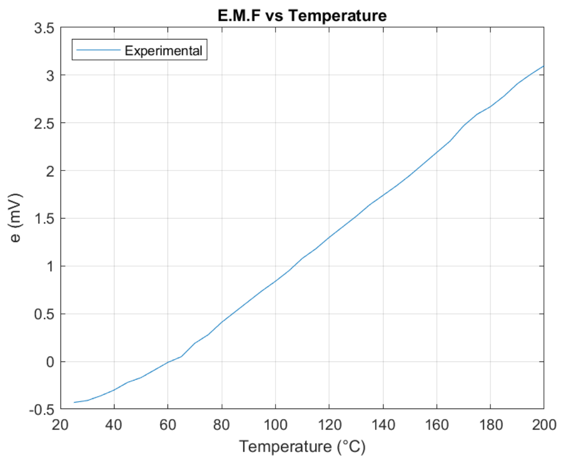
Temperature (°C)	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
Millivoltmeter (e) [mV]	1.41	1.52	1.64	1.74	1.85	1.96	2.08	2.18	2.30	2.42	2.55	2.67	2.79	2.91	3.03	3.15

IV. Results and Analysis

This section will include the graphs of $e\ vs\ \theta$ and its derivative, a discussion of results, and errors with some suggestions. Any detailed calculations will be placed in section VI.

IV.1 Experimental Results

The graph of the variation of e.m.f as a function of the temperature is as follows:



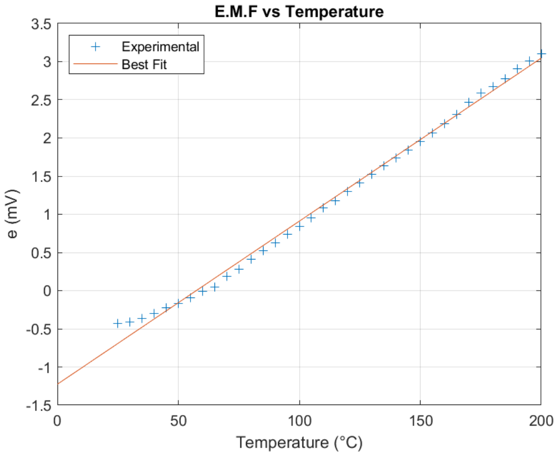
The graph on the left directly plots the data from **Table 1** and shows an approximately *linear* trend..

Graph I:E.M.F versus Temperature

To further improve the plot, one must find the slope b and the y-intercept a of the **Equation 1** and then plot, both by using software like MATLAB. The best-fitted equation becomes:

$$e = 0.021\theta - 1.23 \tag{2}$$

Where e is in V and θ is in $°C$. The slope of e is $b = 0.021$ and the y-intercept is $a = -1.23$.



The figure on the left is the best-fit line that was extrapolated to show the b line along with the data points to show the deviation from the line.

Graph II:E.M.F versus Temperature

IV.2 Result Analysis

From **Equation 2**, the thermoelectric power or the **Seebeck coeffiecient** can calculated by deriving e with respect to θ:

$$S = \frac{de}{d\theta} = 21.38\,\mu V/°C \tag{3}$$

S is also the slope of e which does not depend on temperature for a linear fitting.

The experimental data points in **Graph II** are very close to the best fit line. In fact, this low deviation can be expressed in the **R-squared** formula:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(e_i - \hat{e}_i)^2}{\sum_{i=1}^{n}(e_i - \bar{e})^2} \approx 0.995 \tag{4}$$

Where $\hat{e}_i$ are the predicted(fitted) values and $\bar{e}$ is the mean value. An R-squared value of 0.995 indicates an excellent fit which is directly under the limit of $R^2 = 1$ for a perfect fitting.

IV.3 Discussion

As in all experiments, **errors** were observed. *Sources* of errors include:

1. **Reading** Errors: Incorrect readings from the person and/or the digital millivoltmeter and thermometer which have uncertainties of:

$$\Delta T_v = smallest\,reading = 0.01mV \quad (5) \qquad\qquad \Delta(T)_{th} = smallest\,reading = 1°C \quad (6)$$

2. **Random** Errors: Fluctuations of ambient temperature, electric noise and poorly soldered copper/constantan couple.

3. **Instrumental** Errors: Non-calibrated or improperly calibrated thermometer and millivoltmeter.

To *minimize* these errors, one must always pay attention while recording data, properly calibrate the instruments, ensure proper soldering of the thermocouple, perform the experiment in a controlled environment, and repeat the experiment many times. In addition, an appropriate uncertainty/error calculation must be presented.

V. Conclusion

In conclusion, the obtained results show a linear relationship between e.m.f and the temperature which is expected for thermocouple in the **studied range**. Despite minor errors, the precision of the obtained data is satisfactory. The high R^2 value of 0.995 shows an excellent agreement between the experimental and fitted models.

VI. Appendix

To compute the coefficient of determination, R^2, which indicates how well the regression line fits the experimental data (with values closer to 1 meaning a better fit):

$$\bar{e} = \frac{1}{n}\sum_{i=1}^{n} e_i \approx 1.177\,\mathrm{mV}$$

$$\mathrm{SSR} = \sum (e_i - \hat{e}_i)^2 \approx 0.223$$

$$\mathrm{SST} = \sum (e_i - \bar{e})^2 \approx 44.550$$

$$R^2 = 1 - \frac{0.223}{44.550} \approx 0.995$$

VII. References

[1]Faculty of Sciences, Lebanese University. *Experimental Physics II Manual*, 2025.
[2]Rojas, J. A., Rivera, I., Figueroa, A., Vázquez, F. (2016). Coupled Thermoelectric Devices: Theory and Experiment. Entropy, 18(7), 255. https://doi.org/10.3390/e18070255