High-Level Introduction

In this lab we are tasked with experimentally proving Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL) through building circuits with resistors in different configurations on our breadboard and use DC power supplies and digital multimeters (DMMs) to collect data so we can mathematically prove the validity of these laws and other electronic circuit analysis concepts.

Objectives, Learning Goals, Expected Outcomes

- Prove Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL) with resistors in a circuit
- Measure and compare resistor values with experimental data to explore deviations.
- Prove that power is conserved across the circuit.
- Analyze differential and common-mode voltages in Wheatstone Bridge circuits.
- Investigate non-linear resistance in an incandescent lamp.

Section 1: Verification of KVL & KCL

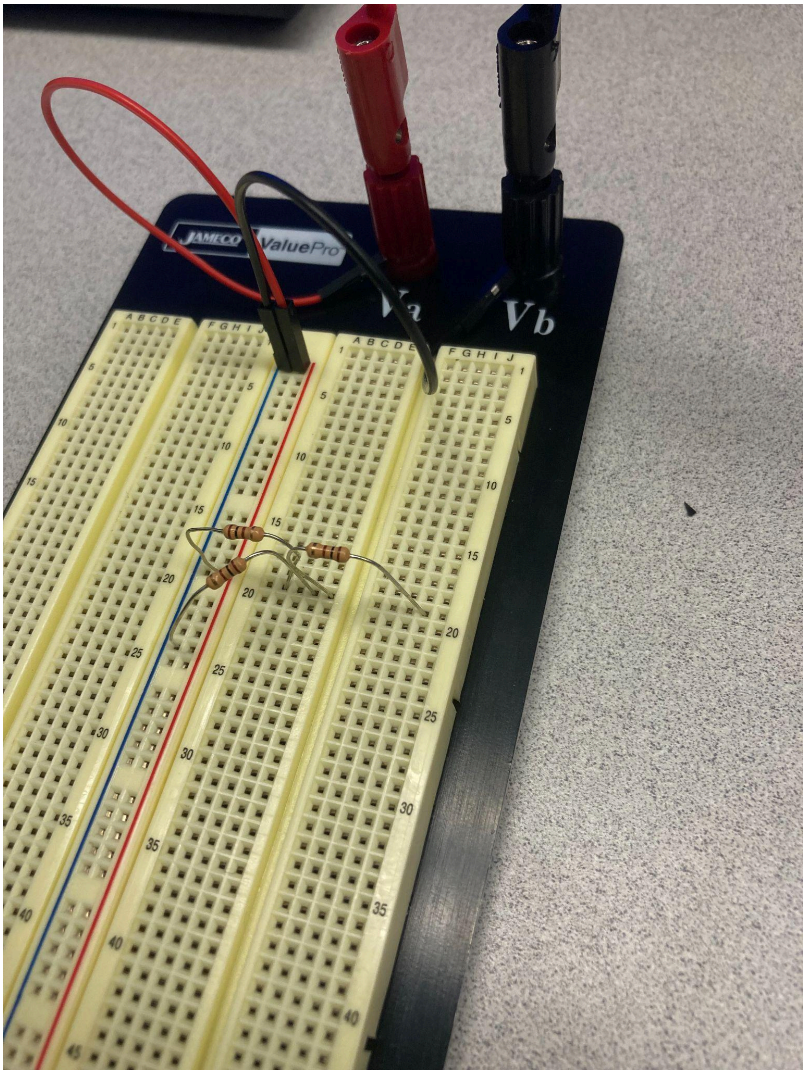
Section 1 Introduction

The first experiment involves constructing a circuit known as a T-Network and verifying Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL). The goal is to experimentally measure voltages and currents across the resistors and verify the conservation of power.

Specific Objectives, Learning Goals, Expected Outcomes

- Verify Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL) in the T-Network circuit.
- Compare the experimental resistance values of the resistors with DMM measurements.
- Verify power conservation by calculating power dissipated in each resistor and comparing it with the power delivered by the power supply.

Section 1 Results, Analysis, Discussion


JAMECO
ValuePro
Va
Vb


KEYSIGHT
EDU36311A
Triple Output Programmable
DC Power Supply
6 V/5 A, 30 V/1 A,
30 V,1 A
4.999 V
0.025 A
0.126 W
5.000 V
CV
OFF
0.002 V
0.000 A
0.000 W
0.000 V
1.000 A
OFF
0.000 V
0.000 A
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0.000 V
1.000 A
Meter View
Source Settings
Output Settings
Store/Recall
Utilities
Lock
Back
Voltage
Meter View
Tracking
Select
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Measured Data

- Resistor Values: R1=100Ω,R2=100Ω,R3=100Ω
- Experimental Resistor Values: R1: 99.12Ω, R2= 99.12Ω, R3= 99.12Ω
- Input Voltage: Vin=5V
- Voltage Measurements:
  - V1= 3.32 V (across R1)
  - V2= 1.66 V (across R2)
  - V3= 1.66 V (across R3)
- Current Measurements:
  - I1=33.36mA (through R1)
  - I2=16.68mA (through R2)

    - $I3=16.68mA$ (through R3)

Kirchhoff's Law Verification

- KVL Verification:

  $V1+V3=3.32V+1.66 = 4.98V = 5V$

  Also $V3 = V2$ so $V3 - V2 = 0$

- The total voltage across the circuit roughly matches the input voltage, verifying KVL.
- KCL Verification:

  $Itotal=I1=I2+I3=33.36mA=16.68mA+16.68mA$
- The current entering and leaving the node is equal, confirming KCL.

Power Calculation

- Power in R1:

  $P1=V1*I1= 3.32\ V \times 33.36mA = 0.111W$
- Power in R2:

  $P2=V2\times I2=1.66V \times 16.68mA = 0.027W$
- Power in R3:

  $P3=V3\times I3=1.66V\ x\ 16.68mA =0.027W$
- Total Power Dissipated:

  $Ptotal=0.111W+0.027W+0.027W=0.165W$
- Power Delivered by Power Supply:

  $Pin=Vin\times Itotal=5V\times 33.36mA=0.166W$
- The difference between power dissipated and power delivered may be due to measurement inaccuracies or losses in wiring and equipment.

Resistance from Two Input Nodes:

- Measured with DMM: 148 Ohms
- Req calculated = (R2 || R3) + R1 = (100 * 100/ 200) + 100 = 150
- They are slightly different but this could be because there is some form of resistance in the wires

Verification of Current and Voltage divider theorems.

$I3 = (I1*R2)/ (R2 + R3) = (33.36 * 100)/(100+100) = 16.68$ mA
$I2 = (I1*R3)/ (R2 + R3) = (33.36 * 100)/(100+100) = 16.68$ mA
$V2 = (V1 * R2) / (R1+R2) = (3.32 * 100) / (100+100) = 1.66V$
$V3 = (V1 * R3) / (R1+R2) = (3.32 * 100) / (100+100) = 1.66V$

Section 1 Conclusion

The experiment confirmed KVL and KCL, with only slight discrepancies due to equipment tolerances and resistor inaccuracies. The reason why the experimental resistances are slightly different from their theoretical values can be due to the cables used to measure containing some form of resistance. Power conservation was nearly achieved, although slight differences between calculated and measured power were observed. Overall, the experiment validated the theoretical expectations of circuit behavior.

Section 2: Single-Ended and Differential Circuits

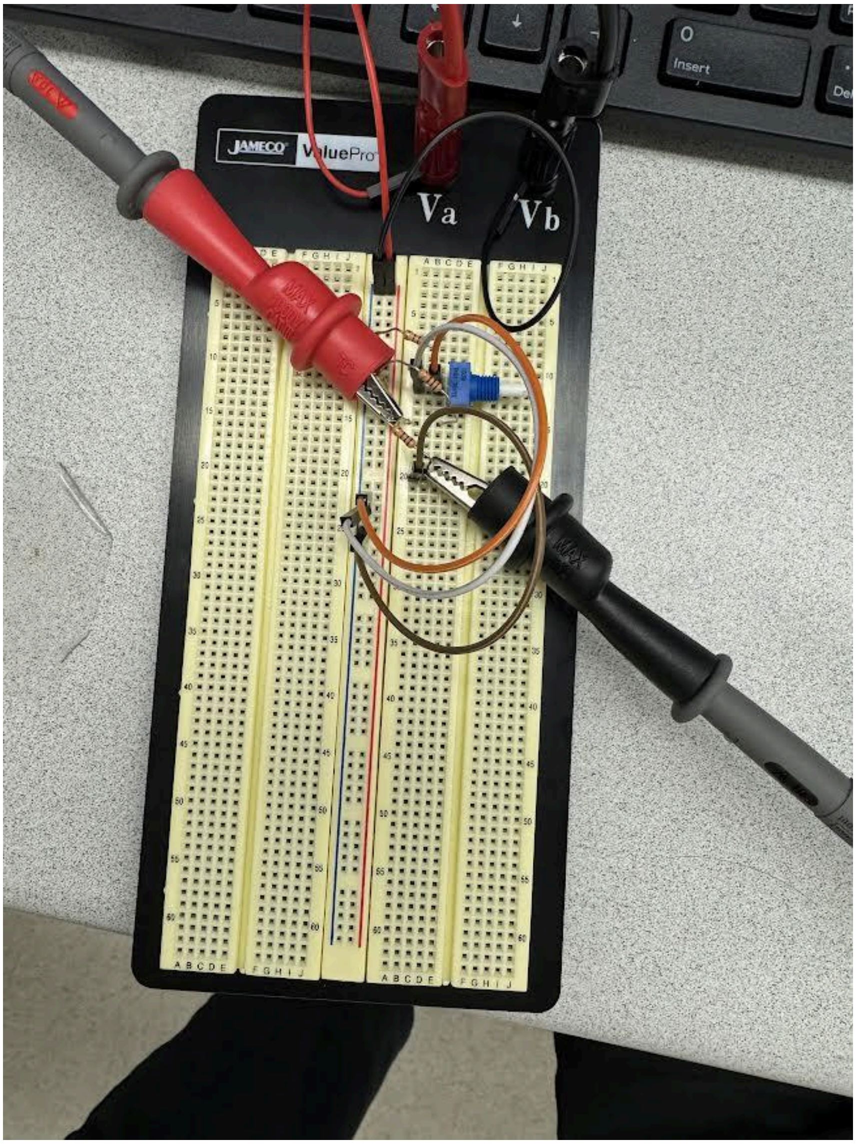
Section 2 Introduction

In this section, we explore differential and common-mode voltages using a Wheatstone Bridge circuit. This circuit is designed to convert a single-ended input voltage to a differential voltage and observe the impact of resistor ratios on the resulting voltages.

Specific Objectives, Learning Goals, Expected Outcomes

- Measure and analyze single-ended voltages and their relationship with differential and common-mode voltages.
- Verify how resistor ratios affect the differential voltage across the bridge.

Section 2 Results, Analysis, Discussion



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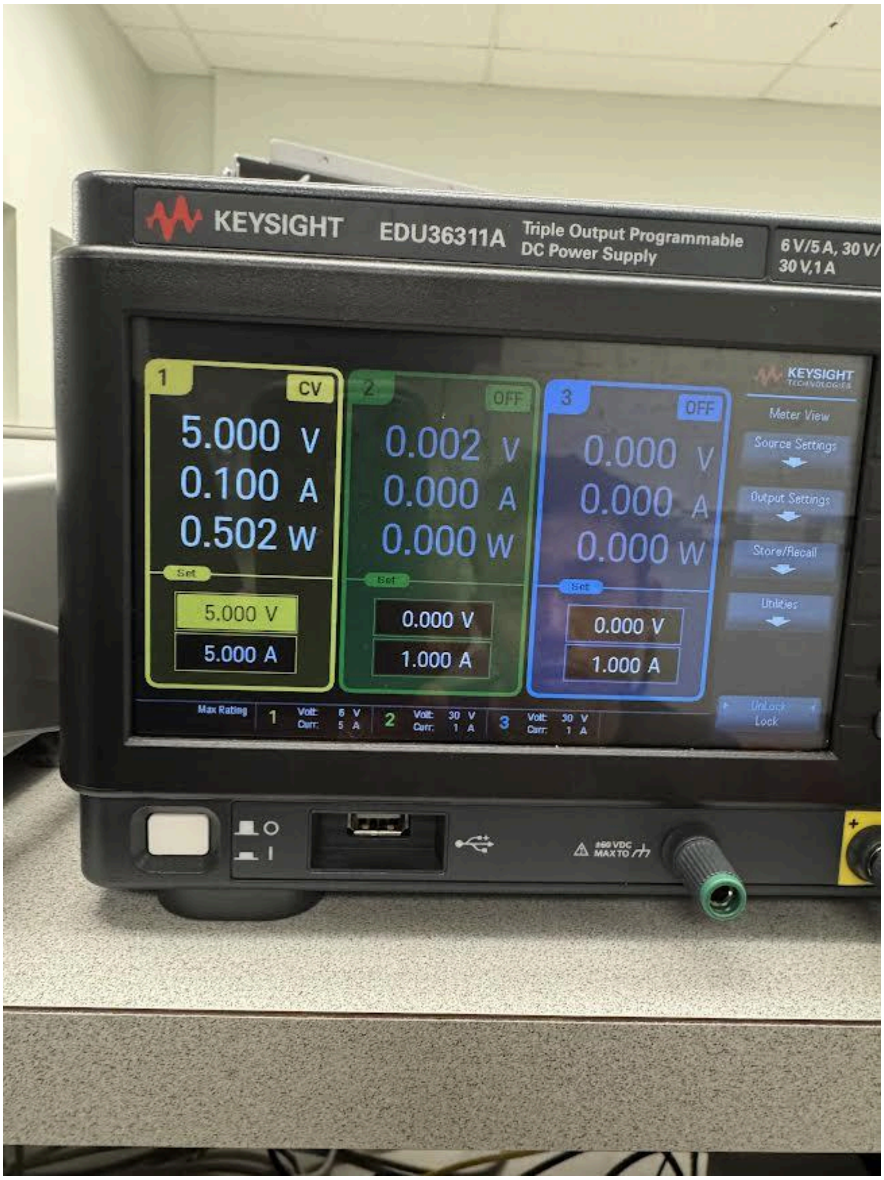

KEYSIGHT
EDU36311A
Triple Output Programmable
DC Power Supply
6 V/5 A, 30 V/
30 V,1 A
1
CV
5.000 V
0.100 A
0.502 W
Set
5.000 V
5.000 A
2
OFF
0.002 V
0.000 A
0.000 W
Set
0.000 V
1.000 A
3
OFF
0.000 V
0.000 A
0.000 W
Set
0.000 V
1.000 A
KEYSIGHT
Meter View
Source Settings
Output Settings
Store/Recall
Utilities
UnLock
Lock
Max Rating
1 Volt: 6 V Curr: 5 A
2 Volt: 30 V Curr: 1 A
3 Volt: 30 V Curr: 1 A

Measured Data:

- Resistor values: R1=R2=R3=100 Ω
- Experimental Resistor Values: R1=R2=R3=99.12Ω
- Input Voltage: V1=5V
- Potentiometer (R4): Variable with a maximum resistance of 100 kΩ

Single-Ended Voltage Measurements

Measure the single-ended voltages V2 and V3 with respect to ground for different values of R4.

R4 (Ω)	V2 (V)	V3 (V)

10k	4.95	0.05
25k	4.96	0.04
50k	4.98	0.02
75k	4.98	0.02
100k	4.99	0.01

Differential Voltage

The differential voltage $V_d = V_2 - V_3$ for various values of R4.

R4 (Ω)	Vd (V)
10k	4.90
25k	4.92
50k	4.96
75k	4.96
100k	4.98

Common-Mode Voltage

The common-mode voltage $V_{cm} = (V_2 + V_3) / 2$

R4 (Ω)	Vcm (V)

10k	2.50
25k	2.50
50k	2.50
75k	2.50
100k	2.50

Analysis:

- Single-ended voltages: As R4 increases, V2 stays close to the input voltage (5V), while V3 becomes very small. The single-ended voltage V3 approaches zero because R4 is much larger than R1,R2,R3, making V3 drop almost entirely across R4.
- Differential voltage: The differential voltage Vd is nearly equal to V1 (the input voltage), as R4's large resistance makes V3 very small.
- Common-mode voltage: The common-mode voltage remains constant at 2.5V, which is half the input voltage. This occurs because V2 is almost at 5V and V3 is close to zero, making their average 2.5V.

Section 2 Conclusion:

The differential voltage Vd increases as R4 increases, nearly reaching the full input voltage when R4 is at its maximum.The common-mode voltage remains constant at 2.5V, regardless of R4 's value. This configuration demonstrates how single-ended, differential, and common-mode voltages behave in a Wheatstone bridge with a 5V input and 100Ω resistors, with a potentiometer reaching up to 100kΩ..

Section 3: Non-Linear Resistances

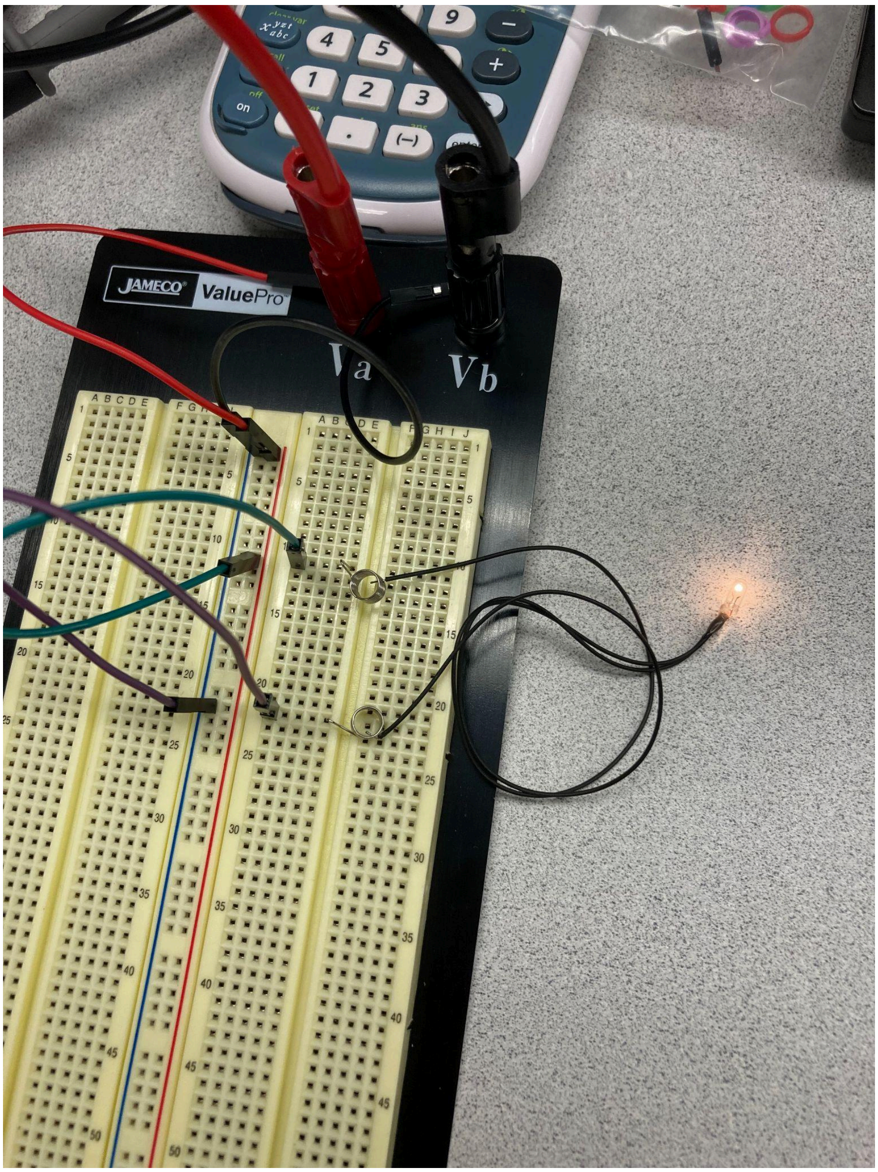
Section 3 Introduction

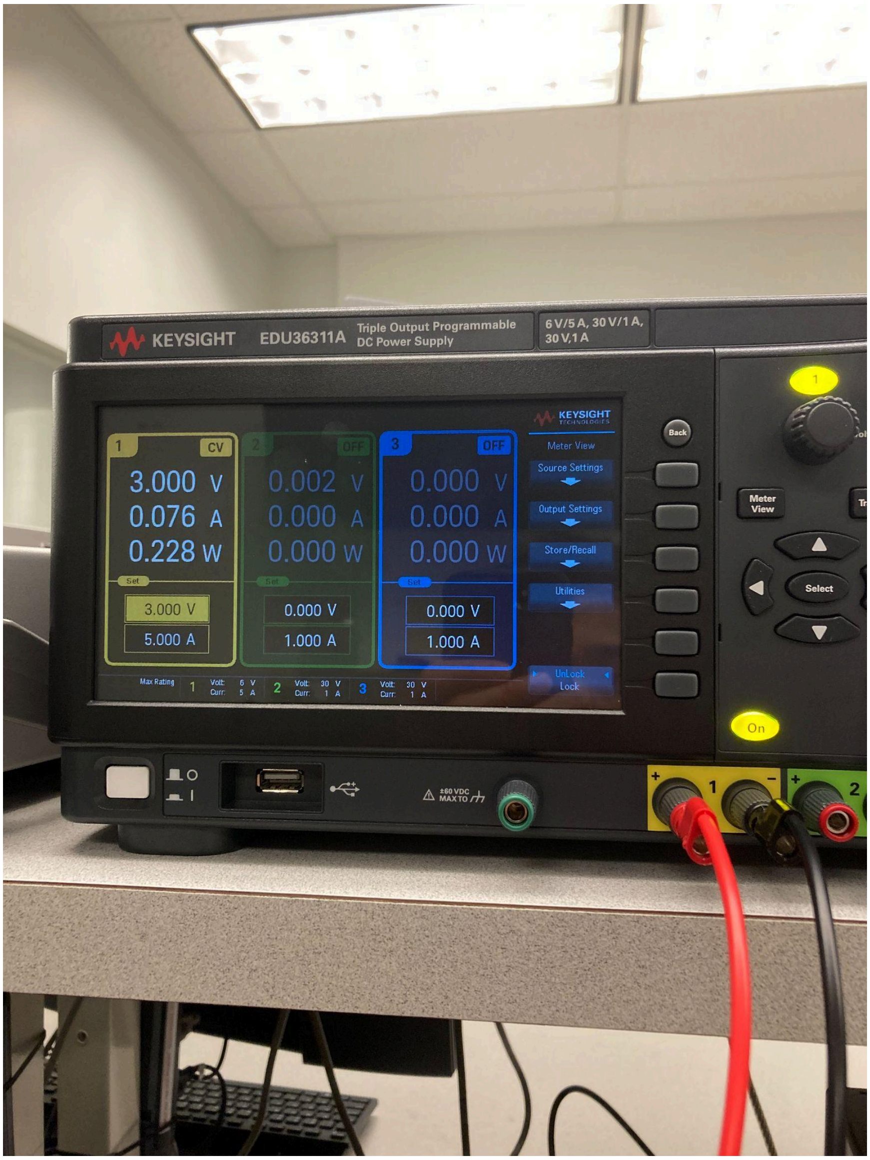
This section introduces the concept of non-linear resistances by measuring the volt-ampere characteristics of an incandescent lamp. The purpose of this experiment is to observe the lamp's non-linear behavior due to its changing resistance with temperature.

Specific Objectives, Learning Goals, Expected Outcomes

Show the non-linear behavior of the incandescent lamp, analyze how its resistance changes with voltage, and prove that the lamp's response does not obey superposition while the fixed resistor's response does.

Section 3 Results, Analysis, Discussion





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CV
3.000 V
0.076 A
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Set
3.000 V
5.000 A
2
OFF
0.002 V
0.000 A
0.000 W
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0.000 V
1.000 A
3
OFF
0.000 V
0.000 A
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0.000 V
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KEYSIGHT
Meter View
Source Settings
Output Settings
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Utilities
UnLock
Lock
Back
Meter
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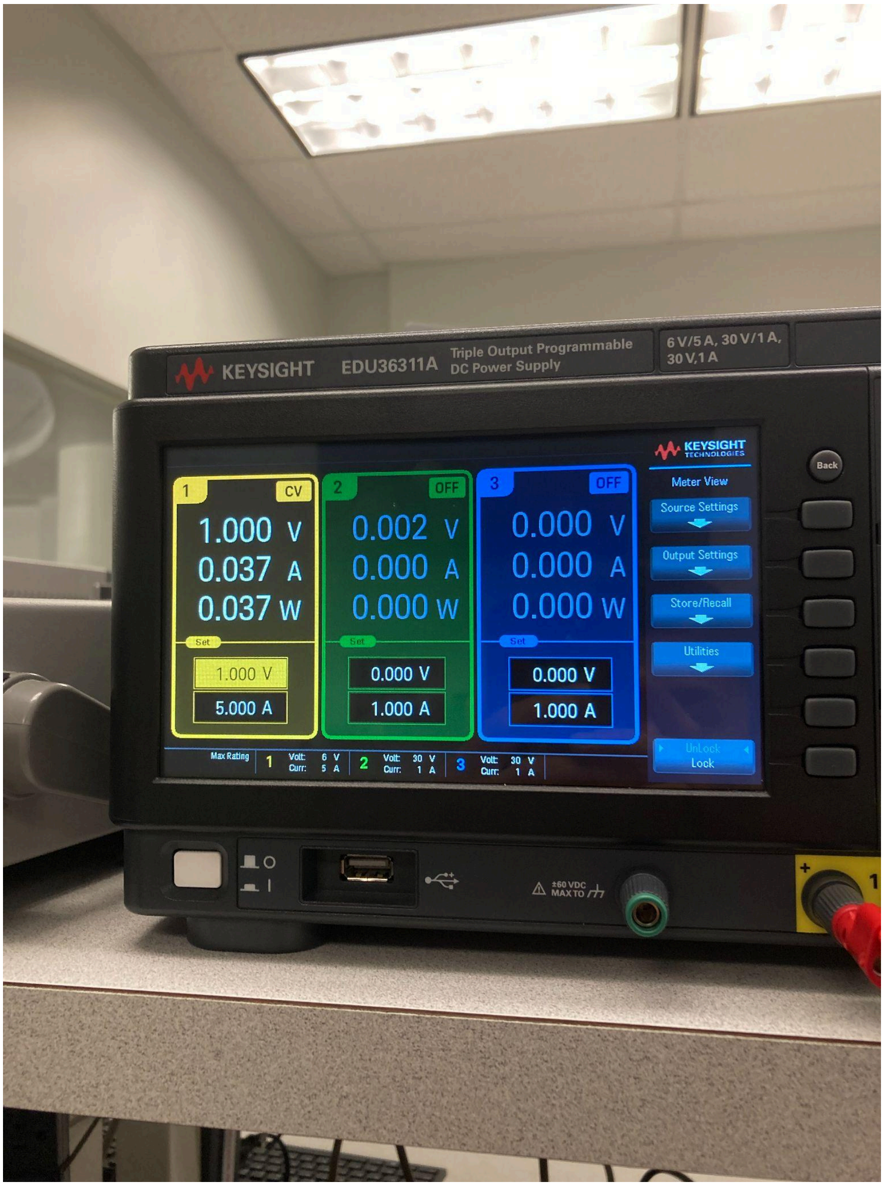
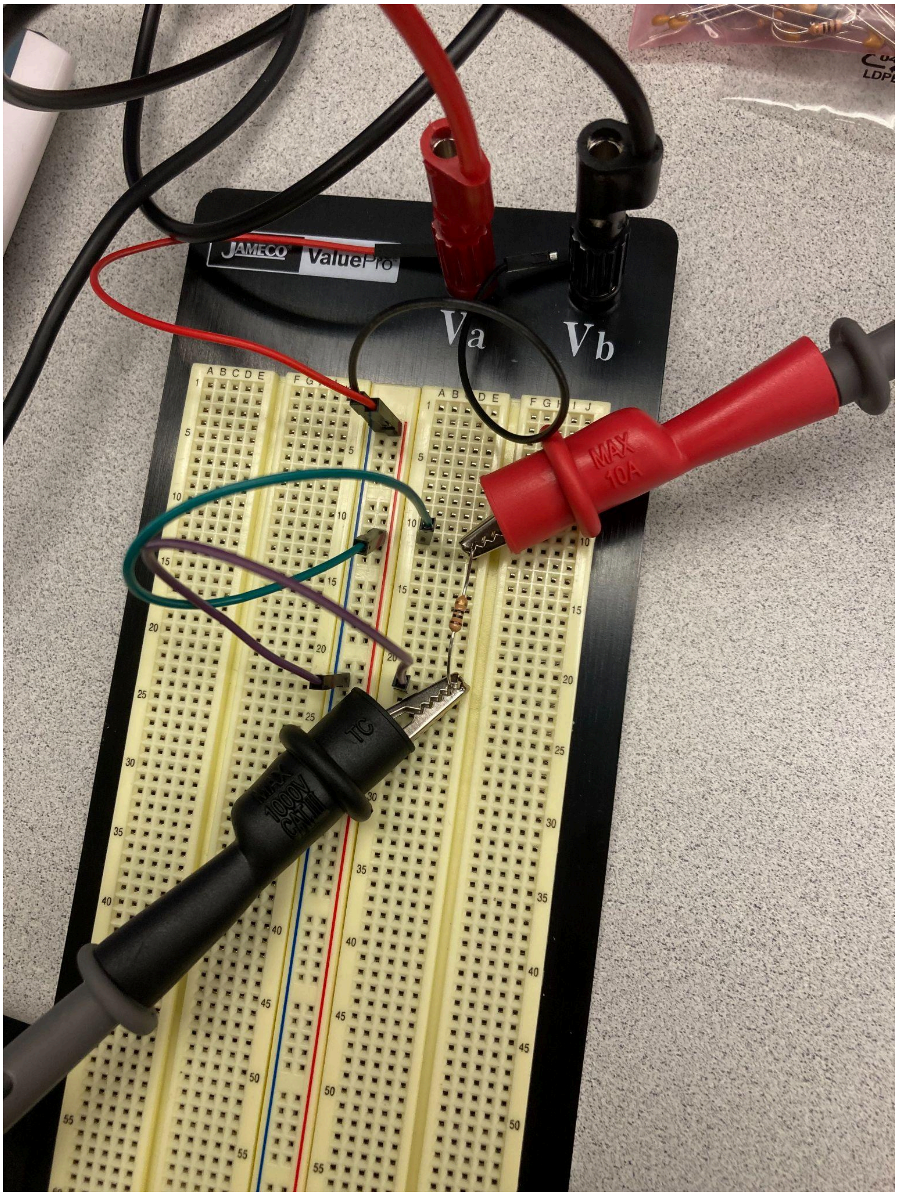

KEYSIGHT
EDU36311A
Triple Output Programmable
DC Power Supply
6 V/5 A, 30 V/1 A,
30 V,1 A
1 CV
1.000 V
0.037 A
0.037 W
Set
1.000 V
5.000 A
2 OFF
0.002 V
0.000 A
0.000 W
Set
0.000 V
1.000 A
3 OFF
0.000 V
0.000 A
0.000 W
Set
0.000 V
1.000 A
KEYSIGHT TECHNOLOGIES
Meter View
Source Settings
Output Settings
Store/Recall
Utilities
UnLock
Lock
Back
Max Rating
1 Volt: 6 V Curr: 5 A
2 Volt: 30 V Curr: 1 A
3 Volt: 30 V Curr: 1 A
±60 VDC
MAX TO


JAMECO
ValuePro
Va
Vb
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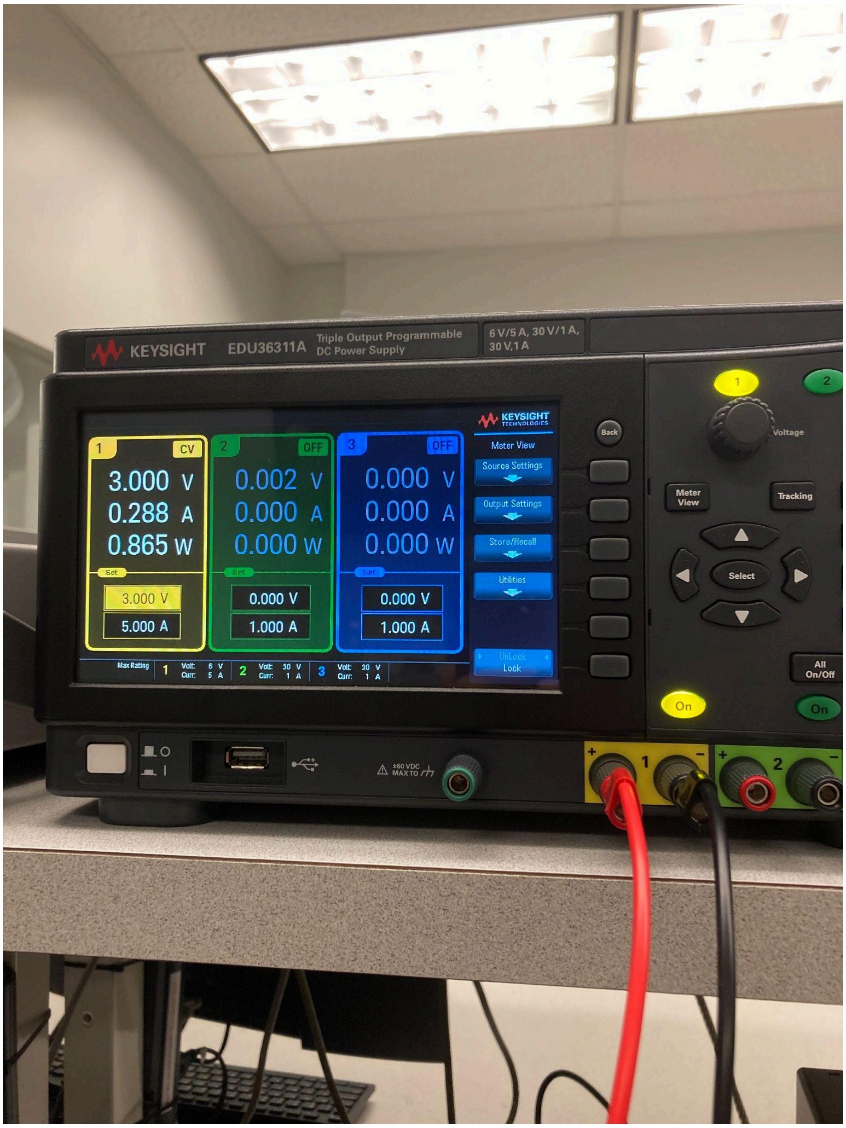
10A
TC



- Input Voltage Range: 1V to 3V (in steps of 0.5V).
- Resistor Values: 10 Ω

Non-Linear Behavior of the Incandescent Lamp

The resistance of the incandescent lamp increases as it heats up when current flows through it. The lamp’s resistance is not constant; it changes with voltage, which creates a non-linear V−IV-IV−I relationship. For this experiment, we'll gather the current at various input voltages and calculate the resistance.

Experimental Data (Voltage vs. Current for the Incandescent Lamp):

Voltage (V)	Current (A)	Resistance (Ω) (calculated as V/I)

1.0V	0.037A	27.02Ω
1.5V	0.051A	29.41Ω
2.0V	0.058A	34.38Ω
2.5V	0.066A	37.87Ω
3.0V	0.074A	40.54Ω

Fixed Resistor Behavior

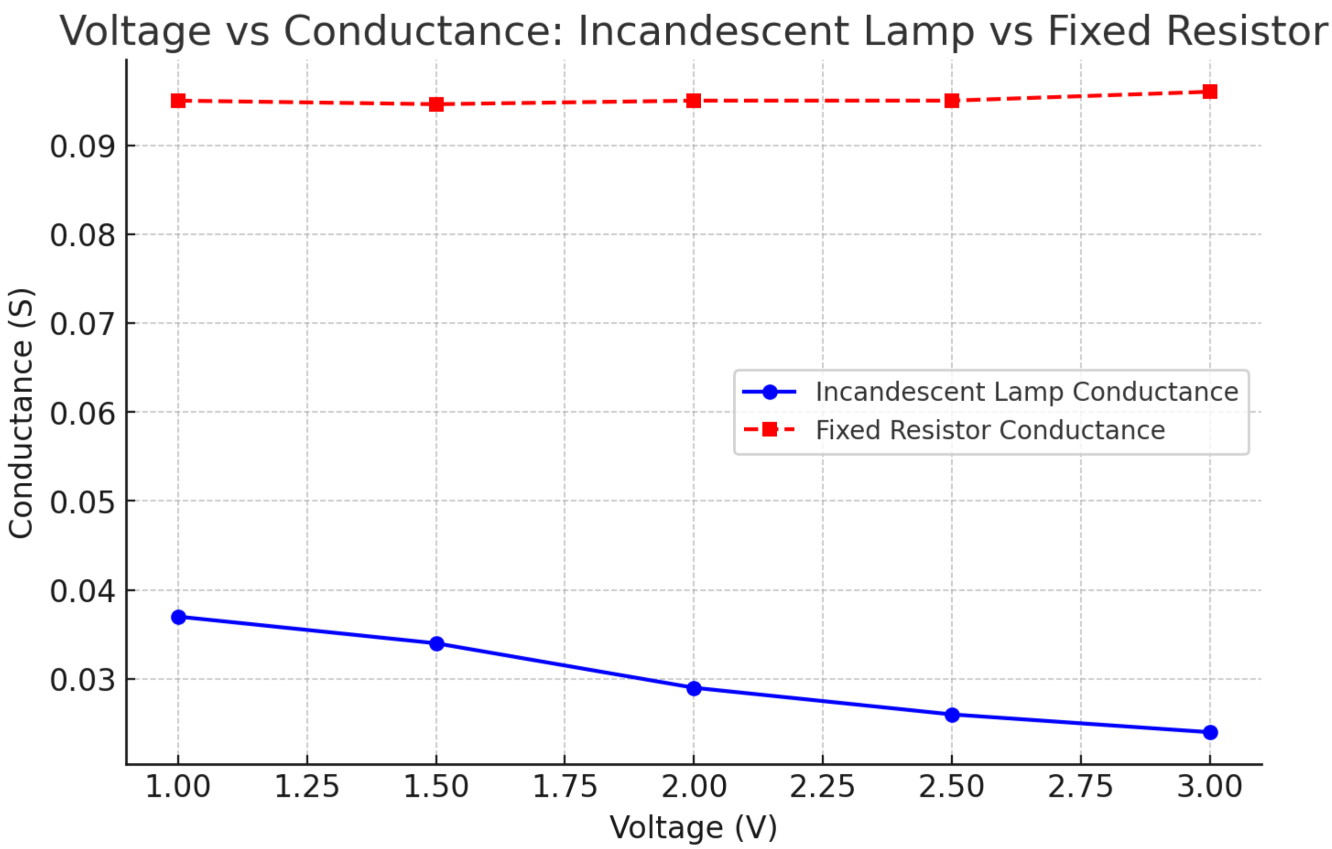
A fixed resistor, by contrast, exhibits a linear relationship between voltage and current (Ohm's law: V=IR). Its resistance remains constant regardless of the applied voltage.

Experimental Data (Voltage vs. Current for the Fixed Resistor (10 Ohms):

Voltage (V)	Current (A)	Resistance (Ω\) (calculated as V/I)
1.0V	0.095A	10.5Ω
1.5V	0.142A	10.5Ω
2.0V	0.190A	10.5Ω
2.5V	0.239A	10.4Ω
3.0V	0.288A	10.4Ω

If you plot the current (I) against the voltage (V) for both the incandescent lamp and the fixed resistor, the fixed resistor graph will be a straight line, indicating a constant resistance of 10 Ω and for the incandescent lamp, the graph will be curved, showing that the current does not increase linearly with voltage. This curvature shows that the lamp's resistance increases as it heats up, making it non-linear.

Conductance Analysis



The conductance is the inverse of resistance, G=1/R. For the fixed resistor, this conductance is constant because the resistance remains constant. For the incandescent lamp, the conductance decreases as the voltage increases, showing that the lamp's resistance is increasing with temperature.

Conductance Values:

Voltage (V)	Lamp Conductance (S)	Fixed Resistor Conductance (S)
1.0V	0.037 S	0.095S
1.5V	0.034 S	0.0946 S
2.0V	0.029 S	0.095 S

2.5V	0.026 S	0.095S
3.0V	0.024 S	0.096 S

Proving Non-Superposition for the Incandescent Lamp

Superposition Principle:

Superposition states that the total response (current or voltage) due to multiple input sources is the sum of the responses due to each individual source. This holds true for linear systems, like the fixed resistor, but not for non-linear systems like the incandescent lamp.

Fixed Resistor (Linear System):

For the fixed resistor V1=1.5V causes a current I1=0.142A, and V2=2.0V causes a current I2=0.19A, and the total current with V1+V2=3.5V is : I(3.5V)=I1+I2=0.142A+0.19A=0.033A. Thus, the resistor follows the principle of superposition because the current scales linearly with the voltage.

Incandescent Lamp (Non-Linear System):

For the incandescent lamp V1=1.5V causes I1=0.051A, and V2=2.0V causes I2=0.058A. The combined voltage V1+V2=3.5V does not equal to I1+I2=0.035A. Instead, due to the increasing resistance, the actual current will be less than expected. This proves that the incandescent lamp does not obey superposition, while the fixed resistor does.

Section 3 Conclusion:

The incandescent lamp exhibits non-linear behavior: As the voltage increases, its resistance increases, leading to a non-linear V−I curve. The fixed resistor behaves linearly: The current is directly proportional to the applied voltage, as expected from Ohm’s law. Superposition holds for the fixed resistor but not for the incandescent lamp because the lamp’s resistance changes with voltage and temperature, making its response non-linear.The incandescent lamp’s behavior confirmed its non-linear resistance, which increased as the temperature rose. This experiment showed the contrast between non-linear and linear components.

High-Level Conclusion

This lab provided a thorough understanding of important circuit principles, from verifying KVL and KCL to understanding non-linear resistances. By conducting hands-on experiments, we were able to confirm theoretical predictions and observe real-world factors like non-idealities and measurement discrepancies. Key takeaways include an improved grasp of differential circuits, the importance of resistor tolerances, and the effects of temperature on non-linear elements.