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Physics Laboratory - Report #4

Experiment: 37

The Seebeck effect investigation and the thermoelectric module application for the thermal-to-electrical energy conversion.

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Theory

The Seebeck coefficient (also known as thermopower, thermoelectric power, and thermoelectric sensitivity) of a material is a measure of the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material, as induced by the Seebeck effect The SI unit of the Seebeck coefficient is volts per kelvin (V/K).

$$S = -\frac{\Delta V}{\Delta T}$$

Electric power, like mechanical power, is the rate of doing work, measured in watts, and represented by the letter *P*. The term *wattage* is used colloquially to mean "electric power in watts." The electric power in watts produced by an electric current *I* consisting of a charge of *Q* coulombs every *t* seconds passing through an electric potential (voltage) difference of *V* is

$$P = \text{work done per unit time} = \frac{VQ}{t} = VI$$

Where;

Q is electric charge in coulombs
t is time in seconds
I is electric current in amperes
V is electric potential or voltage in volts

On the second part of the project, the electric pwer dissipated by the load resistors will be calculated with two separate approach and the results will be compared.

First equation is:

$w = \dfrac{U^2}{R_L}$, where U denotes the voltage drop across the load resistor R_L.

And the second is:

$$w = \left(\frac{\alpha \Delta T}{R + R_L} \right)^2 R_L$$

where R is the module resistance, α denotes the effective Seebeck coefficient for the module,

ΔT is the temperature difference between the module plates.

Measurement Equipment

– A measurement setup composed of the thermoelectric module, a heat exchanger immersed in the heat sink (a vessel with cold water), a copper disc, a heater and digital thermometers,

– A digital universal meter,

– DC power supply equipped with built-in voltmeter and ammeter,

– A load resistor.

Bibliography

"Seebeck Coefficent", Wikipedia Article, "https://en.wikipedia.org/wiki/Seebeck_coefficient"

Ryszard Poprawski, Beata Radojewska, Wojciech Poprawski, Experiment 37, "http://lpf.wppt.pwr.edu.pl/docs/procedures/eng/E037.pdf"

Data Tables

1.)

	I(A)	T_1(◦C)	T_2(◦C)	∆T(◦C)	U(mV)	U/T
resolution	0,01	0,1	0,1		0,01	43,128
1	0	21,5	21	0,5	23	
2	0,3	21,7	20,9	0,8	34,4	
3	0,6	23,5	21,5	2	87,3	
4	0,9	26,8	22,5	4,3	180	
5	1,2	31,7	24,1	7,6	320	
6	1,5	38	26	12	508	
7	1,8	42,7	27,3	15,4	664	
8	2,1	53,9	30,5	23,4	1011	

2.)

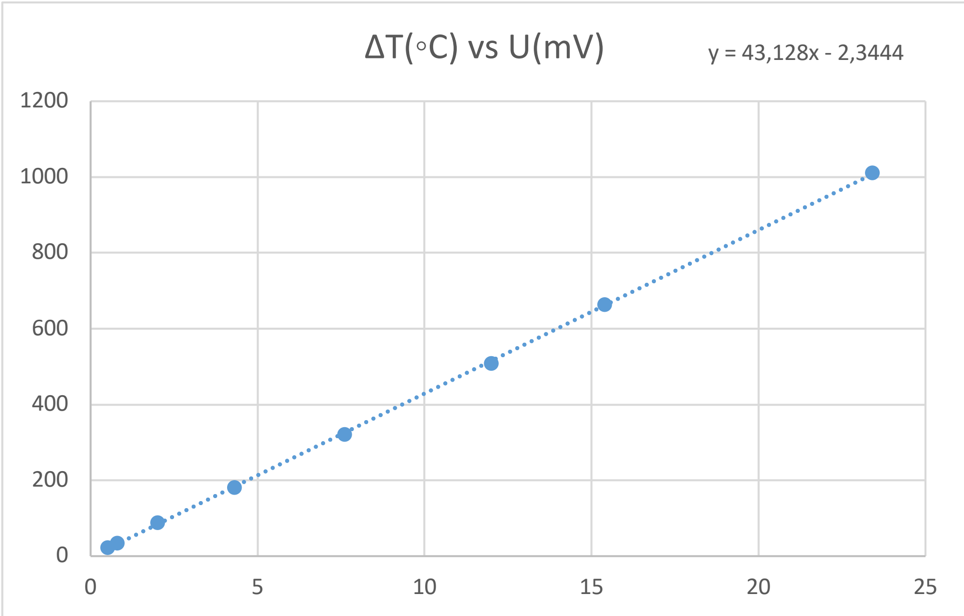
	I(A)	T_1(◦C)	T_2(◦C)	∆T(◦C)	U(mV)
resolution	0,01	0,1	0,01		0,01
1	0	22,8	21,5	1,3	26,4
2	0,3	22	20,9	1,1	28
3	0,6	23	20,9	2,1	50
4	0,9	25,4	21,4	4	88,3
5	1,2	29,9	22,3	7,6	165,1
6	1,5	32,7	23,2	9,5	210
7	1,8	37,9	24,3	13,6	300
8	2,1	49	27,5	21,5	453

	P	w	R	w_2	u_w	OHM
1	0	0,000155			1,38E-08	4,5
2	8,4	0,000174	0,093333	0,000115	1,55E-08	
3	30	0,000556	0,083333	0,000423	4,94E-08	
4	79,47	0,001733	0,098111	0,001523	1,54E-07	
5	198,12	0,006057	0,137583	0,005406	5,38E-07	
6	315	0,0098	0,14	0,008438	8,71E-07	
7	540	0,02	0,166667	0,017096	1,78E-06	
8	951,3	0,045602	0,215714	0,041842	4,05E-06	

Resistance of the resistor is 4,5 OHMs.

Calculations

1.)



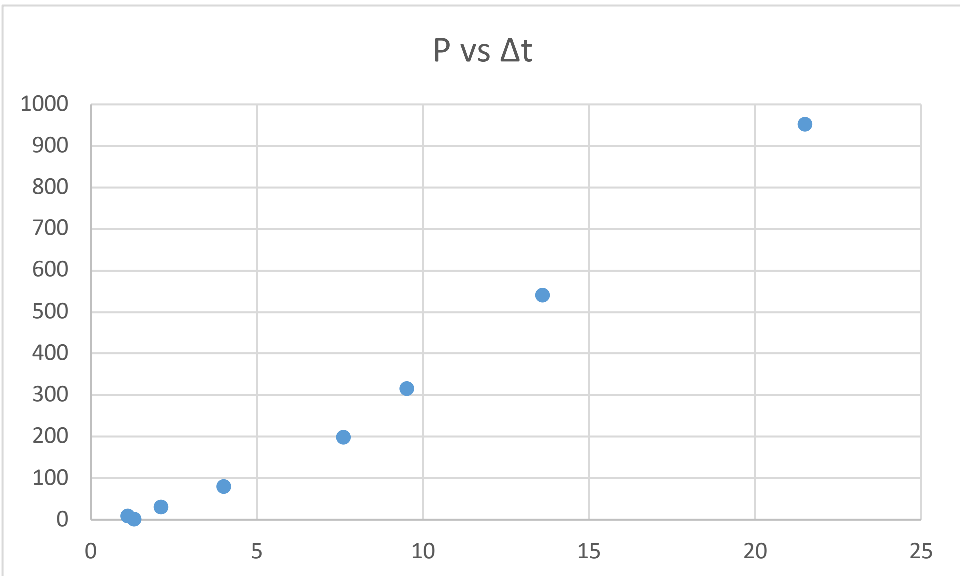
The relation between temperature difference and the thermoelectric voltage is linear, monotonic and strictly increasing with the slope of a = 43,128. Therefore the expression:

$$S = -\frac{\Delta V}{\Delta T},$$

would be -43,128 U/T .

2.)

a.)



Where P is calculated by the equation given in the theory segment;

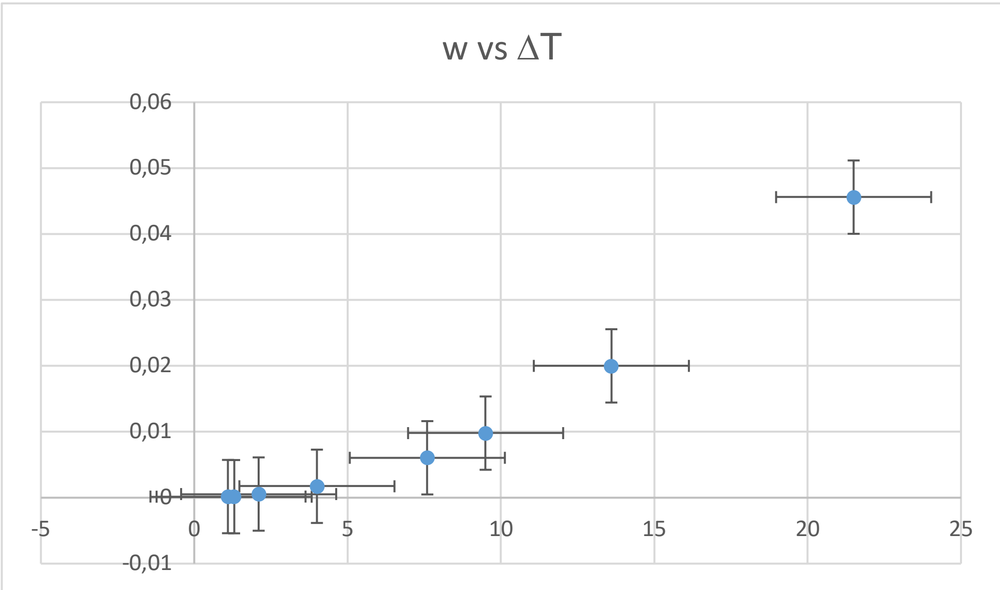
$$P = \text{work done per unit time} = \frac{VQ}{t} = VI$$

b.)

To calculate the electric power dissipated by the load resistors, the formula used is;

$w = \dfrac{U^2}{R_L}$, where U denotes the voltage drop across the load resistor R_L.

The graph denotes the resulting w vs temperature difference, with the error bars.



- Uncertainty of Electric Power

$$u_w = \sqrt{(2\, u_U\, \frac{U}{R_L})^2}$$

For I = 0A;

u_w = 1,37671E-08

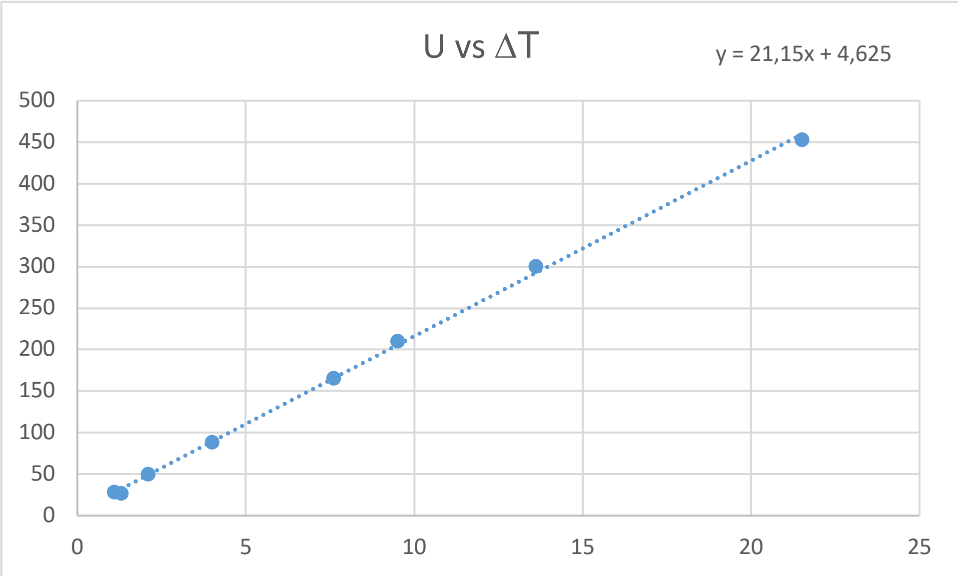
For I =1,2A

u_w = 4,93827E-08

For =2,1A

u_w = 4,05351E-06

c.)



Seeback coefficent for the second part of the experiment:

α = 21,15

With the formula given;

$$w = \left(\frac{\alpha \Delta T}{R + R_L} \right)^2 R_L$$

R values and w values are calculated and denoted in the table as “R” and w2.

Uncertainties:

The formula for uncertainty type A (standard deviation):

$$u_A(x) \equiv s_{\bar{x}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n(n-1)}}$$

Calculated using Excel formula "stdev()" for each variable.

The formula for uncertainty type B:

$$u_B(x) = \sqrt{\frac{(\Delta_p x)^2}{3} + \frac{(\Delta_e x)^2}{3} + \frac{(\Delta_t x)^2}{3} + \cdots}$$

Where we only considered the calibration uncertainty (e.g. uncertainty of used instrument) $\Delta_p x$.

Summation of A and B are done by:

$$u(x) = \sqrt{u_A^2(x) + u_B^2(x)}$$

Uncertainty of density:

$$u_c(y) = \sqrt{\sum_{j=1}^{k}\left(\frac{\partial f}{\partial x_j}\right)^2 u^2(x_j)}$$

Translates to:

$$u_c(d) = \sqrt{(\frac{dd}{dm})^2 \cdot {u_m}^2 + (\frac{dd}{dV})^2 \cdot {u_V}^2}$$

$$= \sqrt{\frac{{u_m}^2}{V^2} + (\frac{-m \cdot u_V}{V^2})^2}$$

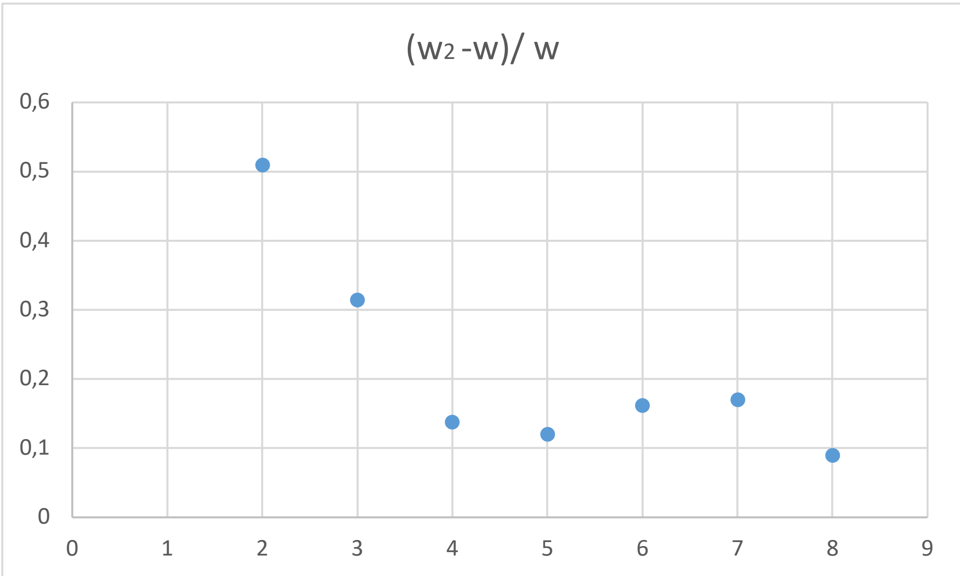
Conclusions

Discussions Theories and Uncertainties

During the measurement stage, we had timing problems. Given time for the calculations were barely enough for the whole experiment and we had to save time by making the measurements faster. It was suggested to wait for 4-5 mins for each measurement, to let the system adjust to the changed current. We only waited for 2,5 mins, which might have caused some error in the outcome.

Another factor that had effect on time was the necessity of waiting for our instrument to get in equilibrium before starting. Initially the ΔT value was different than 0 and it took around 10 minutes in total until it got low enough for us to start.

Results



The results of calculations were fitting to the expected outcome.

Two independent calculations of the value w differs less than %0,6 for every measurement. Which (probably..) indicates that the experiment was successful.