Analyzing relation between voltage and current in a simulation

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1 Introduction

The purpose of this experiment is to measure the relationship between current and voltage by determining the resistance of an unknown resistor using a linear fit. Ohm's Law is used to relate the current and voltage to the resistance. This experiment was conducted in the circuit simulator located at:

`https://phet.colorado.edu/sims/html/circuit-construction-kit-dc-virtual-lab/latest/circuit-construction-kit-dc-virtual-lab_en.html`

2 Theory

Two equations are used in the calculations in this lab:
Ohm's Law (Equation 1): $\Delta V = IR$
Kirchoff's Loop Law (Equation 2): $\Delta V_{circuit} = 0$

3 Methods and Procedures

There were two resistors used in this experiment and the experiment is divided into three sections.

Experiment 1 (1st resistor): Resistor 1 is connected in series with a battery without any wire resistance. Multiple voltage measurements are taken at various battery voltages of the potential difference across the resistor as well as the current through the circuit.

Experiment 2 (2nd Resistor): Experiment 1 is repeated with the second resistor.

Experiment 3 (2nd Resistor): Resistor 2 is connected in series with a battery with wires that have wire resistance. The unknown resistor in this experiment the sum of all the wire resistance in the circuit. Multiple measurements are taken of the potential difference across the battery as well as the circuit current.

The following are images of the apparatus for each experiment:

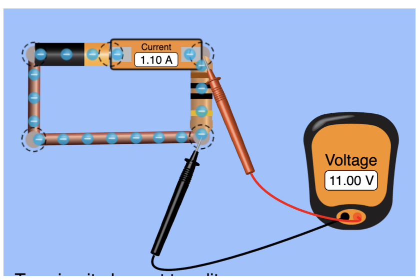

Figure 3.1: Experiment 1 Apparatus

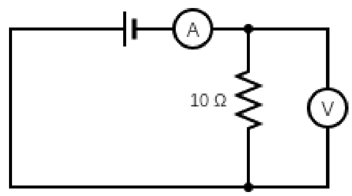

Figure 3.2: Experiment 1 Diagram

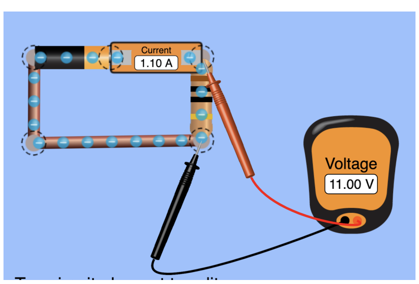

Figure 3.3: Experiment 2 Apparatus

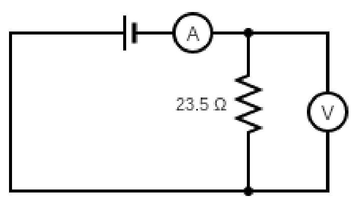

Figure 3.4: Experiment 2 Diagram

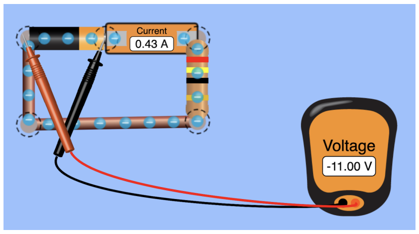

Figure 3.5: Experiment 3 Apparatus

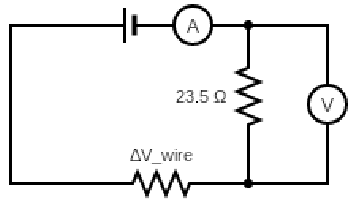

Figure 3.6: Experiment 3 Diagram

4 Results

A linear fit was performed on all 3 sets of experimental data resulting in the following graphs. The curve_fit function from scipy.optimize along with the ohm's law python model defined in **Figure 4.4**. The covariance of the linear fit as well as the calculated resistance is included in the graph. The method of resistance calculation is discussed in the following **Analysis** section.

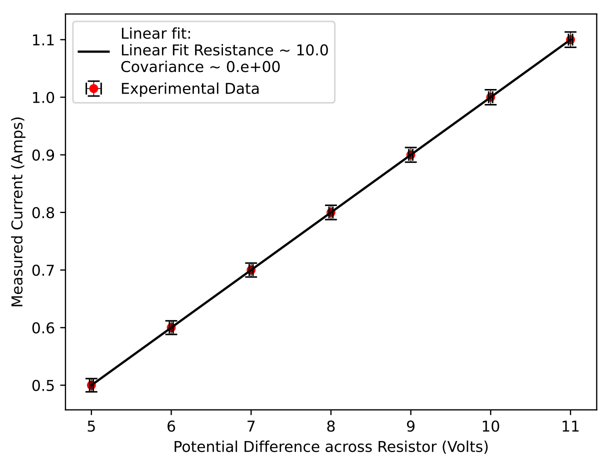

Figure 4.1: Experiment 1 Current vs Potential difference across a resistor for a simulated nonparallel circuit containing one resistor with no wire resistance.

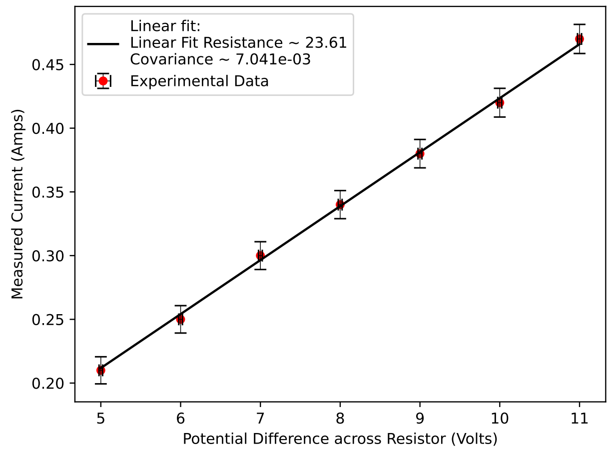

Figure 4.2: Experiment 2 Current vs Potential difference across a resistor for a simulated nonparallel circuit containing one resistor with no wire resistance.

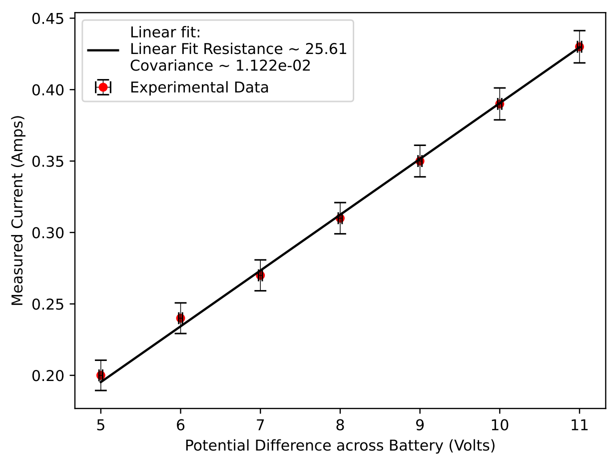

Figure 4.3: Experiment 3 Current vs Potential difference across a resistor for a simulated nonparallel circuit containing one resistor with wire resistance.

```
def current_model(voltage, resistance):
    return voltage / resistance
```

Figure 4.4: Ohm's Law python model used to generate best fit line

5 Analysis

Calculating Uncertainty Values

The uncertainty measurement calculations were based on the information available in the **U1270 Series Handheld Digital Multimeter** manual. All current uncertainties were calculated based on the $10A$ setting and all voltage uncertainties were calculated based on the $300V$ setting. Uncertainty sample calculations can be found in the **Appendix** section under **Sample Calculations**

Calculating net resistance in the circuit

Let ΔV_{net} be the potential difference across all parts of the circuit except the battery. (ie $\Delta V_{net} = \Delta V_{wire} + \Delta V_{resistor}$ and $R_{net} = R_{wire} + R_{resistor}$)
By Equation 1:

$$\Delta V_{net} = IR_{net} \implies I = \frac{\Delta V_{net}}{R_{net}} \text{ (Equation 3)}$$

Experiments 1 & 2
For experiments 1 & 2, since there is no wire resistance, $R_{wire} = 0$ and therefore $R_{net} = R_{resistor}$ and $\Delta V_{net} = \Delta V_{resistor}$, simplifying equation 3 to.

$$I = \frac{\Delta V_{resistor}}{R_{resistor}}$$

Experiment 3
Equations 2/3 give the following description of experiment 3's apparatus:

$$\Delta V_{battery} + \Delta V_{net} = 0 \implies -\Delta V_{battery} = \Delta V_{net} \implies -\Delta V_{battery} = IR_{net}$$

$$\implies \frac{-\Delta V_{battery}}{R_{net}} = I$$

Using these two derivations with the linear model defined in Figure 5.4 and the experimental data, the unknown resistances for all 3 experiments can be solved for using a linear fit of the data.

Figures 4.1, 4.2 and 4.3 represent the linear fit that was done in this way .

Final Values

Experiment 1
The linear fit gave a value of 10.0Ω for the first resistor.

Experiment 2
The linear fit gave a value of 23.5Ω for the second resistor.

Experiment 3
The linear fit gave a value of 25.61Ω for the net resistance.
The $R_{resistor}$ is the same as the resistor in experiment 2 which is a previously determined value. R_{wire} can be calculated using the previously determined $R_{resistor}$ and R_{net} calculated values as follows.

$$R_{net} = R_{wire} + R_{resistor} \implies R_{wire} = R_{net} - R_{resistor} = 25.6 - 23.5 = 2.1\Omega$$

Therefore the calculated resistance of the wire is 2.1Ω

6 Discussion

The first resistor has the following colours: Brown Black Black Gold. This corresponds to $10 \times 10^0\Omega \pm 5\% = 10\Omega \pm 0.5\Omega$. The experimentally calculated value was 10.0Ω, therefore the experiment was a completely accurate representation of Ohm's Law.

The second resistor had the following colours: Red Yellow Black Gold. This corresponds to $24 \times 10^0\Omega \pm 5\% = 24\Omega \pm 1.2\Omega$. The experimentally calculated value was 23.6Ω, therefore the experimental value was within the uncertainty range of the resistor.

7 Appendix

Figure 7.1: Experiment 1 Raw Data

Resistor ΔV (Volts)	Current (Amps)
11.00 ± 0.03	1.100 ± 0.01
10.00 ± 0.03	1.000 ± 0.01
9.00 ± 0.02	0.900 ± 0.01
8.00 ± 0.02	0.800 ± 0.01
7.00 ± 0.02	0.700 ± 0.01
6.00 ± 0.02	0.600 ± 0.01
5.00 ± 0.02	0.500 ± 0.01

Figure 7.2: Experiment 2 Raw Data

Resistor ΔV (Volts)	Current (Amps)
11.00 ± 0.03	0.470 ± 0.01
10.00 ± 0.03	0.420 ± 0.01
9.00 ± 0.02	0.380 ± 0.01
8.00 ± 0.02	0.340 ± 0.01
7.00 ± 0.02	0.300 ± 0.01
6.00 ± 0.02	0.250 ± 0.01
5.00 ± 0.02	0.210 ± 0.01

Figure 7.3: Experiment 3 Raw Data

Battery ΔV (Volts)	Current (Amps)
-11.00 ± 0.03	0.430 ± 0.01
-10.00 ± 0.03	0.390 ± 0.01
-9.00 ± 0.02	0.350 ± 0.01
-8.00 ± 0.02	0.310 ± 0.01
-7.00 ± 0.02	0.270 ± 0.01
-6.00 ± 0.02	0.240 ± 0.01
-5.00 ± 0.02	0.200 ± 0.01

Sample calculations

Current

With a setting of $10A$ the multimeter has a uncertainty value of 0.3% of the measurement +10 counts of the least significant digit. Since the corresponding resolution is $0.001A$, the final uncertainty for every current measurement I_i, $u(I_i)$ is defined:

$$u(I_i) = \pm\,(0.003I_i + 10 \times 0.001)\,A = \pm\,(0.003I_i + 0.01)\,A$$

For example in experiment 1, the first current value that was measured: $I_1 = 1.100A$.

$$u(I_1) = \pm(0.003 \times 1.100 + 0.01)A = \pm 0.0133A$$

Voltage

With a setting of $300V$ the multimeter has a uncertainty value of 0.05% of the measurement +2 counts of the least significant digit. Since the corresponding resolution is $0.01V$, the final uncertainty for every current measurement V_i, $u(V_i)$ is defined:

$$u(V_i) = \pm\,(0.0005V_i + 2 \times 0.01)\,V = \pm\,(0.0005 + 0.02)\,V$$

For example in experiment 1, the first voltage value that was measured was $V_1 = 11.00V$.

$$u(V_1) = \pm(0.0005 \times 11.00 + 0.02)V = \pm 0.0255V$$