Experiment 1: Metric Prefixes, Scientific Notation, and Graphing

Procedure:

Some possible responses are listed in Table 1-3.

Table 1-3

Instrument	Control	Metric Unit	Meaning
Oscilloscope	SEC/DIV	ms	10^{-3} s
Oscilloscope	**SEC/DIV**	**μs**	**10^{-6} s**
Function Gen	**Range**	**kHz**	**10^{3} Hz**
DMM	**Function**	**kΩ**	**10^{3} Ω**
Oscilloscope	**V/DIV**	**mV**	**10^{-3} V**

Table 1–4

Dimension	Length in Millimeters	Length in Meters
A	7.2 mm	7.2×10^{-3} m
B	**15.4 mm**	**15.4×10^{-3} m**
C	**9.0 mm**	**9.0×10^{-3} m**
D	**31.3 mm**	**31.3×10^{-3} m**
E	**14.0 mm**	**14.0×10^{-3} m**
F	**6.0 mm**	**6.0×10^{-3} m**
G	**10.2 mm**	**10.2×10^{-3} m**

Table 1-5

Number	Scientific Notation	Engineering Notation	Metric Value
0.0829 V	8.29×10^{-2} V	82.9×10^{-3} V	82.9 mV
48,000 Hz	**4.8×10^{4} Hz**	**48×10^{3} Hz**	**48 kHz**
2,200,000 Ω	**2.2×10^{6} Ω**	**2.2×10^{6} Ω**	**2.2 MΩ**
0.000 015 A	**1.5×10^{-5} A**	**15×10^{-6} A**	**15 μA**
7,500 W	**7.5×10^{3} W**	**7.5×10^{3} W**	**7.5 kW**
0.000 000 033 F	**3.3 10^{-8} F**	**33×10^{-9} F**	**33 nF**
270,000 Ω	**2.7×10^{5} Ω**	**270×10^{3} Ω**	**270 kΩ**
0.000 010 H	**1.0×10^{-5} H**	**10×10^{-6} H**	**10 μH**

Table 1–6

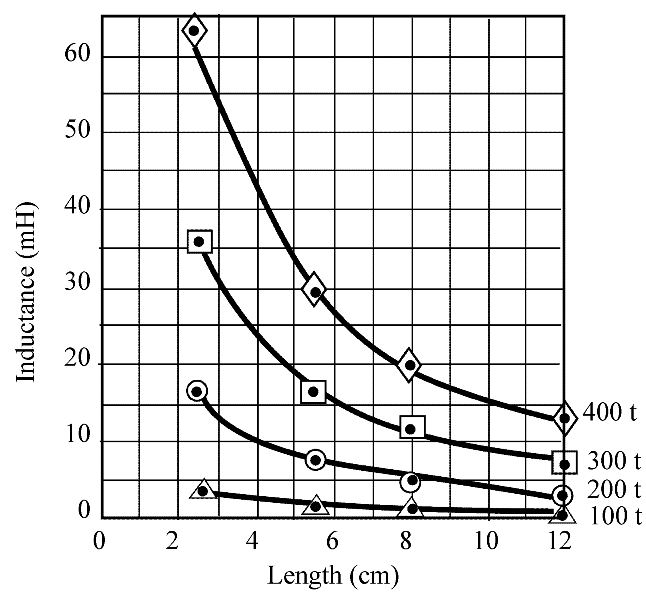
Metric Value	Engineering Notation
100 pF	**100×10^{-12} F**
12 kV	**12×10^{3} V**
85.0 μA	**85.0×10^{-6} A**
50 GHz	**50×10^{9} Hz**
33 kΩ	**33×10^{3} Ω**
250 mV	**250×10^{-3} V**
7.8 ns	**7.8×10^{-9} s**
2.0 MΩ	**2.0×10^{6} Ω**

Table 1–7

Metric Unit in Operand	Mathematical Operation	Metric Unit in Operand		Metric Unit in Result
milli	multiplied by	milli	=	micro
kilo	multiplied by	micro	=	**milli**
nano	multiplied by	kilo	=	**micro**
milli	multiplied by	mega	=	**kilo**
micro	divided by	nano	=	**kilo**
micro	divided by	pico	=	**mega**
pico	divided by	pico	=	**unit**
milli	divided by	mega	=	**nano**

Table 1–8 Inductance, *L*, of coils wound on identical iron cores (mH).

Length, *l* (cm)	Number of Turns , *N* (t)			
	100	200	300	400
2.5	3.9	16.1	35.8	64.0
5.5	1.7	7.5	16.1	29.3
8.0	1.2	5.1	11.4	19.8
12.0	0.8	3.3	7.5	13.1



Plot 1-1

Evaluation and Review Questions:

1. a) kW b) mA
   c) pF d) ns
   e) MΩ f) μH

2. a) megawatt b) nanoampere
   c) microjoule d) millivolt
   e) kilohm f) gigahertz

3. a) 3.2×10^{1}
   b) -1.1×10^{-6}
   c) 1.9×10^{-2}
   d) 5.0×10^{-2}

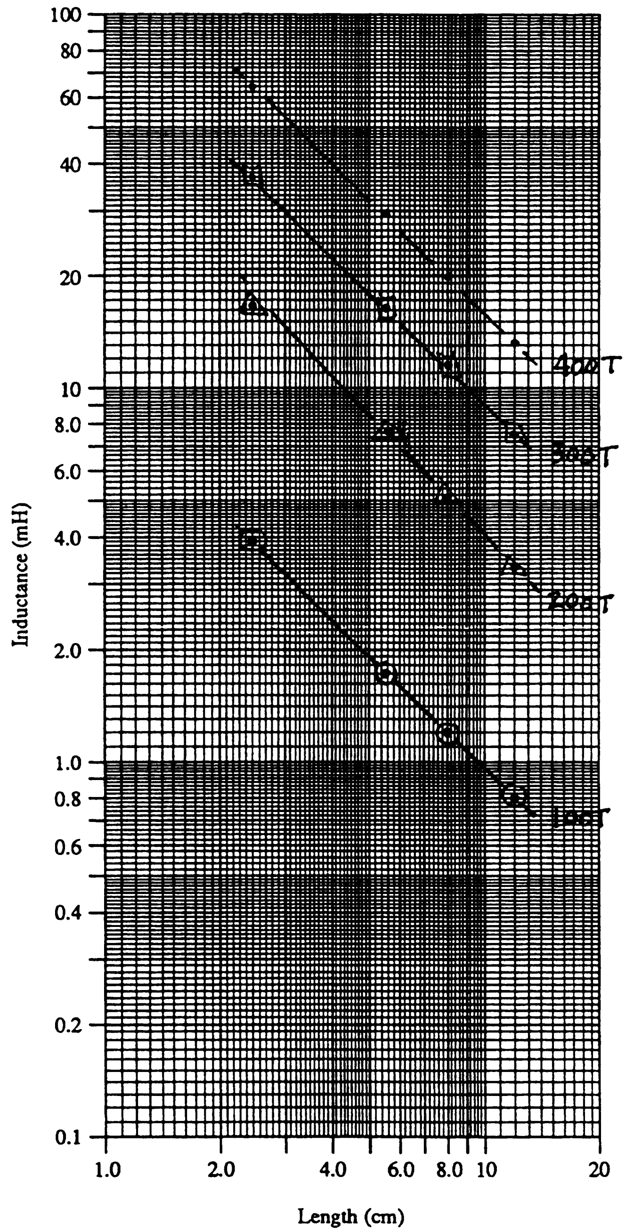
4. a) -6.3×10^{5} b) 7.6×10^{6}
   c) 3.1×10^{9} d) -2.2×10^{-5}

5. a) $-630 \times 10^{3} = -630$ k b) $7.6 \times 10^{6} = 7.6$ M
   c) $3.1 \times 10^{9} = 3.1$ G d) $-22 \times 10^{-6} = -22$ μ

6. Steps in preparing a linear graph:
   1. Choose a scale factor that enables all of the data to be plotted on the graph.
   2. Number the major divisions along each axis.
   3. Label each axis to indicate the quantity being measured and the measurement units.
   4. Plot the data points with a small dot with a small circle around each point.
   5. Draw a smooth line that represents the data trend.
   6. Title the graph.

For Further Investigation:

The data from Table 1-8, plotted on log-log paper.



Experiment 2: Laboratory Meters and Power Supply

Procedure:

1. Each secondary division is worth 0.5 V. The meter reads 15.0 V.

2. Each secondary division is worth 5.0 V. The meter reads 150 V.

3. The voltmeter reads 25.5 V.

4. The ohmmeter reads 175 Ω. On the 12 V DC VOLTS scale, the reading is 2.4 V.

5. The ohmmeter reads 155 Ω. On the 30 V AC VOLTS scale, the reading is 21.9 V.

6, 7. Answers vary depending on particular power supply.

9. Reading on the power supply meter: 5.0 V. Reading on the DMM: 4.98 V.

10. Reading on the power supply meter: 12. V. Reading on the DMM: 12.0 V.

11. Reading on the power supply meter: 0 V. Reading on the DMM: 0.01 V.

Evaluation and Review Questions:

1. The precision of a typical 3 1/2 digit DMM is one part in 2000. The precision of a power supply meter depends on the type of meter but is typically one part in 100. This question can lead to a post-lab discussion of the difference between resolution and accuracy.

2. An autoranging meter automatically switches to the appropriate range to display the measured quantity.

3. A multiple scale is one with more than one range on the scale. A complex scale is used for more than one function on the same scale.

4. A linear scale has equally spaced divisions across the meter face; a nonlinear scale does not.

5. Each secondary mark has a value of 0.2. The meter reading is 3.2.

6. The three basic measurements are voltage, resistance, and current. Many DMMs have additional capabilities.

For Further Investigation:

Results will vary depending on equipment and meter used.

Experiment 3: Measurement of Resistance

Procedure:

Answers for both tables depend on the particular resistors used. Note that the sum of the readings on Table 3-3 (column 3) is approximately constant.

Evaluation and Review Questions:

1. Answer depends on the potentiometer used. Normally, the resistance is a minimum between terminals 1 and 2 and maximum between terminals 2 and 3 when the shaft is rotated fully CW.

2. a) Answers vary.
   b) Check result with another meter or measure a known resistor with the meter in question.

3. a) brown - red - black - silver
   b) blue - gray - red - silver
   c) white - brown - brown - silver
   d) yellow - violet - green - silver
   e) brown - black - gold - silver

4. a) 22 Ω (5%)
   b) 750 Ω (10%)
   c) 510 Ω (5%)
   d) 9.1 Ω (5%)
   e) 820 kΩ (10%)

5. a) largest value = 28,350 Ω
   b) smallest value = 25,650 Ω

6. A rheostat is a two-terminal variable resistor used to control current in a circuit. A potentiometer is a three-terminal variable resistor with a wiper that slides along a fixed resistance. A potentiometer can be connected as a rheostat by leaving open one of the fixed terminals.

For Further Investigation:

Although not as meaningful statistically as standard deviation, the average deviation is easy to find by computing the average value and finding the variation of each resistor from the average. Results vary but the student will observe that all (or nearly all) are within the deviation specified by the tolerance.

Experiment 4: Voltage Measurement and Reference Ground

Procedure:

Table 4-2

	Measured Value
V_S	**+10.0 V**
V_{AB}	**+1.64 V**
V_{BC}	**+3.38 V**
V_{CD}	**+4.98 V**

Table 4-3

	Measured Voltage
V_A	**+10.0 V**
V_B	**+8.36 V**
V_C	**+4.98 V**
V_D	0.0 V (ref)

Voltage Difference Calculation
$V_{AB} = V_A - V_B =$ **+1.64 V**
$V_{BC} = V_B - V_C =$ **+3.38 V**
$V_{CD} = V_C - V_D =$ **+4.98 V**

Table 4-4

	Measured Voltage
V_A	**+5.02 V**
V_B	**+3.38 V**
V_C	+0.0 V (ref)
V_D	**–4.98 V**

Voltage Difference Calculation
$V_{AB} = V_A - V_B =$ **+1.64 V**
$V_{BC} = V_B - V_C =$ **+3.38 V**
$V_{CD} = V_C - V_D =$ **+4.98 V**

Table 4-5

	Measured Voltage
V_A	**+1.64 V**
V_B	0.0 V (ref)
V_C	**–3.38 V**
V_D	**–8.36 V**

Voltage Difference Calculation
$V_{AB} = V_A - V_B =$ **+1.64 V**
$V_{BC} = V_B - V_C =$ **+3.38 V**
$V_{CD} = V_C - V_D =$ **+4.98 V**

Table 4-6

	Measured Voltage
V_A	0.0 V (ref)
V_B	**–1.64 V**
V_C	**–5.02 V**
V_D	**–10.0 V**

Voltage Difference Calculation
$V_{AB} = V_A - V_B =$ **+1.64 V**
$V_{BC} = V_B - V_C =$ **+3.38 V**
$V_{CD} = V_C - V_D =$ **+4.98 V**

Evaluation and Review Questions:

1. The voltage difference calculations indicate that the voltage difference is independent of the ground reference point. Voltage is frequently defined with respect to ground (using a single subscript), but voltage difference is measured between the two points named by the subscripts.

2. Reference ground is the point in a circuit defined as 0 V. All other voltages in a circuit are referenced to this point.

3. −12 V

4. −70 V

5. +8.3 V

For Further Investigation:

The voltage difference calculations should be the same as the results in Tables 4-3 to 4-6.

Experiment 5: Ohm's Law

Procedure:

Table 5-2 (R_1) (0.996 kΩ)

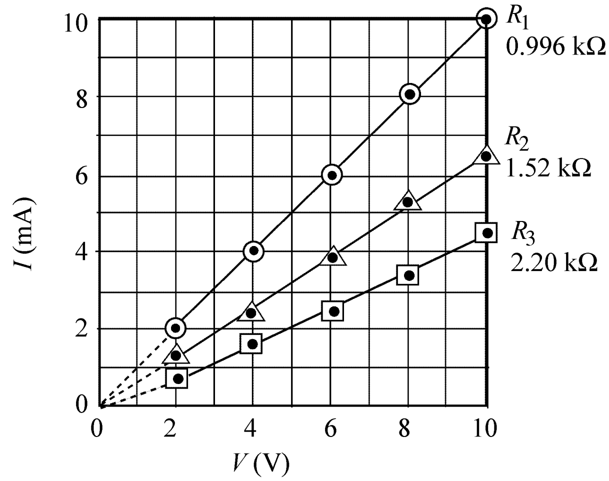
V_S =	2.0 V	4.0 V	6.0 V	8.0 V	10.0 V
I =	**2.0 mA**	**4.0 mA**	**6.0 mA**	**8.0 mA**	**10.0 mA**

Table 5-3 (R_2) (1.52 kΩ)

V_S =	2.0 V	4.0 V	6.0 V	8.0 V	10.0 V
I =	**1.3 mA**	**2.7 mA**	**4.0 mA**	**5.3 mA**	**6.7 mA**

Table 5-4 (R_3) (2.20 kΩ)

V_S =	2.0 V	4.0 V	6.0 V	8.0 V	10.0 V
I =	**0.9 mA**	**1.8 mA**	**2.7 mA**	**3.6 mA**	**4.5 mA**



Plot 5-1

Evaluation and Review Questions:

1. The slope represents the conductance of each resistor. For R_1, the slope is 1.0 mS; for R_2 the slope is 0.67 mS, for R_3 the slope is 0.45 mS.

2. The slope is lower for larger resistors.

3. a) The current is doubled.
   b) The current is doubled.

4. 2.0 kΩ

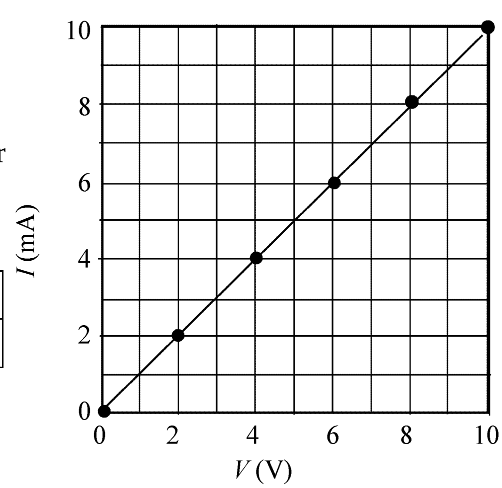
5. 0.5 A

For Further Investigation:

Measured data for a Jameco 120299 CdS cell is shown below and in plot 5-2. Room light was held constant for these measurements.

Table 5-5 (CdS Cell)

V_S =	2.0 V	4.0 V	6.0 V	8.0 V	10.0 V
I =	**1.99 mA**	**3.97 mA**	**5.96 mA**	**8.03 mA**	**10.21 mA**



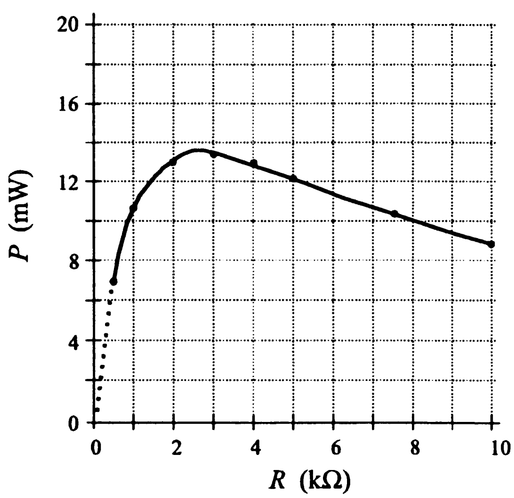
Plot 5-2

Experiment 6: Power in DC Circuits

Procedure:

Table 6-1

Variable Resistance Setting (R_2)	$I_T = \frac{V_T}{R_T}$	V_1 (measured)	V_2 (measured)	Power in R_2: P_2
0.5 kΩ	3.75 mA	**10.12 V**	**1.88 V**	**7.0 mW**
1.0 kΩ	**3.24 mA**	**8.76 V**	**3.24 V**	**10.5 mW**
2.0 kΩ	**2.55 mA**	**6.89 V**	**5.11 V**	**13.0 mW**
3.0 kΩ	**2.11 mA**	**5.68 V**	**6.32 V**	**13.3 mW**
4.0 kΩ	**1.79 mA**	**4.84 V**	**7.16 V**	**12.8 mW**
5.0 kΩ	**1.56 mA**	**4.21 V**	**7.79 V**	**12.1 mW**
7.5 kΩ	**1.17 mA**	**3.18 V**	**8.82 V**	**10.4 mW**
10.0 kΩ	**0.94 mA**	**2.55 V**	**9.45 V**	**8.9 mW**



Plot 6-1

Evaluation and Review Questions:

1. The resistance of R_2 at the peak is 2.7 kΩ (matching load). The data should support the answer that it is approximately 3 kΩ.

2. The total current was decreasing.

3. Since R_1 is a fixed resistor the current in it will decrease as the resistance of R_2 increases. The power equation $P = I^2R$ shows that the power must also go down as R_2 increases. Student may also observe that the tabulated voltage drop across R_1 is lower as the resistance of R_2 increases indicating lower power in R_1.

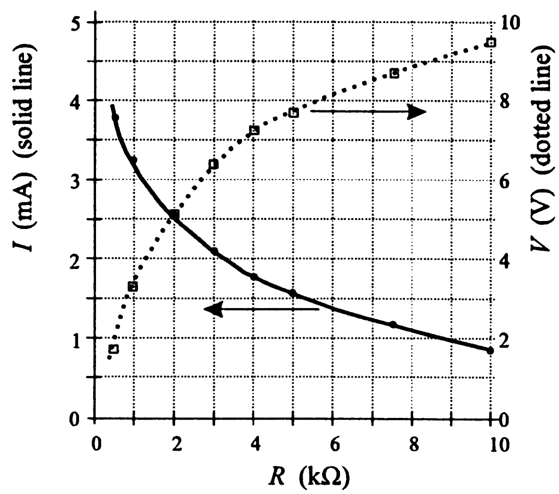
4. a) 15 mA
   b) 337.5 mW
   c) A 1/4 watt = 250 mW. A 1/4 watt resistor should not be used.

5. Size.

6. It is dissipated as heat.

For Further Investigation:

See Plot 6-2 for current and voltage plots. The solid line represents the current; the dotted line represents the voltage. The current-voltage product is the same as Plot 6-1.



Plot 6-2

Experiment 7: Series Circuits

Procedure:

Table 7-1

Component	Listed Value	Measured Value
R_1	1.0 kΩ	**996 Ω**
R_2	1.5 kΩ	**1.52 kΩ**
R_3	2.2 kΩ	**2.20 kΩ**
R_4	330 Ω	**332 Ω**
R_T =	**5.03 kΩ**	**5.05 kΩ**

Table 7-2

	Computed Value	Measured Value
I_T	**2.98 mA**	**3.0 mA**
V_{AB}	**2.98 V**	**2.96 V**
V_{BC}	**4.47 V**	**4.46 V**
V_{CD}	**6.58 V**	**6.54 V**
V_{DE}	**0.98 V**	**0.99 V**

7. –15.0 + 2.96 + 4.46 + 6.54 + 0.99 = –0.05 V √

8. Answers vary but should be similar to result from step 7.

9. –15.0 + 0 + 15.0 + 0 + 0 = 0 V √ (The +15.0 V reading is across the open).

Evaluation and Review Questions:

1. The numbers used in the summation are the same regardless of the starting point. The commutative property of mathematics applies to Kirchhoff's voltage law.

2. There was no current in the circuit of step 9; yet Kirchhoff's voltage law was found to be valid.

3. The open fuse would have 120 V across it.

4. V_X = 3 V.

5. a) 4 V
   b) 0.4 A
   c) 20 Ω

For Further Investigation:

The three currents will all be the same, approximately 1.9 mA. The same current flows throughout a series circuit.

Note: The solutions to Multisim troubleshooting problems are on page 237-240.

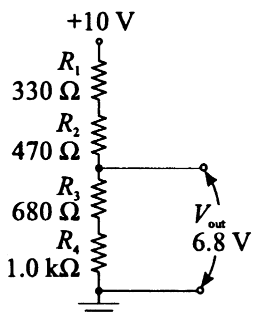
Experiment 8: The Voltage Divider

Procedure:

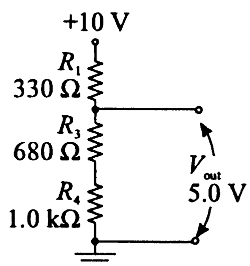
Table 8-1

Resistor	Listed Value	Measured Value	$V_X = V_S\left(\frac{R_X}{R_T}\right)$	V_X(measured)
R_1	330 Ω	**333 Ω**	**1.34 V**	**1.34 V**
R_2	470 Ω	**473 Ω**	**1.90 V**	**1.90 V**
R_3	680 Ω	**683 Ω**	**2.75 V**	**2.75 V**
R_4	1000 Ω	**998 Ω**	**4.01 V**	**4.01 V**
Total	**2478 Ω**	**2487 Ω**	10.0 V	**10.0 V**

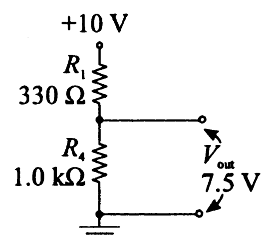
Circuit for step 5:



Circuit for step 6:



Circuit for step 8:



9. Computed: V_{min} = +2.61 V V_{max} = +8.17 V.

10. Measured: V_{min} = 2.54 V V_{max} = 8.10 V.

Evaluation and Review Questions:

1. a) Output voltage is unchanged. b) Power dissipated is a factor of ten less.

2. a) V_{out} = 0 V b) V_{out} = 10.0 V

3. The range of output voltages increases. V_{min} = 0.44 V V_{max} = 9.7 V.

4. V_A = 10 V V_B = 1.0 V V_C = 0.10 V V_D = 0.010 V

5. V_{min} 0 V V_{max} = 6.67 V.

For Further Investigation:

The student should find that a load resistance of ten times the divider resistance it is across will decrease the output voltage by less than 10%.

Experiment 9: Parallel Circuits

Procedure: Measured resistors are: $R_1 = 3.30\ \text{k}\Omega$, $R_2 = 4.71\ \text{k}\Omega$, $R_3 = 6.82\ \text{k}\Omega$, $R_4 = 9.97\ \text{k}\Omega$

Table 9-2

	R_1	$R_1 \| R_2$	$R_1\|R_2\|R_3$	$R_1\|R_2\|R_3\|R_4$
R_T (measured)	**3.30 kΩ**	**1.93 kΩ**	**1.51 kΩ**	**1.31 kΩ**
I_T (measured)				**9.15 mA**

5. The voltage across each resistor is the same as the source voltage.

Table 9-3

	$I_1 = \frac{V_S}{R_1}$	$I_2 = \frac{V_S}{R_2}$	$I_3 = \frac{V_S}{R_3}$	$I_4 = \frac{V_S}{R_4}$
I (computed)	**3.64 mA**	**2.55 mA**	**1.76 mA**	**1.20 mA**

Table 9-4

	$I_1 = \left(\frac{R_T}{R_1}\right)I_T$	$I_2 = \left(\frac{R_T}{R_2}\right)I_T$	$I_3 = \left(\frac{R_T}{R_3}\right)I_T$	$I_4 = \left(\frac{R_T}{R_4}\right)I_T$
I (computed)	**3.63 mA**	**2.54 mA**	**1.76 mA**	**1.20 mA**

8. 9.15 mA = 3.64 mA + 2.55 mA + 1.76 mA + 1.20 mA √

9. The new total current is 7.95 mA.

Evaluation and Review Questions:

1. Subtract the observed current from the original total current. The difference is the “missing” current due to an open branch. Apply Ohm’s law to find the open resistance.

2. The short is a very low resistance path causing the current to go very high. If the power supply does not have short circuit current limiting, a fuse will blow or damage will result.

3. a) Current should be 167 mA. b) The 820 Ω resistor is open.

4. I_4 is entering the junction and is equal to 25 mA.

5. The high current in the short may cause a fuse to open or could cause another open to occur.

For Further Investigation:

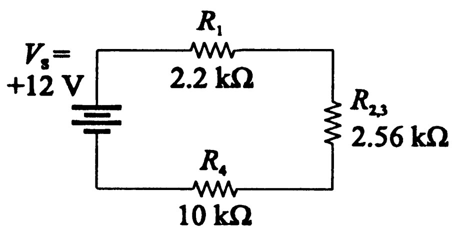
The student should be able to confirm Kirchhoff’s current law through the measurements.

Experiment 10: Series-Parallel Combination Circuits

Procedure: Measured resistors are: R_1 = 2.22 kΩ, R_2 = 4.69 kΩ, R_3 = 5.63 kΩ, R_4 = 9.96 kΩ

2. a) R_1 YES R_2 NO R_3 NO R_4 YES
   b) R_1 NO R_2 YES R_3 YES R_4 NO

3. Equivalent Circuit:



10. Equivalent circuit:

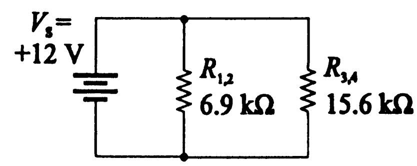


Table 10-2

	Computed		Measured
	Voltage Divider	Ohm's Law	
R_T	**14.7 kΩ**	**14.7 kΩ**	**14.7 kΩ**
I_T		**0.82 mA**	
V_1	**1.81 V**	**1.82 V**	**1.81 V**
$V_{2,3}$	**2.09 V**	**2.10 V**	**2.09 V**
V_4	**8.13 V**	**8.16 V**	**8.13 V**
I_2		**0.45 mA**	
I_3		**0.37 mA**	
V_T	12.0 V	12.0 V	**12.0 V**

Table 10-3

	Computed	Measured
$R_{1,2}$	**6.91 kΩ**	**6.90 kΩ**
$R_{3,4}$	**15.59 kΩ**	**15.6 kΩ**
R_T	**4.79 kΩ**	**4.78 kΩ**
I_T	**2.51 mA**	
$I_{1,2}$	**1.74 mA**	
$I_{3,4}$	**0.77 mA**	
V_1	**3.86 V**	**3.84 V**
V_2	**8.16 V**	**8.16 V**
V_3	**4.34 V**	**4.33 V**
V_4	**7.67 V**	**7.67 V**

Evaluation and Review Questions:

1. a) The voltage divider rule was applied to an equivalent series circuit.

   b) Yes. The voltage divider rule can be applied to any set of series resistor for which the total voltage across the resistors is known. The voltage divider rule can be applied to each series branch in Figure 10-3 independently to find the voltage drops across each resistor.

2. Answers vary. One possible path around the outside loop is:

   –12.0 V + 4.33 V + 7.67 V = 0 √

3. The currents entering and leaving the junction are equal. This can be shown as:

   2.51 mA = 1.74 mA + 0.77 mA √

4. a) The path through $R_1 - R_2$ is open.

b) Check the resistors to see if a +12 V drop is across one or the other. If not, check for a drop across the connection points.

5. +24 V.

For Further Investigation:

Student should summarize a procedure for solving the problem. The total resistance seen by the voltage source is 1.74 kΩ and the total current is 6.90 mA. The voltage and current for each resistor are as follows:

V_1 = 12.0 V I_1 = 5.45 mA
V_2 = 6.80 V I_2 = 1.45 mA
V_3 = 5.20 V I_3 = 0.93 mA
V_4 = 5.20 V I_4 = 0.52 mA

Experiment 11: The Superposition Theorem

Procedure: Measured resistors for this experiment: R_1 = 4.69 kΩ, R_2 = 6.8 kΩ, R_3 = 9.90 kΩ

Table 11-2 Computed and measured resistances.

	Quantity	Computed	Measured
Step 4	R_T (V_{S1} operating alone)	**8.74 kΩ**	**8.73 kΩ**
Step 7	R_T (V_{S2} operating alone)	**9.98 kΩ**	**10.1 kΩ**

Table 11-3 Computed and measured current and voltage.

	Computed Current*			Computed Voltage			Measured Voltage		
	I_1	I_2	I_3	V_1	V_2	V_3	V_1	V_2	V_3
Step 5	**+0.57**	**+0.34**	**+0.23**						
Step 6				**+2.67 V**	**+2.31 V**	**+2.28 V**	**+2.69 V**	**+2.32 V**	**+2.32 V**
Step 8	**–0.68**	**–1.00**	**+0.32**						
Step 9				**–3.19 V**	**–6.80 V**	**+3.18 V**	**–3.18 V**	**–6.80 V**	**+3.18 V**
Step 10 (totals)	**–0.11**	**–0.66**	**+0.55**	**–0.52 V**	**–4.49 V**	**+5.46 V**	**–0.50 V**	**–4.49 V**	**+5.49 V**

*all currents are shown in milliamps

Evaluation and Review Questions:

1. a) –5.0 V + (–0.51 V) + (–4.49 V) + 10 V = 0 √
   b) –1.09 mA = –0.66 mA + 0.55 mA √

2. The actual direction of current is the opposite of the assumed direction.

3. The sign of all results would be reversed. Since the original assumed direction of current is also reversed, the net result is that there is no effect on the circuit.

4. a) Replace all sources except one with their internal resistance.
   b) Compute the current or voltage due to the one source acting alone.
   c) Repeat steps a and b for all sources.
   d) Algebraically sum the results.

5. Current due to V_{S1} is = 54.5 mA. Current due to V_{S2} = –145.5 mA. Net current = –91 mA

For Further Investigation:

The results indicate that the superposition theorem does not apply to power.

Experiment 12: Thevenin's Theorem

Procedure:

Measured resistors: $R_1 = 274\ \Omega$, $R_2 = 556\ \Omega$, $R_3 = 680\ \Omega$, $R_{L1} = 151\ \Omega$, $R_{L2} = 471\ \Omega$, $R_{L3} = 810\ \Omega$

2. Load voltage calculation (using equivalent circuits and the voltage divider theorem):
   a) $R_{L1} + R_2 = 151\ \Omega + 556\ \Omega = 707\ \Omega$
   b) $(R_{L1} + R_2) \parallel R_3 = 707\ \Omega \parallel 680\ \Omega = 347\ \Omega$
   c) $V_{L1,2,3} = 10\text{ V}^* (347\ \Omega/594\ \Omega) = 5.62\text{ V}$
   d) $V_{L1} = 5.62\text{ V}^* (151\ \Omega/707\ \Omega) = 1.20\text{ V}$

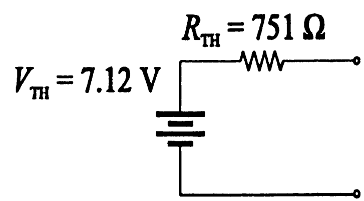
Table 12-2

	Computed	Measured
V_{L1}	**1.20 V**	**1.20 V**
V_{L2}	**2.76 V**	**2.76 V**
V_{L3}	**3.72 V**	**3.70 V**
V_{TH}	**7.13 V**	**7.12 V**
R_{TH}	**751 Ω**	**751 Ω**

Table 12-3

	Computed	Measured
V_{L1}	**1.19 V**	**1.20 V**
V_{L2}	**2.74 V**	**2.76 V**
V_{L3}	**3.69 V**	**3.71 V**
V_{TH}	**7.13 V**	**7.12 V**
R_{TH}	**751 Ω**	**751 Ω**

8. The Thevenin circuit consists of a 7.12 V source in series with a 751 Ω resistor as shown on the right (Measured results are given.)



Thevenin circuit for step 8

Evaluation and Review Questions:

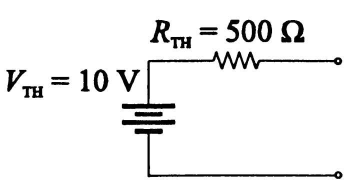
1. The original circuit and the Thevenin circuit are equivalent as seen by the load resistor.

2. The load current in a short is 9.5 mA for both circuits.

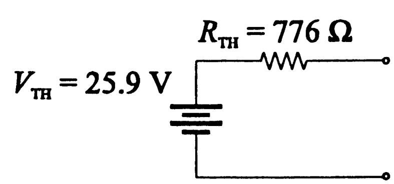
3. Calculations are simplified.

4. The voltage and resistance looking from the output are not affected by R_1, therefore it is not part of the Thevenin circuit.

5. **(a)**



(b)



For Further Investigation:

When the voltage across the load is one-half the unloaded voltage, the internal Thevenin resistance is dropping the same voltage as the load resistor is dropping. Application of the voltage divider theorem shows that the two resistances must be equal.

Experiment 13: The Wheatstone Bridge

Procedure:

Measured resistors: R_1 = 99 Ω, R_2 = 151 Ω, R_3 = 332 Ω, R_L = 475 Ω, R_4 = 970 Ω (max)

Table 13-2

	Computed	Measured
V_A	**6.0 V**	**5.98 V**
V_B	**7.52 V**	**7.50 V**
R_{TH}	**60 Ω**	**59 Ω**
R'_{TH}	**248 Ω**	**246 Ω**
V_L	**0.92 V**	**0.91 V**

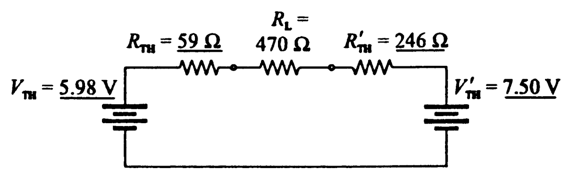


Figure 13-4 (unbalanced bridge)

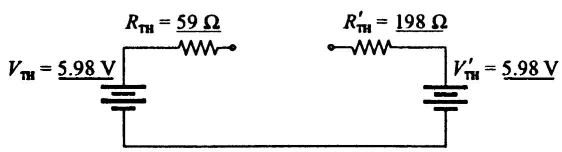


Figure 13-5 (balanced bridge)

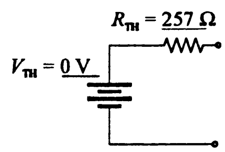


Figure 13-6 (balanced bridge)

Evaluation and Review Questions

1. Doubling the load resistance is not doubling the total resistance; therefore, the current is not halved.

2. a) Yes. See the equivalent circuit in Figure 13-4 for example.
   b) No. In a balanced bridge, there is no current in the load.

3. a) The Thevenin resistance would increase causing the total current to decrease.
   b) In a balanced bridge, there is no current in the load. Doubling all bridge resistors keeps the bridge balanced, so has no effect on the current in the load.

4. a) Load current would increase.
   b) Doubling the voltage has no effect on the balance (although is does affect the sensitivity).
   The balanced bridge will remain in balance with no load current.

5. The voltage between point **A** and **B** is zero or no current is sensed in the load.

For Further Investigation:

In 150 feet of wire, the short can be located to within about 1 foot.

Experiment 14: Magnetic Devices

Procedure:

1. Relay diagrams will vary but should show the connections to the coil and contacts, terminal numbers, and measured coil resistance (test relay measured 59 Ω).

3–6. The pull-in and release voltages depend on the specific relay. A typical small 12 V relay that was tested is given as an example:

Table 14-1

		Pull-in Voltage	Release Voltage
Steps 3 and 4	Trial 1	**7.4 V**	**3.4 V**
Step 5	Trial 2	**7.4 V**	**3.2 V**
	Trial 3	**7.5 V**	**2.9 V**
Step 6	Average	**7.43 V**	**3.17 V**

7. Red light turns on when S_1 is closed; it stays on when S_1 is open.

8. Relay "buzzes" and both red and green LEDs are rapidly switched on and off. This occurs because when power is applied through the NC contact, the relay coil energizes opening the NC contact and removing power from the coil. With power removed, the NC contact closes, and the process repeats.

Evaluation and Review Questions:

1. Answers depend on the particular relay tested. The relay tested for this experiment had a coil resistance of 59 Ω. The average pull-in current was 126 mA.

2. The tested relay had an average release current of 53.7 mA.

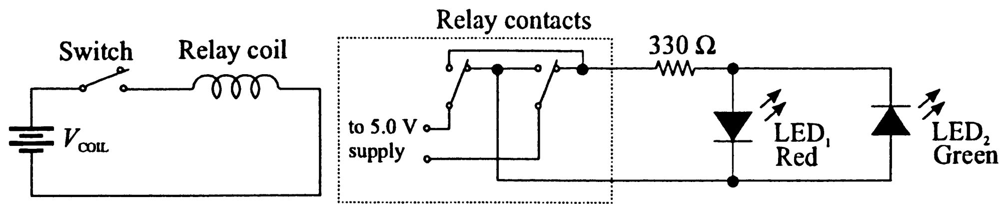
3. The hysteresis of the test relay was 7.43 V – 3.16 V = 4.27 V.

4. a) SPDT means there is one switch with two contacts.
   b) DPST means there are two switches, each with one contact.

5. a) Relay coil could be open, control voltage could be off or too low, or switch S_1 is not making contact.
   b) With switch closed, check voltage on relay coil; if it is correct, the relay is likely bad.

For Further Investigation:

The reversing circuit is shown below.



Experiment 15: The Oscilloscope

Procedure:

Table 15-1 (computed values shown)

Power Supply Setting	VOLTS/DIV Setting	Number of Divisions of Deflection	Oscilloscope (measured voltage)	DMM (measured voltage)
1.0 V	0.2 V/DIV	5.0 DIV	1.0 V	1.0 V
2.5 V	**0.5 V/DIV**	**5.0 DIV**	**2.5 V**	**2.5 V**
4.5 V	**1.0 V/DIV**	**4.5 DIV**	**4.5 V**	**4.5 V**
8.3 V	**2.0 V/DIV**	**4.15 DIV**	**8.3 V**	**8.3 V**

Table 15-2 (computed values shown)

Signal Generator Amplitude	VOLTS/DIV Setting	Number of Divisions (peak-to-peak)	Oscilloscope Measured (peak-to-peak)	Oscilloscope Measured (rms)
1.0 V_{rms}	0.5 V/DIV	5.6 DIV	2.8 V_{pp}	1.0 V_{rms}
2.2 V_{rms}	**1.0 V/DIV**	**6.2 DIV**	**6.2 V_{pp}**	**2.2 V_{rms}**
3.7 V_{rms}	**2.0 V/DIV**	**5.25 DIV**	**10.5 V_{pp}**	**3.7 V_{rms}**
4.8 V_{rms}	**2.0 V/DIV**	**6.8 DIV**	**13.6 V_{pp}**	**4.8 V_{rms}**

Evaluation and Review Questions:

1. a) Answers vary.
   b) Answers depend on the specific equipment used but generally favor the DMM. An analog oscilloscope linearity is typically 3% and has less resolution than a DMM. A digital scope depends on the resolution and accuracy of the digitizer.

2. *Vertical controls:* control the vertical axis of the oscilloscope and coupling of the input signal.
   Trigger controls: determine when the horizontal sweep occurs and the source of triggers.
   Horizontal controls: control the horizontal axis (typically the time axis) of the oscilloscope.
   Display controls: control the CRT.

3. Trigger controls.

4. a) 17.0 V_{pp} b) 6.01 V_{rms}

5. The signal is 56.6 V_{pp}. Use 10.0 volts/div control to spread the signal over 5.7 divisions.

6. When viewing two waveforms on an analog (dual trace) oscilloscope, select ALTernate to view high frequencies, CHOP for low frequencies (below about 1kHz).

For Further Investigation:

Most oscilloscopes will have a 1 kHz square wave output at a small connector labeled Probe Comp. The operator’s manual typically will show how to adjust the probe and representative waveforms of a properly compensated probe. Forgetting to check probe compensation and not initializing the control setup of an oscilloscope are the two most common operator errors.