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Circuits with Non-Linear Resistance

Introduction:

This experiment explores Ohm's law and blackbody radiation. The importance of this lab is to see how resistance and radioactive power are both dependent on temperature for black bodies, and to examine the voltage-current curve for a lightbulb. We also apply curve fitting tools in Python to non-linear curves, and examine our fit quality in relation to theoretical values.

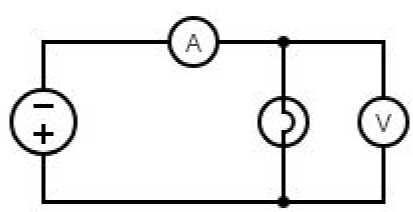
Method:

Materials:

1. Variable DC power supply
2. 2 Tegam 130A multimeters
3. A small lightbulb
4. Wires

Experiment:

First, set up the circuit as shown below, with a DC power supply, two multimeters and a lightbulb.



Next, turn on the DC power supply and measure the voltage and the current that is going through the bulb. Change the voltage on the DC power supply and take the measurements again. Repeat the previous steps 20 (or more) times.

Results:

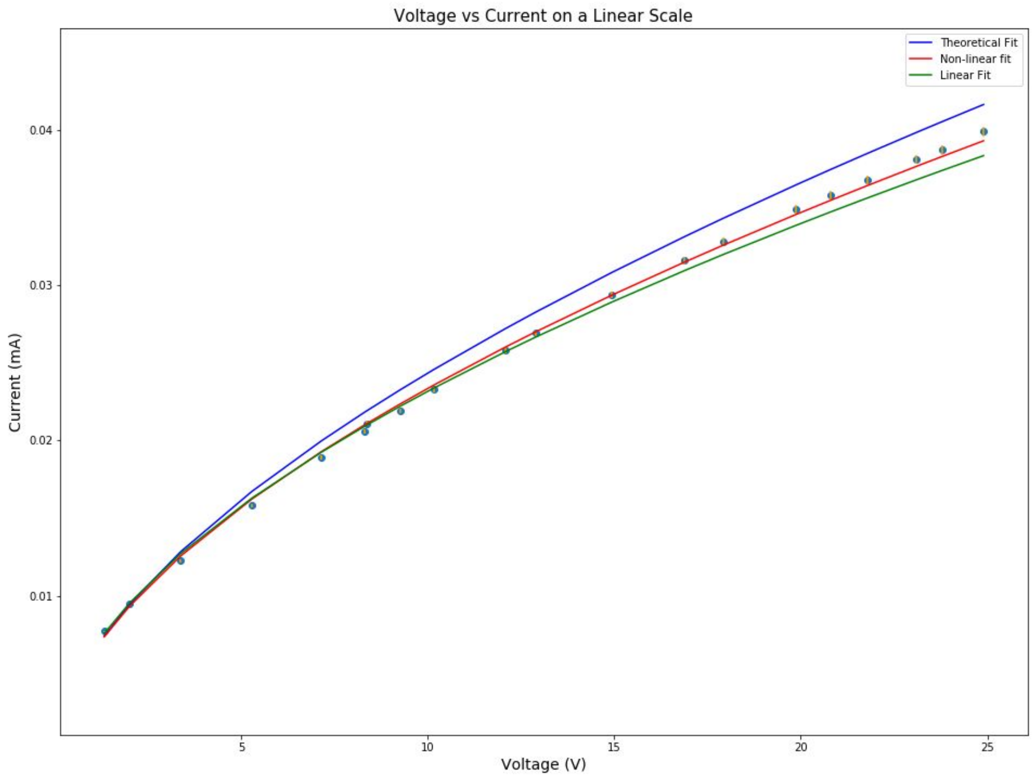
Table One

Voltage (V)	Voltmeter Setting (V)	Current (mA)	Ammeter Setting (mA)
1.319 ± 0.003	2	7.71 ± 0.06	20
2.01 ± 0.01	20	9.51 ± 0.07	20
3.37 ± 0.01	20	12.26 ± 0.09	20
5.28 ± 0.01	20	15.82 ± 0.12	20
7.14 ± 0.02	20	18.88 ± 0.14	20
8.30 ± 0.02	20	20.6 ± 0.2	200
8.35 ± 0.02	20	21.1 ± 0.2	200
9.25 ± 0.02	20	21.9 ± 0.2	200
10.17 ± 0.03	20	23.3 ± 0.2	200
12.08 ± 0.03	20	25.8 ± 0.2	200
12.89 ± 0.03	20	26.9 ± 0.2	200
14.94 ± 0.04	20	29.4 ± 0.2	200
16.87 ± 0.04	20	31.6 ± 0.2	200
17.92 ± 0.04	20	32.8 ± 0.2	200
19.88 ± 0.05	20	34.9 ± 0.3	200
20.8 ± 0.1	200	35.8 ± 0.3	200
21.8 ± 0.1	200	36.8 ± 0.3	200
23.1 ± 0.1	200	38.1 ± 0.3	200
23.8 ± 0.1	200	38.7 ± 0.3	200
24.9 ± 0.1	200	39.9 ± 0.3	200

Analysis:

The equation used to calculate the theoretical curve we use the proportional equation $I \propto V^{0.5882}$ (Eq. 6 from the lab manual), where I is the current and V is the voltage. We once again calculated the reduced chi squared, using the equation $\chi^2_{red} = \frac{1}{N-m}\sum_{i=1}^{N}(\frac{y_i - y(x_i)}{\sigma_i})^2$ (Eq. 4 from PyLab1 manual). The model function used to calculate the linear fit was $y = ax + b$ and to calculate the non-linear fit was $y = ax^b$ (Eq. 7 from lab manual). For the standard deviation we took the square root of the variance (given in the diagonal entries of pcov).

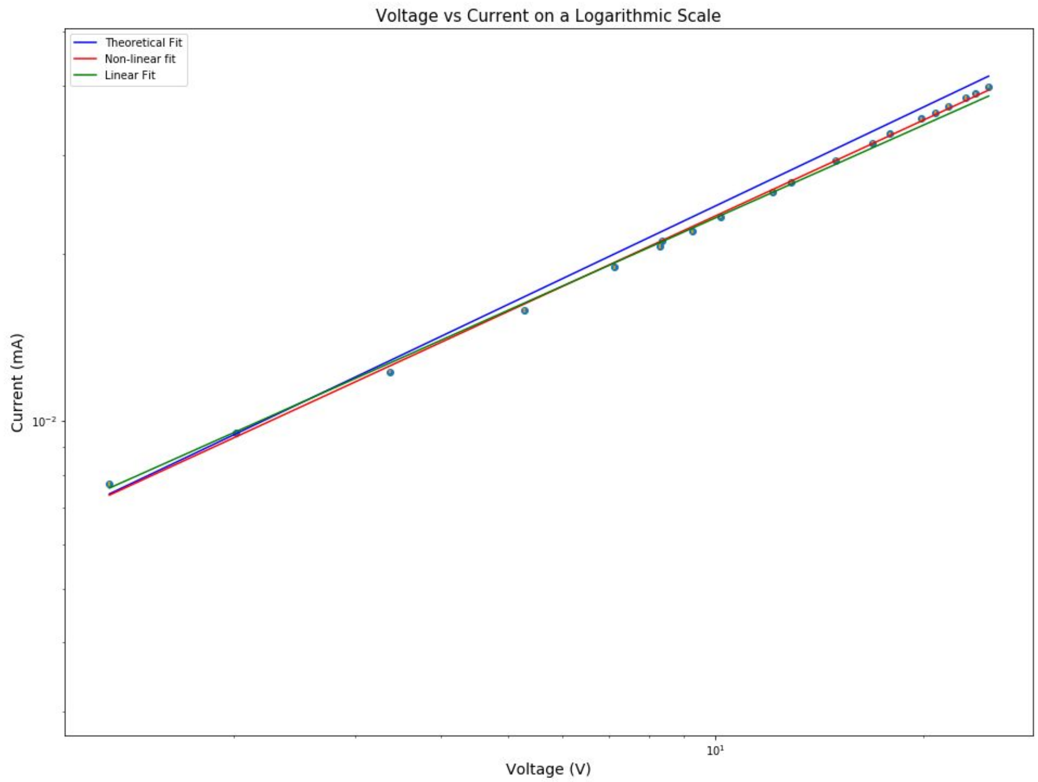
Image One



The figure above shows the measured data points, with corresponding uncertainties. The lines correspond to theoretical curve (with the constant of proportionality taken from the parameter of the fitted non-linear model) as well as the fitted curves of the linear and non-linear models. This figure shows how the different fits compare to each other and to the measured data.

Unlike for a resistor, we can see that the resistance of the light bulb is not constant. As the voltage passing through the light bulb increases, the light bulb emits more energy as heat. This heat increases the temperature of the light bulb, and according to Eq. 4 from the lab manual, the resistance and temperature follow a power law of $R(T) \propto T^{1.209}$. Thus, an increase in temperature leads to an increase in resistance.

Image Two



The figure above has the same physical representation Image One. However, the plot has logarithmic scales on both the x and y axes. This allows the power law between voltage and current to be represented linearly.

The reduced chi square for the linear fit is 11.35. The equation that was calculated from the data for the linear fit is $I =- 5.0 * V^{0.5520}$ (more specifically $-5.0 \pm 5 * 10^{-5}$ and $0.5520 \pm 3 * 10^{-5}$). The reduced chi squared for the non-linear fit is 5.83. The equation that was calculated from the data for the non-linear fit is $I = 0.006 * V^{0.5702}$ (more specifically $0.006 \pm 3 * 10^{-5}$ and $0.570 \pm 2 * 10^{-3}$).

The fitted exponent of the non-linear model ranges (including standard deviation) from 0.5681 to 0.5723. Because the standard deviation is so small, the fitted exponent of the linear model ranges from 0.5220 to 0.5220. For both models, neither the blackbody values (0.6) nor the expected value for tungsten (0.5882) fall within the acceptable ranges. However, the non-linear model gives an exponent which is closer to the expected values, and this is apparent in both the plots.

Ths non-linear curve is closer to the theoretical curve, and has a lower reduced chi squared value than the linear curve.

The reduced chi squared is 11.35 for the linear fit, and 5.83 for the nonlinear fit. These numbers indicate that the models, relative to uncertainties, differ from the measured data points.

Sources of error could occur due to the resistance in the wires and the DC power supply. Other sources of error could come from the electromagnetic fields in the room. The equations themselves assume a perfect environment, which is not possible. To decrease the sources of error, the experiment should be conducted in an electromagnetically shielded environment. Additionally, the experiment could be repeated for multiple different (similarly made) light bulbs to reduce the standard deviation.

Conclusion:

The goal of this lab was to investigate power laws in the voltage-current curve of a light bulb. We analyze this relation using curve-fitting tools, and found that the results we obtained for the exponent in the voltage-current power law using both linear and non-linear models, taking into account errors, were not consistent with reference values for blackbodies and for tungsten.