

Lab Notes: Thermo-couple Experiment

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Chapter 1

First part

1.1 theoretical background

The thermoelectric phenomenon was discovered by Thomas Johann Seebeck in the early 1820s. Seebeck observed that when two different metals are joined together at two junctions, forming a closed loop, and these junctions are maintained at different temperatures, an electric current flows through the circuit. Initially, Seebeck mistakenly attributed this effect to magnetic polarization of the metals, but later it was correctly understood as an electromotive force (voltage) generated due to the temperature difference.

This voltage arises due to thermoelectric properties which depend on the interactions between heat flow and the behavior of electric charge carriers in metals. The phenomenon is broadly categorized under thermoelectric effects, with the Seebeck effect being one of the three primary effects:

1. **Seebeck Effect:** Generation of a voltage when there is a temperature difference across the junctions of two different metals.
2. **Peltier Effect:** Heat absorption or release at the junction of two different metals when an electric current flows through the junction.
3. **Thomson Effect:** Heat absorption or release when current flows through a conductor subjected to a temperature gradient.

A typical thermocouple consists of two dissimilar metals joined at both ends. When the junctions are at different temperatures (T_1 and T_2), a voltage (V) is generated, which can be measured. Importantly, a thermocouple measures the temperature difference, not absolute temperature. In order to measure the absolute temperature one junction, called the reference junction, is maintained at a known temperature, and the other junction measures the unknown temperature.

The voltage generated in the thermocouple is a function of the types of metal (specifically their band gap), call them A and B, and the reference temperature and the unknown temperature. Although the first three are known so the voltage is actually a function of the unknown temperature.

As with every other function, the relation between the voltage and the temperature difference $V(\Delta T)$ can be approximated by a Taylor polynomial expansion:

$$V(\Delta T) = C_0 + C_1\Delta T + C_2(\Delta T)^2 + \dots \quad (1.1)$$

the assumption made is that the relation will be close enough to a linear function::

$$V = k \cdot \Delta T \quad (1.2)$$

Here, k is the Seebeck coefficient specific to the pair of metals used, and ΔT is the temperature difference between the two junctions.

The thermoelectric voltage is a bulk property of the metals themselves and does not specifically originate at the junction interface. Thus, each metal inherently contributes to the total generated voltage when subjected to a temperature gradient.

Thermocouples are widely used for temperature measurement due to their simplicity, quick response, robustness, and suitability for a wide temperature range.

In practical applications, thermocouples require calibration. This involves accurately measuring the voltage output at known reference temperatures to create a calibration curve. With this curve, the unknown temperature can be determined from the measured voltage.

In this laboratory, we will investigate the thermocouple's behavior by measuring voltage responses across various temperature differences. The thermocouple results will be compared against an alternative temperature measurement method using a thermistor, whose resistance varies predictably with temperature according to the relation:

$$R = R_0 e^{\alpha\left(\frac{1}{T} - \frac{1}{T_0}\right)} \quad (1.3)$$

Here, R is the resistance at temperature T , R_0 is the resistance at reference temperature T_0 , and α is a material-dependent constant.

1.2 Methodology

1.2.1 Materials

- Dewar vessel filled with liquid nitrogen and enclosed with a light cover.
- Dewar vessel filled with ice water (about 0°C) and enclosed with a light cover.
- Cup of ice flakes.
- Rod used for mixing.
- Flask filled with ethanol connected to a mixing rod and a handle.
- Electric kettle.
- Stand.
- Cup for hot water and system for dipping sensors.
- Thermocouple of type K. (see [1](#))

- Digital voltmeter with a measurement range of 200[mV].
- Temperature sensor PT-100 (-200°C to $+400^{\circ}\text{C}$) with a resolution of 0.188°C .
- Multi-Log logger.
- Thermal insulation gloves.

1.2.2 Experimental Procedure

General Directions

1. Be sure to wipe any probe that you move into a different liquid.
2. Mix the liquid after heating/cooling it.
3. Be careful of liquid nitrogen and boiling water; use gloves when needed.
4. Always keep the reference probe of the type K thermocouple inside the icy water container.

Preparation for Measurements

First, open the Multilab software and turn on the multilog device. Configure the temperature sensor in Multilab to measure temperature every second continuously. Next, activate the voltmeter connected to the thermocouple.

Part A

Initially, measure room temperature and ice water temperature with the temperature sensor. Then measure the thermoelectric voltage when both probes are placed in ice water.

Boil water using the electric kettle, transfer it into the measurement cup, and immerse both thermocouple and temperature sensor probes. After stabilization, record temperature and voltage. Gradually add ice flakes, stirring to melt, taking additional measurements until the water temperature reaches approximately 10°C . Obtain at least 20 measurements.

Part B

Begin by measuring the temperature of liquid nitrogen. Place both probes into the ethanol flask, and after stabilization, record initial voltage and temperature. Then, briefly immerse the flask in liquid nitrogen, mixing thoroughly after each immersion, and record stabilized measurements until the ethanol reaches approximately -100°C . Collect at least 12 measurements.

1.3 Data Processing Plan

1.3.1 Part A

Calculate voltage uncertainty as:

$$\Delta V = 3 \times 10^{-4} \cdot |V| + 2 \times 10^{-2} \quad (1.4)$$

Given the sensor resolution (0.188°C), the temperature uncertainty is:

$$\Delta T = 0.054^\circ\text{C}$$

Fit voltage linearly as:

$$y = a_0 + a_1x$$

Expecting $a_0 \approx 0$ V, identify $k_{\text{exp}} = a_1$.

Determine voltages at room temperature and nitrogen temperature by interpolation and extrapolation, respectively. Uncertainty is calculated by:

$$\Delta(\Delta T) = \sqrt{(\Delta T \cdot \Delta a_1)^2 + (\Delta a_0)^2}$$

Conduct N_σ tests for comparisons:

$$N_\sigma\{k_{\text{theo}}, k_{\text{exp}}\}, \quad N_\sigma\{V_{\text{room temp, measured}}, V_{\text{room temp, exp,1}}\}, \quad N_\sigma\{V_{\text{nitro, measured}}, V_{\text{nitro, exp,1}}\}$$

1.3.2 Part B

Fit voltage to a third-order polynomial:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3$$

Again, expect $a_0 \approx 0$ V.

Calculate voltages at room and nitrogen temperatures by polynomial fit interpolation/extrapolation. Uncertainty calculation is:

$$\Delta(\Delta T) = \sqrt{(\Delta T^3 \cdot \Delta a_3)^2 + (\Delta T^2 \cdot \Delta a_2)^2 + (\Delta T \cdot \Delta a_1)^2 + (\Delta a_0)^2}$$

Perform N_σ tests:

$$N_\sigma\{V_{\text{room temp, measured}}, V_{\text{room temp, exp,2}}\}, \quad N_\sigma\{V_{\text{nitro, measured}}, V_{\text{nitro, exp,2}}\}$$

1.4 Data analysis

Part A: After the aquired data is fitted to the expectd linear fit the results are as follows:

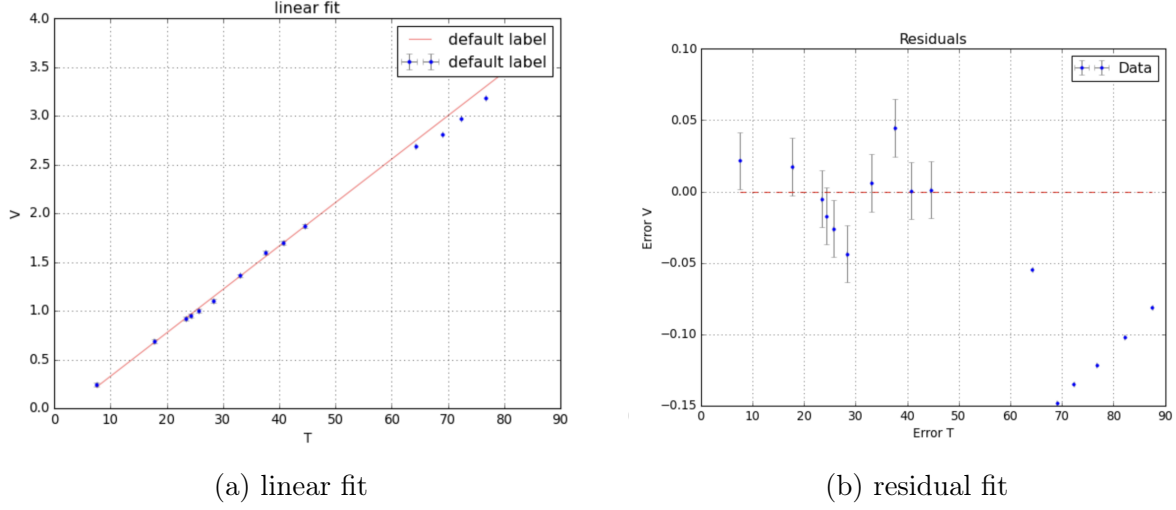


Figure 1.1: Part A results

$\chi^2_{reduced}$	P-probabilty	a_1	a_0
1.1	0.33	$4.32 \cdot 10^{-2} \pm 2.79 \cdot 10^{-4}(0.6\%)$	$-0.09 \pm 0.01(13.3\%)$

Table 1.1: Part A results

Note that the results were fitted after removing the points arround $\Delta T = 50$ because they showed a dramatic non linear behavior and a parabolic shape in the residual graph, that hints that it was most likely due to user error. Taking that into considaraton we see that the ersults agree well with the theoretical model.

Now extracting the values of V_{room} and $V_{nitrogen}$ using interpolation and extrapolation respectively, we get:

V_{room}	$V_{nitrogen}$
$0.864 \pm 1.727 \cdot 10^{-7}(2 \cdot 10^{-5}\%)$	$-8.550 \pm 1.529 \cdot 10^{-6}(1.8 \cdot 10^{-5}\%)$

Table 1.2: Tempreture results

And performing the N_σ test on both voltages we get:

$N_{\sigma_{room}}$	$N_{\sigma_{nitrogen}}$
0.079	150.079

Table 1.3: N-sigma test results

The test concluded that the calculated value of V_{room} is relatively close to the theoretical value. That makes sense looking at the measurements. On the other hand, the test concluded that the calculated value of $V_{nitrogen}$ is far from the theoretical value. After taking a closer look it is possible to assume that the relatively small error calculated for the experimental value is what caused the bad result.

Part B After fitting the data to the third order polynomial we get the following results:

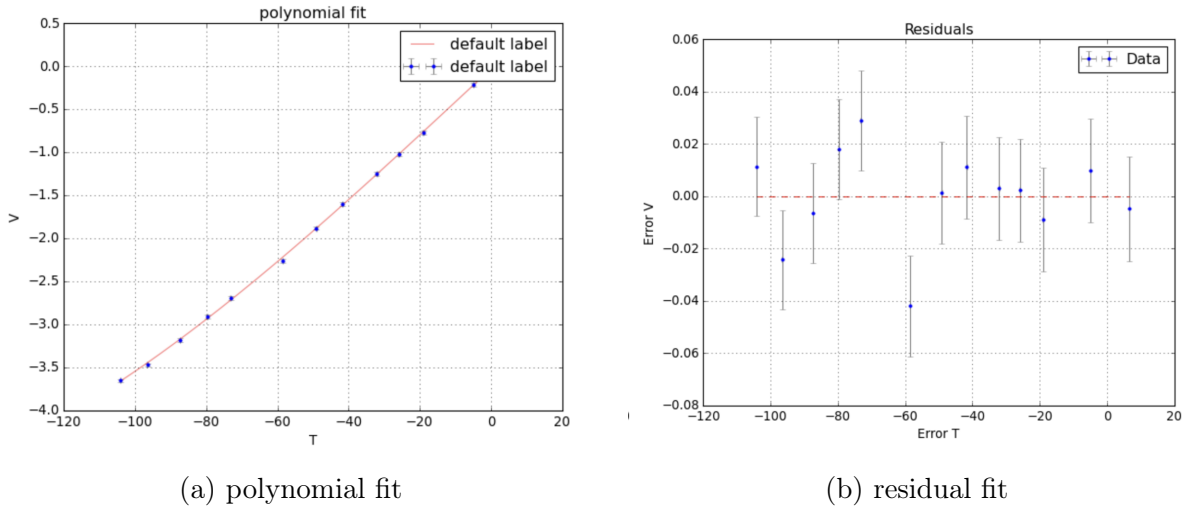


Figure 1.2: Part B results

$\chi^2_{reduced}$	P-probability	a_0	a_1	a_2	a_3
1.197	0.2918	$(-0.02884) \pm (0.01377)(47\%)$	$(3.8503 \times 10^{-2}) \pm (1.106 \times 10^{-3})(2.8\%)$	$(-1.969 \times 10^{-6}) \pm (2.7777 \times 10^{-5})(140\%)$	$(-3.552 \times 10^{-7}) \pm (1.861 \times 10^{-7})(52\%)$

Table 1.4: Part B results

We can see that the $\chi^2_{reduced}$ is close to 1, and the P-probability is greater than 0.05, that means that the fit is good and we can use it as an accurate way to measure the voltage for different temperatures. Furthermore, a_0 is close to 0 taking into consideration its 47.7% error.

Now we can intrapolate and extrapolate different values of the voltage for different temperatures. :

V_{room}	$V_{nitrogen}$
$0.8162 \pm 0.0312(3.8\%)$	$-4.976 \pm 1.7687(35.5\%)$

Table 1.5: Temperature results

And performing the N_σ test on both voltages we get:

$N_{\sigma_{room}}$	$N_{\sigma_{nitrogen}}$
1.716	0.4715

Table 1.6: N-sigma test results

Again we get very good results, well within or error range for the value of V_{room} . furthermore, the value of $V_{nitrogen}$ is also within the error range of the theoretical value, according to the N_σ test.

It is apperent that the polynimial fit described the data better than the linear fit, and that is expected.

1.5 discussion

1.5.1 Part A

In Part A, a linear regression over moderate temperature differences yielded a Seebeck coefficient of $a_1 = (4.322 \pm 0.028) \times 10^{-2} \text{ mV K}^{-1}$ with reduced chi-squared $\chi_{reduced}^2 = 1.148$ and $P = 0.327$, indicating a statistically satisfactory fit in the restricted range. The interpolated room-temperature voltage, $V_{\text{room}} = 0.864 \pm 1.7 \times 10^{-7} \text{ V}$, agrees within 0.08σ of the theoretical expectation, confirming linearity near ambient conditions. However, the extrapolated liquid-nitrogen value deviates by 150σ , demonstrating that the linear model breaks down at large ΔT due to the temperature dependence of the Seebeck coefficient and nonideal measurement effects.

1.5.2 Part B

In Part B, a third-order polynomial fit captures the full temperature span with $\chi_{reduced}^2 = 1.197$ and $P = 0.292$, showing that higher-order terms are necessary to model the observed nonlinearity. The extracted voltages, $V_{\text{room}} = 0.816 \pm 0.031 \text{ V}$ and $V_{\text{nitrogen}} = -4.976 \pm 1.769 \text{ V}$, both fall within 3σ of their theoretical values, validating the polynomial calibration. This improved model provides an accurate calibration curve, highlighting the limitations of simple linear approximations across wide temperature ranges.

.1 Appendix: Figures

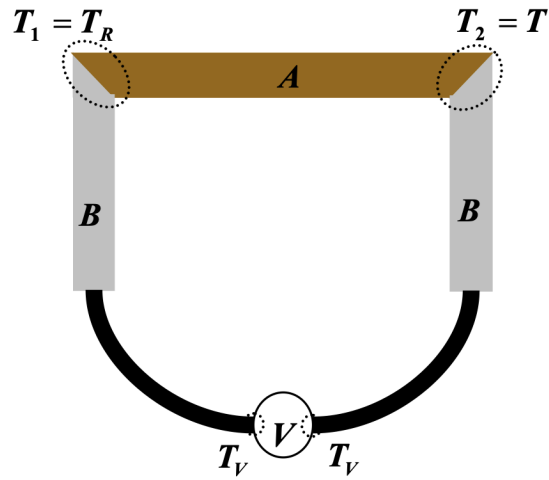


Figure 1: Thermocouple

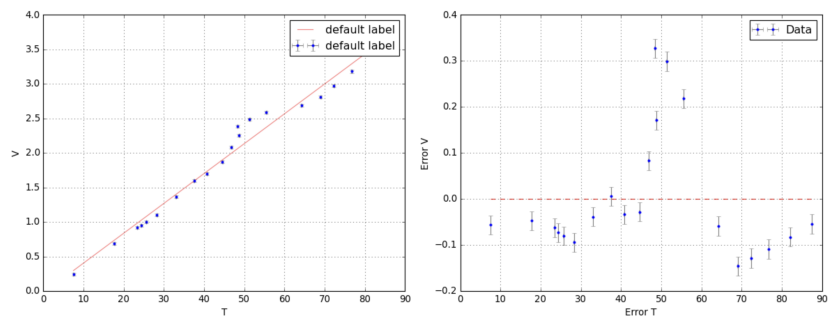


Figure 2: linear fit and residual of the unmodified set, part A

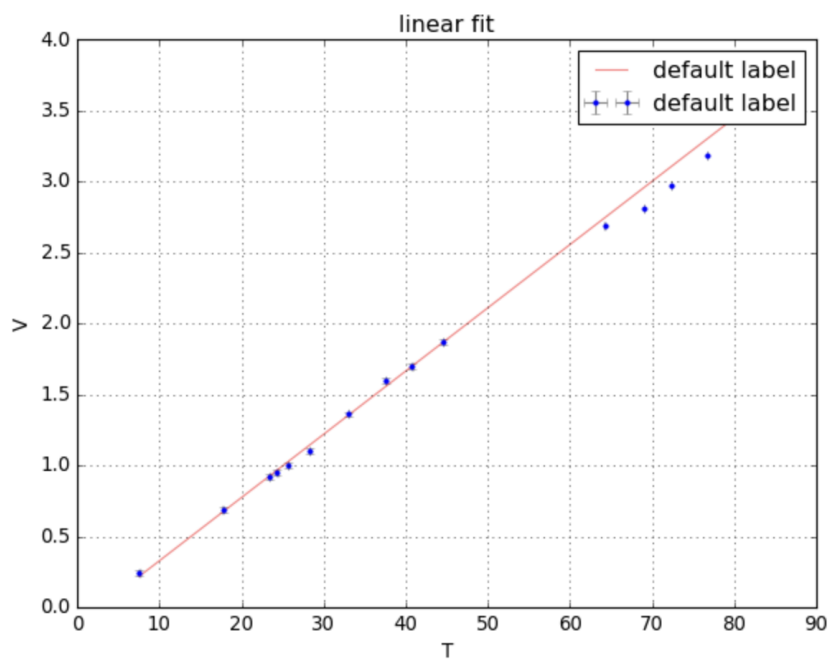


Figure 3: Linear fit for Part A

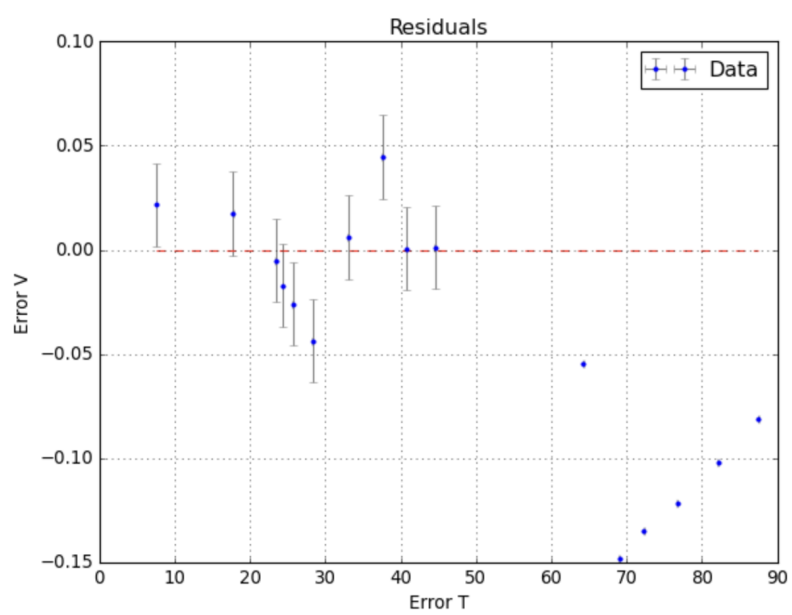


Figure 4: Residual fit for Part A

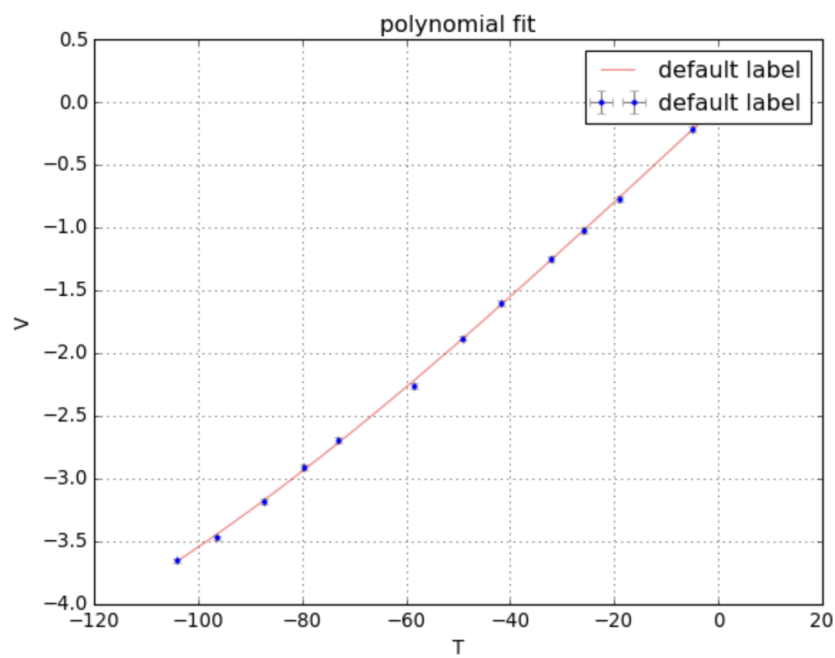


Figure 5: Polynomial fit for Part B

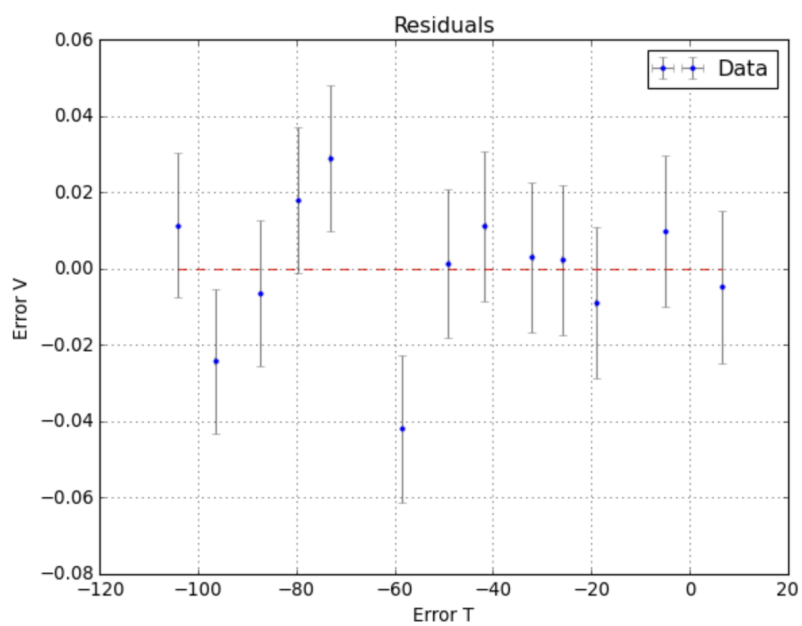


Figure 6: Residual fit for Part B

.2 Appendix: tables

$T[C]$	$V[mV]$	ΔV
82.108	3.44	0.021032
76.708	3.18	0.020954
72.3	2.97	0.020891
69.008	2.81	0.020843
64.217	2.69	0.020807
55.51	2.59	0.020777
51.33	2.49	0.020747
48.36	2.39	0.020717
48.74	2.25	0.020675
46.84	2.08	0.020624
44.56	1.87	0.020561
40.76	1.7	0.02051
37.533	1.6	0.02048
33.013	1.36	0.020408
28.287	1.1	0.02033
25.65	1	0.0203
24.332	0.95	0.020285
23.39	0.92	0.020276
17.72	0.69	0.020207
7.533	0.24	0.020072

Table 1: first set of measurments

T	V
6.592	0.22
-4.96	-0.21
-19.067	-0.77
-25.93	-1.02
-32.045	-1.25
-41.675	-1.6
-49.079	-1.88
-58.533	-2.26
-73.217	-2.69
-79.633	-2.91
-87.457	-3.18
-96.58	-3.47
-104.24	-3.65

Table 2: Second set of measurments