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Experiment No.8

THERMOELECTRIC EFFECTS

To investigate the thermoelectric processes of the Seeback and Peltier Effects, the temperature and voltage variations across the hot and cold ends of a thermoelectric module were measured first as the system approached thermal equilibrium for an applied voltage and then at thermal equilibrium for different applied powers. The Seeback coefficient was determined to be $S_{12} = 0.011 \pm (3.262 \times 10^{-5})$V/K for this system from the linear relation between voltage and temperature change. The observed correlations between voltage and temperature, as well as heat flow and current, matched the theoretical predictions proposed by Seeback and Peltier's equations, which indicated the influence of thermoelectric processes on the system.

THEORY

A thermoelectric process is a process which converts between temperature differences and current, or vice versa. This experiment seeks to observe two such processes: the Seeback Effect (temperature differences create a heat current) and the Peltier Effect (a current creates heat flow).

If a conductor has two ends of different temperatures, electrons will flow from the hotter, higher energy end to the colder end, lower energy end in a 'heat current'. The heat current generates a voltage proportional to the change in temperature between the ends by a constant S_1. If there are two different connected conductors joined together at the ends, then this constant is S_{12} and is known as the Seeback coefficient and is described by:

$$\Delta V = S_{12} \cdot \Delta T \tag{1}$$

The thermal resistance is the opposition to this heat current and is determined by:

$$R_{th} = \frac{T_c - T_h}{P} \tag{2}$$

where T_c and T_h are the temperatures in kelvin of the cold block and heat sink respectively, and P is the power to the resistors used to heat the cold block. P can be calculated by

$$P = IV \tag{3}$$

where I is the current from the power supply to the resistors and V is the corresponding voltage. Since power is energy transferred over time and the energy transfer through the conductor is equivalent to the heat transfer through the conductor, $P = H_{emp}$ where H_{emp} is an empirical determination of the rate of heat flow from the heat block through the module. A theoretical determination of the this value (H_{th}) can be found using:

$$H_{th} = S_{12} T_c I_m - \frac{1}{2} I_m^2 R_m + \frac{T_c - T_h}{R_{th}} \tag{4}$$

where I_m is the current through the module and R_m is its electrical resistance. When a current is applied through the two connected conductors, the system acts as a heat pump. The heat flow across the junction between the conductors is proportional to applied current by the Peltier coefficient π_{12}, which is determined by

$$\pi_{12} = S_{12}T \tag{5}$$

where T is the temperature at the junction. The efficiency of the heat pump to utilize its energy input to move heat can be expressed as a coefficient of performance, given by

$$C.O.P. = \frac{H}{I_m V_m} \tag{6}$$

Typical C.O.P. for a Peltier thermoelectric module fall within a range of 1–5.

APPARATUS

- Two digital thermometers
- Thermoelectric module containing a cold block and a heat sink
- Two digital voltmeters
- Ammeter and a milliameter
- Variac
- Tubing connected to water source

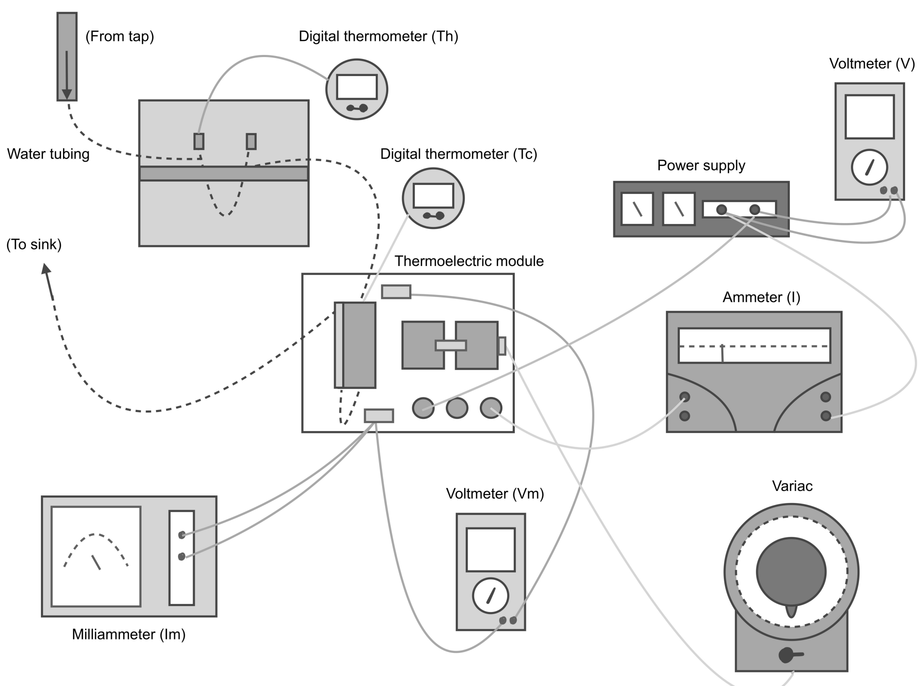


FIG. 1. Experiment set-up diagram.

PROCEDURE

The apparatus was assembled as in FIG. 1, with the current to the resistors set at around 3.0 A and the water through the tubing stabilized. To observe the Seeback Effect, the voltage and temperatures of the cold block and the heat sink were recorded for approximately every degree of change until they stopped increasing.

Next, the apparatus was set up to observe the Peltier Effect by adjusting the power supply to around 2 Watts of power through the heating resistors on the cold block. The voltage (V) and current (I) from the power supply were recorded. The variac was then adjusted so that the temperature of the cold block remained in equilibrium with that of the heat sink, and the temperature ($T_c = T_s$), the module voltage (V_m) and the module current (I_m) were recorded. This process was repeated by increasing the power from the power supply and recording measurements for each increment of 2 Watts up to 10 Watts inclusive.

DATA

For the observation of the Seeback Effect, the voltage and current from the power supply were set to $V = 6.29$V and $I = 3.0$A, respectively. The voltage through the module and the temperature of the cold block increased very quickly initially before progressively slowing down as thermal equilibrium was obtained, while the heat sink temperature increased very slowly and by negligible amount. Periodic measurements were recorded in TABLE II (see Appendix) and the

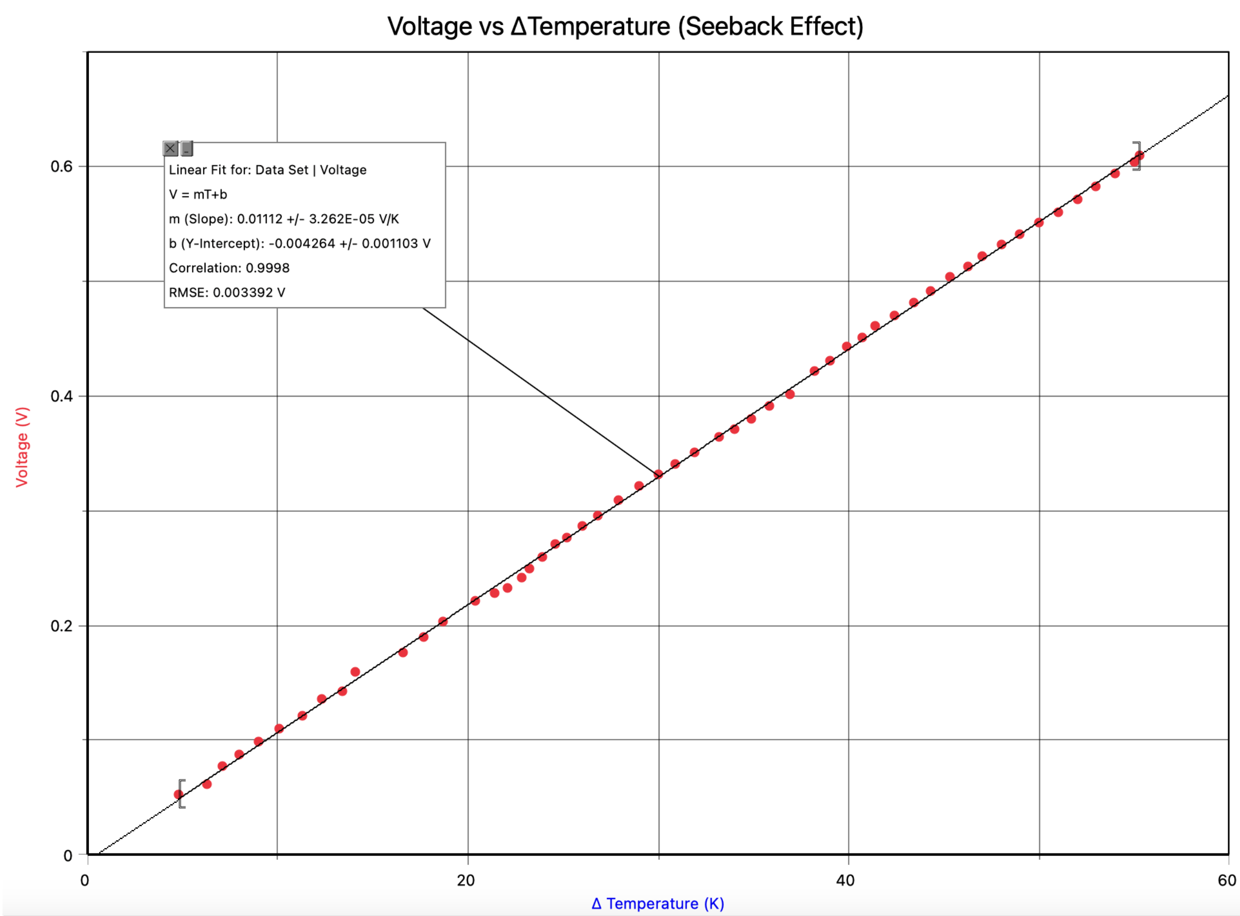


FIG. 2. Plot of the voltage through the module as a function of the difference in temperature between the cold block and heat sink ($\Delta T = T_c - T_h$).

Seeback coefficient was determined to be $S_{12} = 0.011 \pm (3.262 \times 10^{-5})$V/K. A linear trend between the voltage and the change in temperature was observed (see FIG.2). The thermal resistance was calculated (see Calculation 1.) to be $R_{th} = (2.93 \pm 0.05)\Omega$

I [A]	V [V]	V_m [V]	I_m [A]	$T_c = T_s$ [$°C$]	π_{12} [V]
1.00	2.020	-0.285	0.85	9.7	3.143
1.52	2.807	-0.577	1.265	9.8	3.145
1.70	3.557	-0.821	2.32	9.9	3.146
1.95	4.19	-1.125	3.30	10.2	3.150
2.20	4.59	-1.388	4.21	10.3	3.151

TABLE I. Measured currents (± 0.05), voltages (± 0.05), and temperatures (± 0.1) from the power supply (no suffix) and through the thermoelectric module ($_m$) at thermal equilibrium for the observation of the Peltier Effect, and the calculated Peltier coefficient (± 0.01).

The electrical resistance of the module was listed as $R_m = 0.23\Omega$. For the observation of the Peltier Effect, the data in TABLE I was recorded and used to determine H (see Calculation 2.), the $C.O.P.$ (see Calculation 3.), and the Peltier coefficients (see Calculation 4.). Different non-linear trends were observed between H and the module current in FIG.3, and the $C.O.P.$ and the module current in FIG.4.

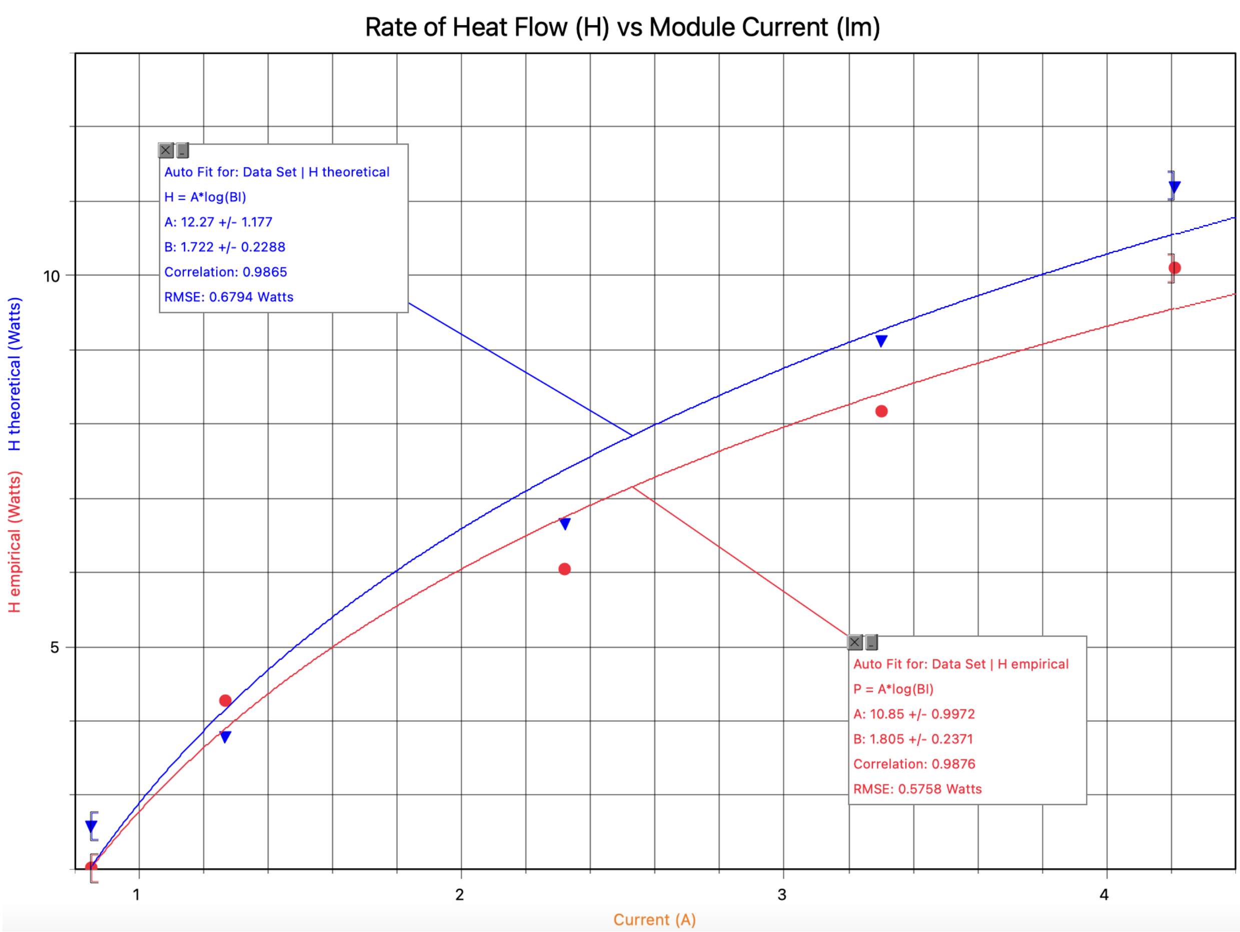


FIG. 3. Plot of the rates of heat flow from the cold block to the thermoelectric module obtained empirically (H_{emp}) and theoretically (H_{th}) as a function of the current through the module (I_m).

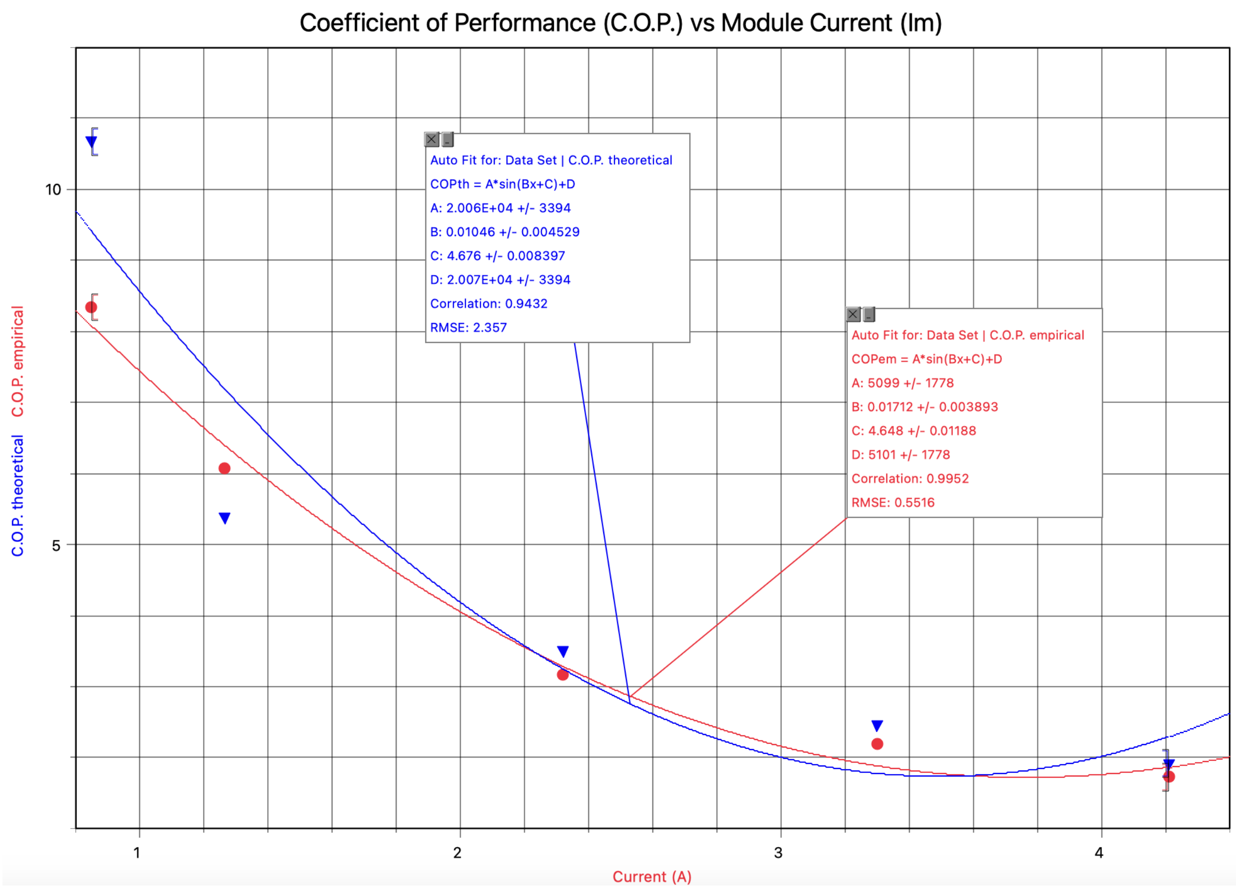


FIG. 4. Plot of the C.O.P. determined using H_{emp} and H_{th} as a function of the current through the module (I_m).

CALCULATIONS

Calculation 1: Thermal Resistance

$$T_c = (64.8 \pm 0.1)°C + 273.15 = (337.95 \pm 0.1)\text{K}$$
$$P = VI = (6.29 \pm 0.05V) \cdot (3.0 \pm 0.05A) = (18.87 \pm 0.02)\text{Watts}$$
$$R_{th} = \frac{T_c - T_h}{P} = \frac{(337.95 \pm 0.1)K - (282.65 \pm 0.1)K}{(18.87 \pm 0.02)Watts} = (2.93 \pm 0.05)\Omega$$

Calculation 2: H_{emp} and H_{th} for $T_c = T_h$

$$T_c = (9.7 \pm 0.05)°C + 273.15 = (282.85 \pm 0.05)K$$
$$H_{emp} = VI = (2.02 \pm 0.05V) \cdot (1.0 \pm 0.05A) = (2.02 \pm 0.11)\text{Watts}$$
$$H_{th} = S_{12}T_cI_m - \frac{1}{2}I_m^2R_m$$
$$= (0.011 \pm (3.26 \times 10^{-5})\frac{V}{K}) \cdot (282.85 \pm 0.05)K \cdot (0.85 \pm 0.05)A - \frac{1}{2}((0.5 \pm 0.05)A)^2 \cdot (0.23\Omega)$$
$$= (2.67 \pm 0.13)A^2\Omega - (0.08 \pm (6.91 \times 10^{-3}))A^2\Omega = (2.59 \pm 0.13)\text{Watts}$$

Calculation 3: $C.O.P.$ for H_{emp} and H_{th}

$$C.O.P. = \frac{H}{|I_m V_m|} = \frac{(2.59 \pm 0.13)Watts}{|(0.85 \pm 0.05)A \cdot (-0.285 \pm 0.05)V|} = \frac{(2.59 \pm 0.13)A^2\Omega}{(0.24 \pm 0.04)A^2\Omega} = 10.69 \pm 2.05$$

*Note that the absolute value is taken since the negative voltage is directional and thus should not affect the coefficient.

Calculation 4: Peltier Coefficient

$$\pi_{12} = S_{12}T = (0.011 \pm (3.26 \times 10^{-5})\frac{V}{K}) \cdot (282.85 \pm 0.05)K = (3.14 \pm 0.01)\text{V}$$

DISCUSSION

The Seeback coefficient was determined to be $S_{12} = 0.011 \pm (3.262 \times 10^{-5})$V/K with very little uncertainty, and FIG.2 shows definitively linear behaviour. This is consistent with the relationship described by (1) and supports its accuracy.

It is important to ensure that the module is in thermal equilibrium each time before data is taken for the Peltier effect measurements. This is because, in thermal equilibrium, there is no more heat transfer between junctions and thus the readings for temperature, voltage, etc. are no longer fluctuating and can be read to an exact value. In addition, if thermal equilibrium was not obtained, then the system would not be stable, so conditions would not be the same for each measurement,m and thus no conclusion could be drawn from their data. In FIG. 3, the empirical and theoretical data follow similar curves, although the empirical curve is notable lower and with a lesser slope. This is likely as a result of the associated equation for H_{emp}, which does not take into account effects such as Peltier or Seeback that may increase the efficiency of the heat transfer, and thus has a lower curve than H_{th}, which does. Slow changes in temperature were observed when the variac was changed, making it difficult to determine if the system was in exact equilibrium and thus introducing a potential source of error. The effects of water temperature or external heat sources such as body heat, heat from electrical devices, or changes in room temperature were likely negligible, but are other potential sources of error. Both H_{emp} and H_{th} increase proportionally to the current, which supports the existence of the Peltier coefficient π_{12} according to (5).

As observed in 4, the $C.O.P.$ decreased with increases in current. C.O.P. values for Peltier modules typically range from 1–5, which was the case for higher amounts of current, but exceptionally high values of efficiency were observed for very low amounts of current. This is likely the result of the internal heat generation of the module which increases with current and causes the efficiency to be lower, since it counteracts the cooling effects of the heat pump.

CONCLUSIONS

A linear relation between voltage and change in temperature between the ends of a conductor was observed with a slope $S_{12} = 0.011 \pm (3.262 \times 10^{-5})$V/K corresponding to the Seeback coefficient for this system. Two determinations of the rate of heat flow were found to increase proportionally to the current. These observations indicate that thermoelectric effects were likely occurring in the system during measurement and in support of the discoveries by Seeback and Peltier.

QUESTIONS

1. The first term on the right side of the equation represents the heat flow due to the current through the conductors as a result of the Peltier effect. The third term represents the heat flow due to the difference in temperature. These two terms represent the flow of heat from the hotter side to the colder side of the conductors. The second term is the heat generated inside the module due to its electrical resistance, and it is negative because it moves heat in the opposite direction in order to cool the system.

2. Electrical resistance is defined as:

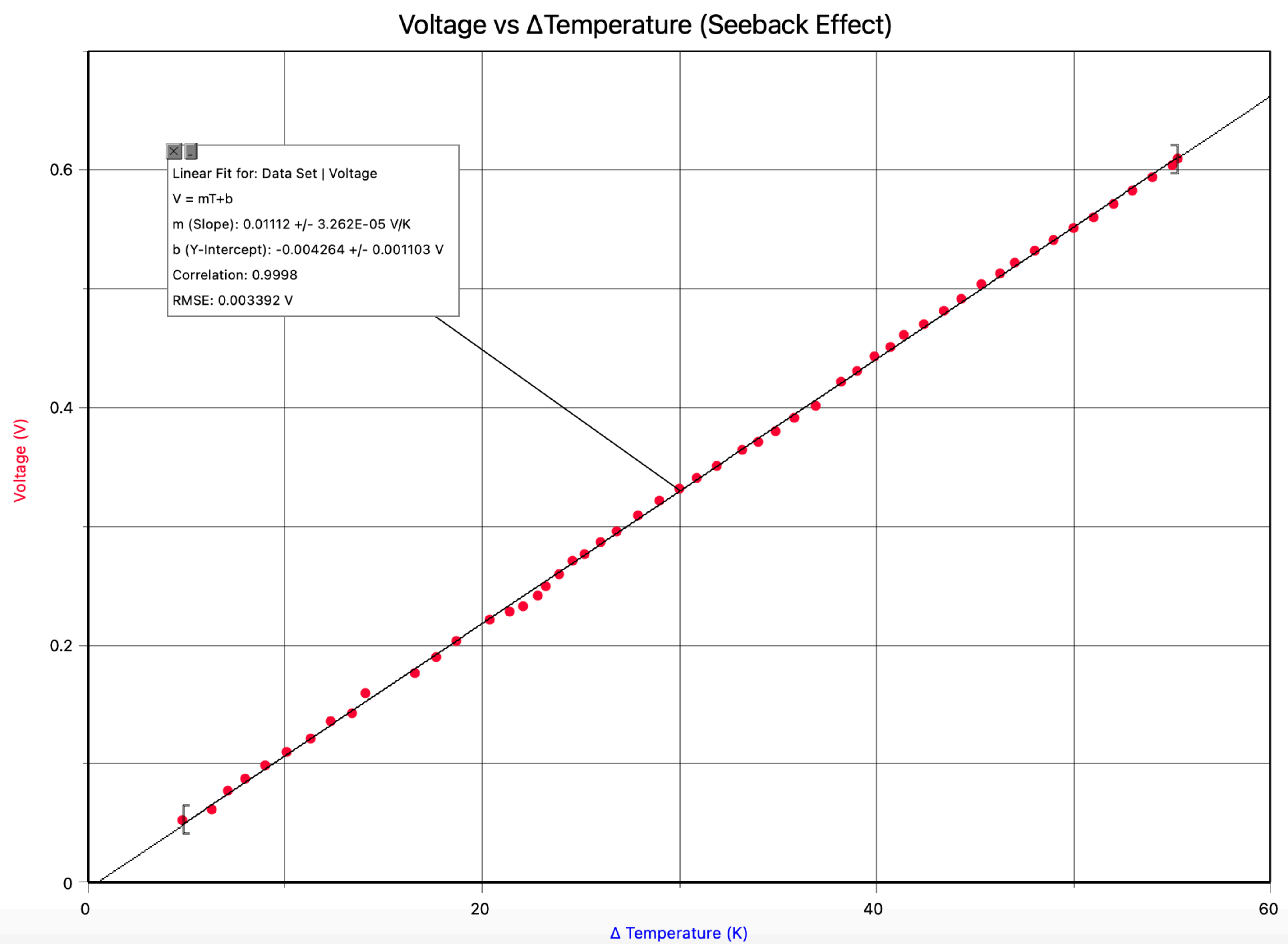
$$R_{ele} = \frac{\Delta V}{I} \tag{7}$$

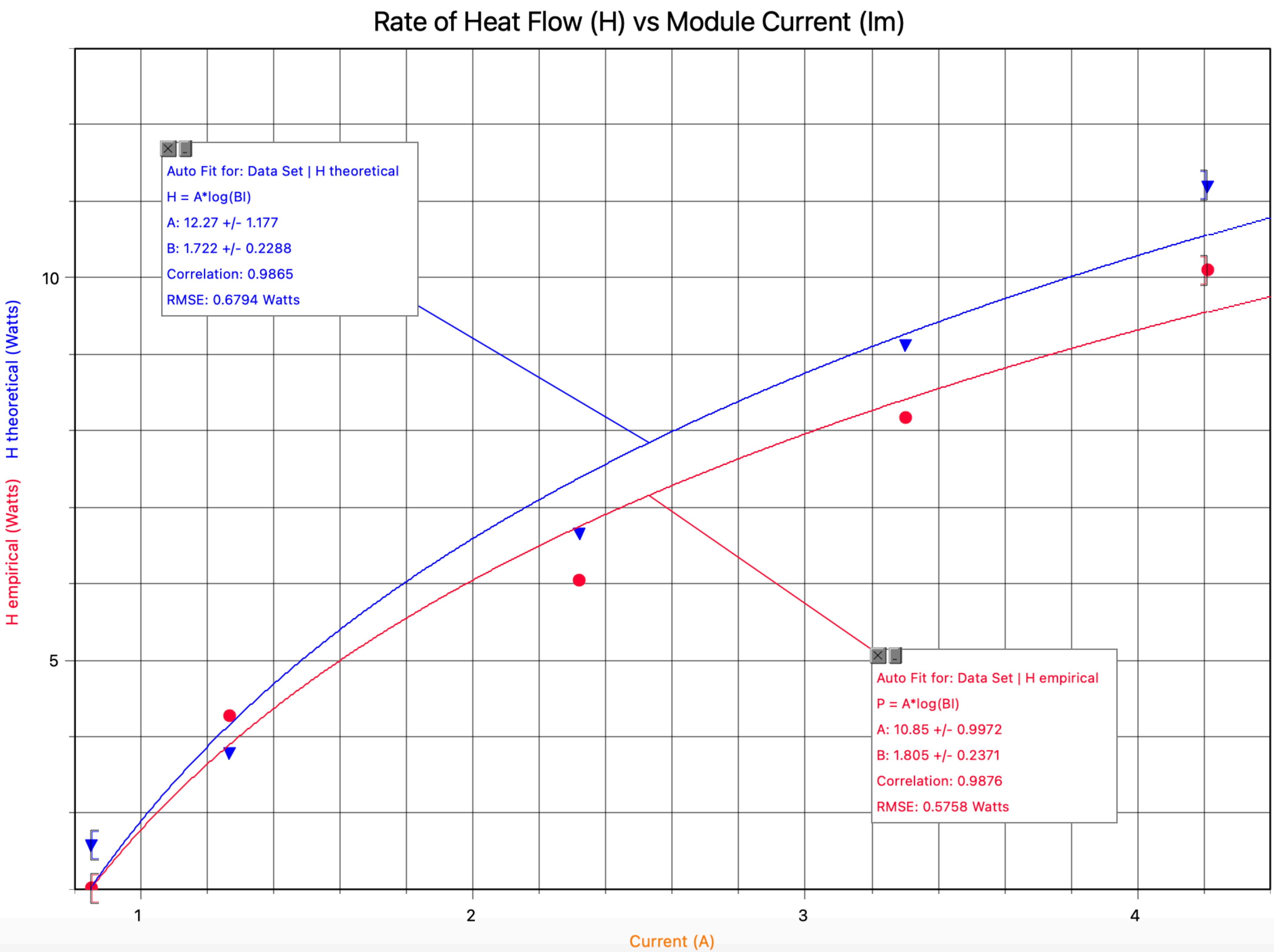
and represents the impedance in the flow of current, while thermal resistance is the impedance in the flow of heat. For electrical resistance, the change in voltage between two points in a circuit is measured, which is similar to to how the change in temperature between two ends of a conductor is measured for thermal resistance. In both, the resistance is inversely proportional to the rate at which energy is transferred through a material.

APPENDIX

V [V]	T_c [°C]	T_h [°C]	V [V]	T_c [°C]	T_h [°C]
0.053	13.8	9.0	0.351	41.1	9.2
0.062	15.3	9.0	0.364	42.4	9.2
0.077	16.1	9.0	0.371	43.2	9.2
0.087	17.0	9.0	0.380	44.1	9.2
0.099	18.0	9.0	0.391	45.1	9.3
0.110	19.1	9.0	0.401	46.2	9.3
0.121	20.3	9.0	0.421	47.5	9.3
0.136	21.3	9.0	0.431	48.3	9.3
0.143	22.4	9.1	0.443	49.2	9.3
0.159	23.1	9.1	0.451	50.0	9.3
0.176	25.7	9.1	0.461	50.7	9.4
0.190	26.8	9.1	0.470	51.7	9.4
0.203	27.8	9.1	0.481	52.7	9.4
0.221	29.5	9.1	0.491	53.7	9.5
0.228	30.5	9.1	0.503	54.7	9.4
0.232	31.2	9.1	0.513	55.7	9.4
0.242	31.9	9.1	0.522	56.5	9.5
0.249	32.4	9.1	0.532	57.5	9.5
0.260	33.1	9.1	0.541	58.5	9.5
0.271	33.8	9.1	0.551	59.5	9.5
0.276	34.4	9.1	0.560	60.5	9.5
0.287	35.2	9.2	0.571	61.5	9.5
0.295	36.0	9.2	0.582	62.5	9.5
0.309	37.1	9.2	0.594	63.5	9.5
0.321	38.2	9.2	0.604	64.5	9.5
0.331	39.2	9.2	0.609	64.8	9.4

TABLE II. Measured voltages (±0.05), and temperatures (±0.1) through the thermoelectric module up to equilibrium for a current of $3.2A$ through the resistors, for the determination of the Seeback Effect.


Voltage vs ΔTemperature (Seeback Effect)
Linear Fit for: Data Set | Voltage
V = mT+b
m (Slope): 0.01112 +/- 3.262E-05 V/K
b (Y-Intercept): -0.004264 +/- 0.001103 V
Correlation: 0.9998
RMSE: 0.003392 V
Voltage (V)
0
0.2
0.4
0.6
Δ Temperature (K)
0
20
40
60



Rate of Heat Flow (H) vs Module Current (Im)
Auto Fit for: Data Set | H theoretical
H = A*log(BI)
A: 12.27 +/- 1.177
B: 1.722 +/- 0.2288
Correlation: 0.9865
RMSE: 0.6794 Watts
Auto Fit for: Data Set | H empirical
P = A*log(BI)
A: 10.85 +/- 0.9972
B: 1.805 +/- 0.2371
Correlation: 0.9876
RMSE: 0.5758 Watts
10
5
1
2
3
4
H empirical (Watts)
H theoretical (Watts)
Current (A)

Coefficient of Performance (C.O.P.) vs Module Current (Im)