PHYSICS 176
UNIVERSITY PHYSICS LAB II

Experiment 2 (two weeks)

Direct Current Measurement and Ohm's Law

Equipment: VOM (volt-ohm-milliammeter), digital multimeter, power supply.

Supplies: 1/2 watt carbon resistors (color coded) with nominal values 680Ω, 1kΩ, 1.5kΩ, 4.7kΩ and 10kΩ, 9 volt battery.

When the terminals of a battery or power supply are connected in a conducting circuit, a direct current of electrons flows out of the negative terminal, around the circuit, and back into the positive terminal. The current continues to flow until the circuit is opened. The magnitude of the current is limited by the resistance of the circuit.

In this experiment you will use a volt-ohm-milliammeter (VOM) and a digital multimeter to make measurements of resistance, voltage, and current. The resistance color code (posted in the laboratory) will be used to determine the nominal values of resistance.

A. Resistance Measurements

   1. Measuring Resistance with the VOM (Refer to the sketch on page 5)

          A resistance measurement with a VOM requires two steps:

   (1) Connect the red and black leads together and then use the ZERO OHMS knob to adjust the needle to 0 on the OHMS scale. The OHMS scale is at the top and is marked in a nonlinear way with numbers that increase from right to left.

   (2) Connect the leads to the resistor to be measured and read its resistance on the OHMS scale. The scale reading is multiplied by the factor indicated on the range switch: Rx1, Rx100, or Rx10,000. Whenever the OHMS scale is changed it must be "zeroed" as described above.

When the range switch is on a resistance setting, the leads are connected to a battery inside the VOM. For this reason, a resistor should be removed from any circuit that it is in before trying to measure its resistance with the VOM. When a VOM is stored it should not be left on a resistance setting because accidental shorting of the leads would drain current from the internal battery.

   2. Measuring Resistance with the Digial Multimeter (Refer to page 6).

          Resistance measurement with the digital multimeter does not require initial zeroing. The resistor is connected via leads to the "COM" and "Ω" sockets. The range switch setting indicates the maximum resistance that can be measured. If a resistance is larger than this maximum, the LED (light emitting diode) display will blink.

B. Voltage Measurements

  1. Measuring Voltage with the VOM (Refer to page 5)

       When the left-hand switch of the VOM is set on +D.C., the red lead should be connected to the +side of a voltage source to be measured and the black lead is connected to the -side of the source. The D.C. voltage scale is directly under the OHMS scale. It is a linear scale marked with three sets of numbers. Use the set of numbers that corresponds to the range setting. For example, if the range switch is set on 2.5 V use the D.C. scale numbers 0, 50, 100, 150, 200, 250.

  2. Measuring Voltage with the Digial Multimeter (Refer to page 6)

       Connect the black lead to "COM" and the red lead to the "V Ω, Hz. % Temp" socket. Set the selector switch to desired "V~" or "V--" position. Connect the probes across the source or load under measurement

  3. The Resistance of a Voltmeter

       The internal resistance of a voltmeter should be large so that it draws as little current as possible. The Simpson 260-6P has a sensitivity of 20,000 ohms per volt, which means that its internal resistance is

$$R_m = (20,000) \text{ x (voltage range)}$$

       For example, on the 50 V range its internal resistance is 1MΩ.

       The internal resistance of the digital voltmeter on all ranges is >10 MΩ.

C. Current Measurements

  1. Measuring Current with the VOM (Refer to page 5)

       When the left-hand switch of the VOM is set on +D.C., the needle deflects properly for an electron current which flows into the -side of the meter and out of the +side. Proper connection of the VOM is shown below. On the left is a picture of a circuit consisting of the meter, a resistor, and a battery; on the right is a schematic diagram of the same circuit.

       In the diagram the current I is opposite to the direction of the electron current flow. This convention for showing current direction is common in all technical disciplines.

The D.C. current scale of the VOM is the same as the D.C. voltage scale. It is directly under the OHMS scale and is marked with three sets of numbers. All of the current ranges use the scale numbers 0, 2, 4, 6, 8, 10.

2. Measuring Current with the Digital Multimeter (Refer to page 6)

Connect the black lead to "COM" and the red lead to the "mA μA" socket when the current is below 300 mA. For current measurements from 300 mA to 10 A, connect the red test lead to the "10A" socket. Set the selector switch to desired "~μA, ~mA, ~10A" or "--μA,--mA, --10A" position. Connect the probes across the source or load under measurement.

3. The Resistance of an Ammeter

The internal resistance of an ammeter is always small so that it alters the current flow as little as possible. On the 100 mA range the Simpson 260-6P has an internal resistance of about 3 ohms. On the "mA" range the digital multimeter has an internal resistance of only about 1 ohm.

Because of its small internal resistance, an ammeter should not be connected directly across a voltage source. When across a voltage source, a meter should be set on a voltage range so that its internal resistance is large. When used as an ammeter, the meter is placed in a circuit and is protected from excessive current by the resistance of the circuit.

In the circuit shown on the previous page, removal of the resistor would leave the VOM milliammeter directly across the battery. The result would be a current overload, i.e. the milliammeter would draw a large current because of its small resistance. The Simpson 260-6P is protected against current overload by relay contacts which latch open and remain open until the white reset button on the front panel is depressed.

D. The Power Supply (Refer to page 7)

The power supply has a 0 to +30 volt output (between terminals 7 and 9; see page 7) that can be varied continuously using the control knobs labeled VOLTAGE (FINE/COARSE). The power supply output is displayed on a meter (10; see page 7).

The power supply output has a current limiting control. The maximum output current is 3 A.

E. Ohm's Law

For a wide range of materials used in electrical circuits, the relationship of the potential difference (or voltage drop) V across a circuit component, the current I through the component, and the resistance R of the component is given by Ohm's law:

V = IR

That is, for a given circuit component which obeys Ohm's law, the voltage is linearly proportional to the current.

Bands A and B		Band C		Band D	
Color	Significant Figure	Color	Multiplier	Color	Resistance Tolerance (%)
Black	0	Black	1	Silver	± 10
Brown	1	Brown	10	Gold	± 5
Red	2	Red	100		
Orange	3	Orange	1.000		
Yellow	4	Yellow	10.000		
Green	5	Green	100.000		
Blue	6	Blue	1.000.000		
Purple	7	Purple	10.000.000		
Gray	8	Gray	100.000.000		
White	9	White	1.000.000.000		
		Silver	0.01		
		Gold	0.1		
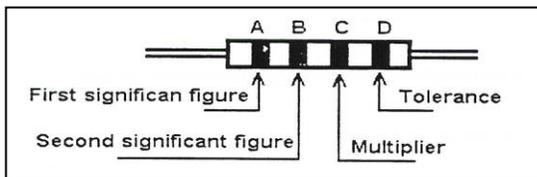
For example, if the bands on a resistor are red (A), black(B), orange (C), and silver (D), then the resistance is 20 H 1,000 = 20,000 Σ or 20 k Σ, and the tolerance is 2,000 Σ (ten percent of 20,000 Σ).
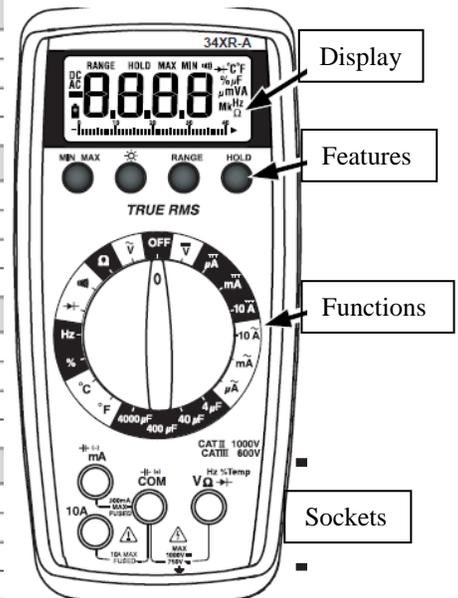
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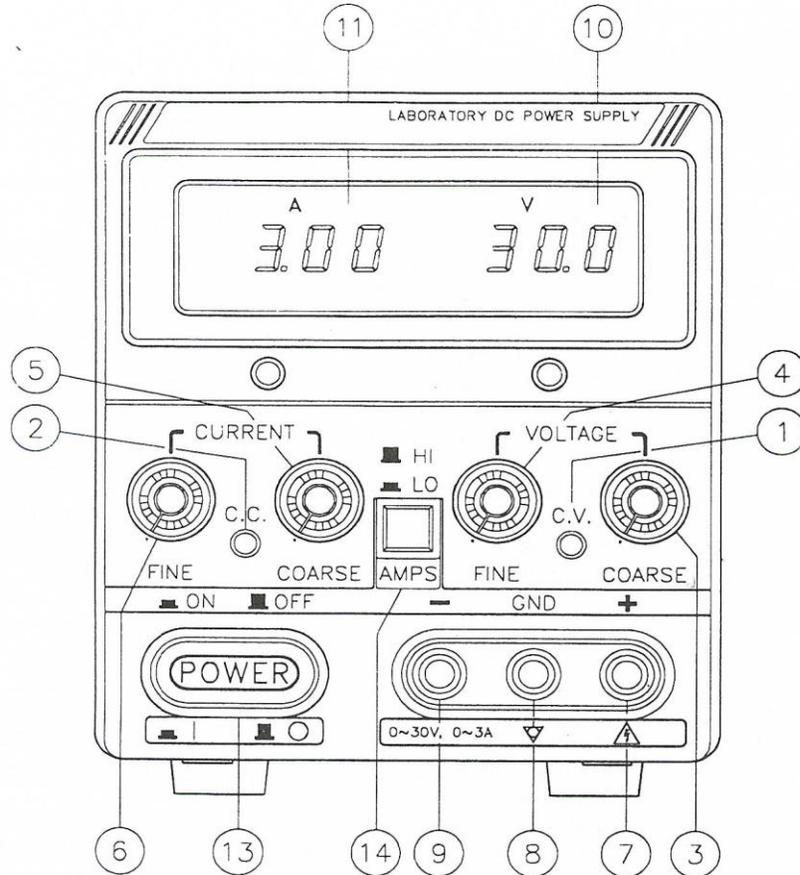Simpson 260-6P Volt-Ohm Milliammeter
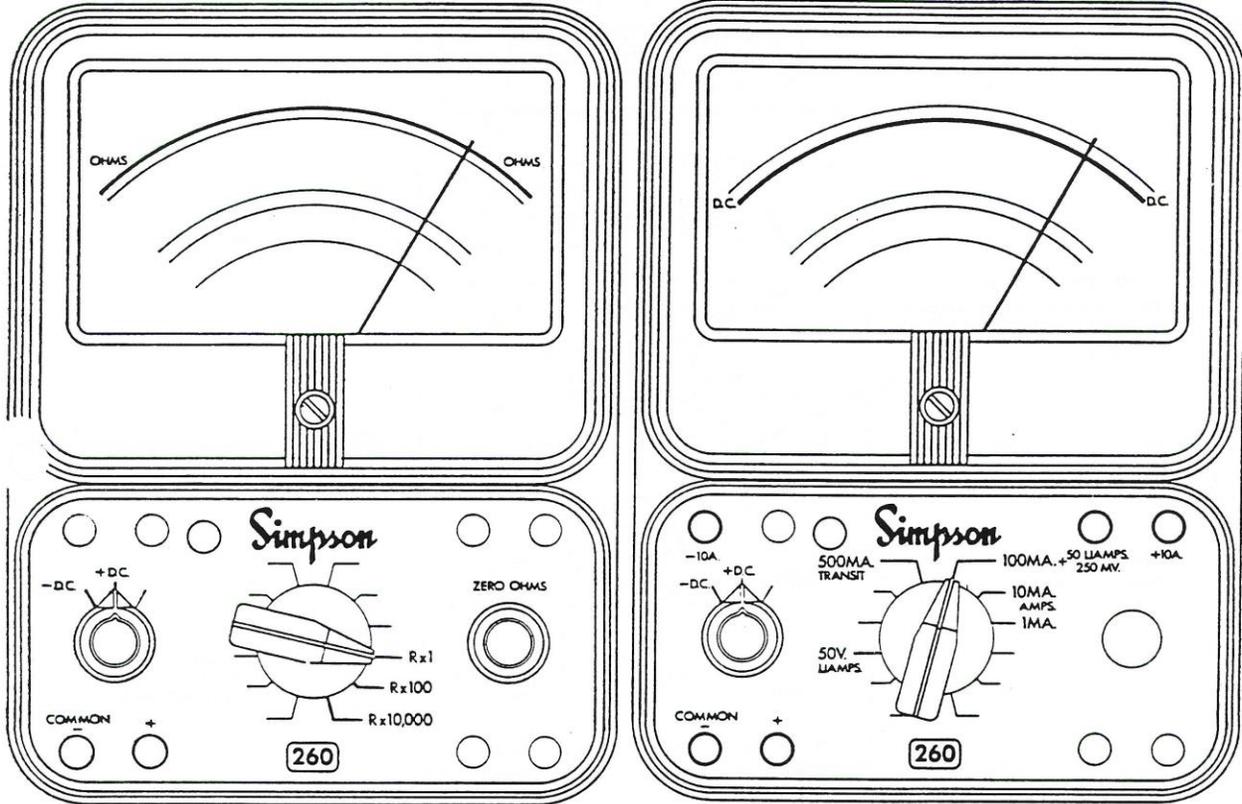
Jacks and switch positions for measuring resistance

Jacks and switch positions for measuring direct current

DC Voltage

Ranges	400 mV, 4 V, 40 V, 400 V, 1000 V
Accuracy	all ranges: ± (0.5 % rdg + 1 dgt)
Resolution	100 µV

AC Voltage (45 Hz to 2 kHz) True RMS

Ranges	400 mV, 4 V, 40 V, 400 V, 750 V
Accuracy	400 mV range, 45 to 100 Hz: ± (1.2 % rdg + 8 dgts)
	750 V range: 45 to 1 kHz: ± (2.0 % rdg + 8 dgts)
	All other ranges, 45 to 500 Hz: ± (1.2 % rdg + 8 dgts)
	All other ranges, 500 to 2 kHz: ± (2.0 % rdg + 8 dgts)
Resolution	100 µV

AC coupled True RMS specified from 5 % to 100 % of range

DC Current

Ranges	400 µA, 4 mA, 40 mA, 300 mA, 10 A
Accuracy	400 µA to 300 mA ranges: ± (1.0 % rdg + 1 dgt)
	10 A range: ± (2.0 % rdg + 3 dgts)
Resolution	0.1 µA

AC Current (45 Hz to 1 kHz) True RMS

Ranges	400 µA, 4 mA, 40 mA, 300 mA, 10 A
Accuracy	400 µA to 300 mA ranges: ± (1.5 % rdg + 8 dgts)
	10 A range: ± (2.5 % rdg + 10 dgts)
Resolution	0.1 µA

Resistance

Ranges	400 Ω, 4 kΩ, 40 kΩ, 400 kΩ, 4 MΩ, 40 MΩ,
Accuracy	400, 4 k, 40 k, 400 k, 4 MΩ ranges: ± (1.0 % rdg + 4 dgts)
	40 MΩ range: ± (2.0 % rdg + 5 dgts)
Resolution	100 mΩ

Capacitance

Ranges	4 µF, 40 µF, 400 µF, 4000 µF
Accuracy	4 µF range: ± (5.0 % rdg + 10 dgts)
	40 µF, 400 uF ranges: ± (5.0 % rdg + 5 dgts)
	4000 µF range: ± (5.0 % rdg + 15 dgts)
Resolution	1 nF

Temperature

Ranges	-20 °C to 1000 °C, -4 °F to 1832 °F
Accuracy	-20 °C to 10 °C: ± (2.0 % rdg + 4 °C)
	10 °C to 200 °C: ± (1.0 % rdg + 3 °C)
	200 °C to 1000 °C: ± (3.0 % rdg + 2 °C)
	-4 °F to 50 °F: ± (2.0 % rdg + 8 °F)
	50 °F to 400 °F: ± (1.0 % rdg + 6 °F)
	400 °F to 1832 °F: ± (3.0 % rdg + 4 °F)
Resolution	1 °C, 1 °F

Display

Features

Functions

Sockets

Tenma DS Power Supply

4-1 Front panel

①	CV indicator	lights when the power turn on and constant voltage operation.
②	CC indicator	lights when this unit in constant current operation.
③	Voltage coarse	for the coarse adjustment of the output voltage.
④	Voltage fine	for the fine adjustment of the output voltage.
⑤	Current coarse	for the coarse adjustment of the output current.
⑥	Current fine	for the fine adjustment of the output current.
⑦	"+" output terminal	positive polarity (Red).
⑧	"GND" terminal	earth and chassis ground (Green).
⑨	"−" output terminal	negative polarity (Black).
⑩	meter	Indicates the output voltage.
⑪	meter	Indicates the output current.
⑫	A/V selects switch	selects the meter indicates of the output voltage or current (Digital type).
⑬	Power control	on/off switch.
⑭	Current HI/LO control	current indicates HI/LO range SELECTS.

<div align="center">Systematic Errors</div>

The following is manufacturer supplied information concerning the accuracy of electronic instruments.

Simpson 260 VOM

DC voltage and current readings: 2% of full scale.

Resistance readings: 2% of reading.

AMPROBE Digital Multimeter – see page 6.

<div align="center">Internal Resistance</div>

The following is manufacturer supplied information concerning the internal resistance (input impedances) of electronic instruments.

Simpson 260 VOM

Voltage settings: 20,000 ohms per full scale volt.

Current settings: approximately (.25 volts)/(range setting).

AMPROBE Digital Multimeter

Voltage settings: >10 MΩ.

NOTE: This procedure assumes you have read the introduction to this lab. If you re not sure how to use a
particular instrument first go to the introduction which describes how to use all the instruments in this lab.
If you are still confused then ask your laboratory instructor for assistance.

A. <u>Resistance Measurements</u>

> HINT: The clever student will order the five resistors as follows: R_1 is the smallest value of resistance, R_2 is
> the second smallest, and so on.....

1. Use the color code posted in the laboratory or on page 4 to determine the nominal values of resistance and
tolerance for the five resistors.

2. Measure the resistance values of the five resistors with the VOM and with the digital multimeter.
Remember to zero the VOM before each resistance measurement.

> <u>Systematic Errors:</u>
>
> There will be systematic errors associated with these measurements. The information needed to
> determine systematic errors is on the previous page for VOM and on page 6 for DMM. It is provided by the
> manufacturers of the equipment.

B. <u>Voltage Measurements</u>

1. Measure the voltage across the battery with the VOM and the digital multimeter. Direct connection of a
meter to a voltage source should be done with care. Before you complete the circuit, check the following:
    a) The meter range should be large enough to accommodate the voltage.
    b) The + side of the meter should be connected to the + side of the source.
    c) Avoid inadvertent switching of the meter into a current or resistance range.

> Include with your measurement of the battery voltage the uncertainty due to systematic error.
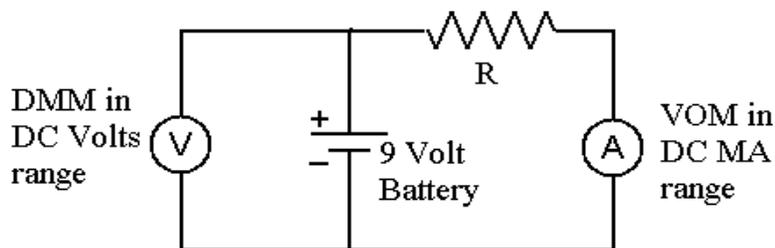
C. <u>Current Measurements</u>

1. Connect a battery, VOM, and resistor in series to form the circuit shown below. The digital voltmeter monitors the voltage across the battery and has practically no effect on the current I because of its large resistance (10 Megohms). For your five values of resistance R measure I and V.


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2.   Replace the battery with the power supply set to a voltage output equal to the battery voltage when zero current is being drawn from it (i.e. connect the digital voltmeter directly to power supply and set the power supply voltage to the value measured in Part B). Repeat the measurements of I and V for the five resistance values.

DMM in DC Volts range ⓥ   red + / black ⊤ Power Supply   R   ⓐ VOM in DC MA range
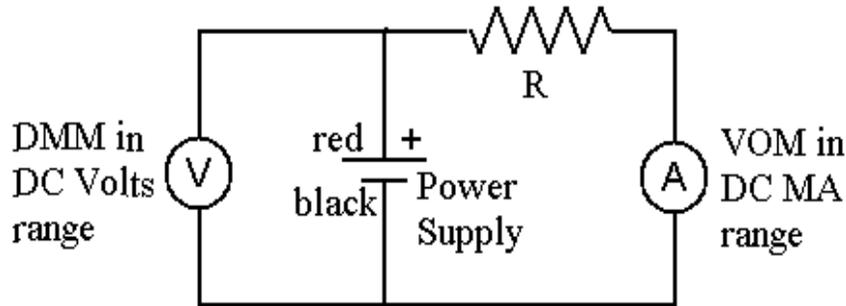
3.   Connect a battery, digital multimeter, and resistor in series to form the circuit shown below. This time the digital multimeter measures the current through the resistor. Be sure that your circuit is connected properly. The multimeter is protected against large currents only by a fuse. In this version of the circuit the VOM is used to monitor the voltage across the battery.

VOM in DC Volts range ⓥ   + / − ⊤ 9 Volt Battery   R   ⓐ DMM in DC MA range
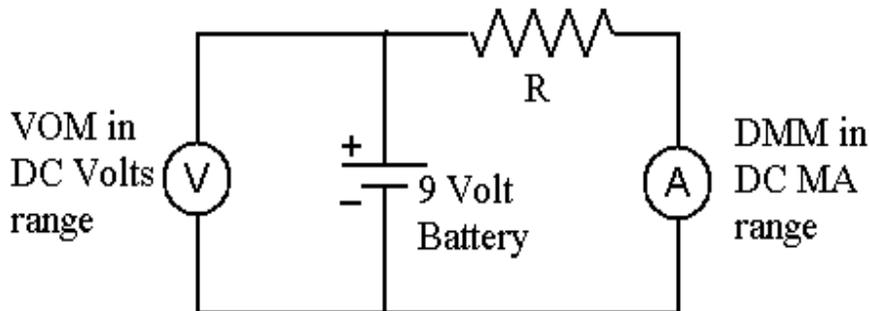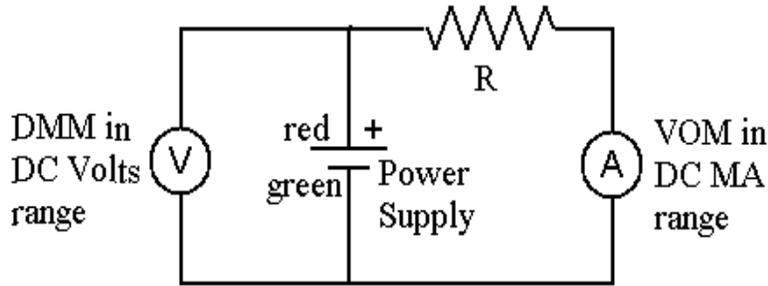
4.   Replace the battery by the power supply set to a voltage output equal to the battery voltage when zero current is being drawn from it. Again use the digital multimeter to measure I and use the VOM to measure V.

VOM in DC Volts range ⓥ   red + / black ⊤ Power Supply   R   ⓐ DMM in DC MA range
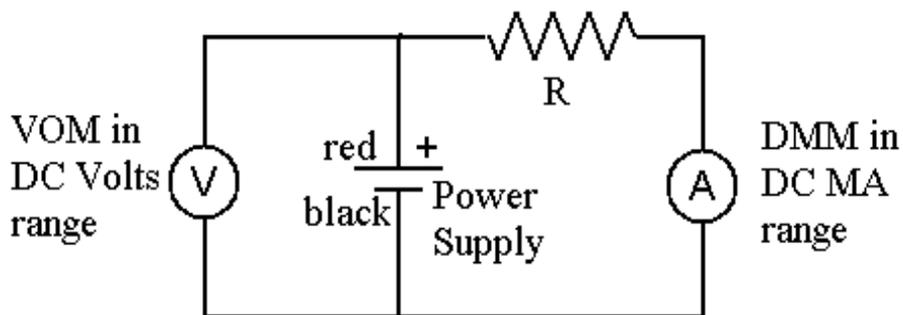
D. Ohm's Law

1. Connect your multimeter (used here as a voltmeter), VOM (used here as an ammeter), power supply, and the largest of your five resistors as shown below. Use the "VOLTAGE COARSE/FINE" control to vary the power supply voltage and measure V as a function of specified values of I for both positive and negative currents up to 1.5 mA. To obtain the negative values of current simply reverse the leads attached to the power supply.

2. Using graph paper, plot V as a function of I. Put the origin of the coordinates in the center of the paper so as to be able to graph both positive and negative quantities equally well.

Your plot should be a straight line, and the slope of this line should be equal to the resistance R. On your graph calculate R from the slope of the line. Compare this to the measurement of R using the digital ohmmeter. Are the results consistent? If not, explain.

Drawing Graphs

When preparing to draw a graph the first thing to do is pick a scale to use on your graph paper. Unless you are merely making a rough graph to visualize the trend of data, the scales should be picked so that the graph fills between a half and a whole sheet of paper. A graph that is too small is useless. The ranges on your scales should span the range of your data and need not include zero unless there is some reason to do so. Always pick a decimal based scale so that you will be able to read it when you plot points. For example, scales in which one division on your paper is equal to 1, 2, or 5 units are reasonable. Avoid all other choices.

Label each axis with the name of the quantity to be plotted and the units which are to be used, including possible powers of 10. Mark the values of enough of the major divisions along each axis so you can find your way. It is not necessary to mark each major division. Doing so makes the graph harder to read.

Plot each data point carefully using the full readable precision of your scales. Locate the point with a small dot using a sharp pencil. Always plot with a pencil so that you can correct errors without making a mess. Since each point is very small and hard to see, draw a circle around it so that the eye can pick it up easily. On a full page graph the circles should be from 1/8 to 1/4 inch in diameter.

Measuring the Slope and Intercept

If the graph is a straight line it can be further analyzed. The formula for a straight line is

$$y = mx + b,$$

where m and b are parameters called the slope and intercept. When your data seems to fit a straight line, estimates of the values of m and b can be obtained from the graph. Draw the best, single straight line that comes closest to each of your data points. You may ignore a point that is obviously way out of line. Of course, you have already checked to be sure you didn't make a plotting or computational error. How many such points you can ignore and how far away from the best line they must be to safely do so are matters of judgment. But be conservative and ignore only extreme examples.

The slope of your best line is given by

$$m = \Delta y / \Delta x$$

where)y and)x refer now to differences in the coordinates of two points <u>on the line, not data points</u>. In general, your line will not pass exactly through any data points. <u>Both)y and)x must be read directly from the graph</u>. Pick two points on the line at major divisions along the x-axis and towards either end of the line. Mark the points with a vertical arrow. Read the y coordinates of each, compute the differences, and then that ratio m =)y/)x. Remember to include the units of y and x in the slope.

Data Sheet - Experiment 1

Name

Section #

A. Resistance Measurements

    1. Nominal values of resistance and tolerance.

Resistor	Stripe Colors	Nominal Resistance (Ohms)	Tolerance (Ohms)
R_1			
R_2			
R_3			
R_4			
R_5			

    2. Measured values of resistance and uncertainty.

Resistor	VOM Resistance Measurement (Ohms)		Systematic $*R$ (Ohms)
R_1			
R_2			
R_3			
R_4			
R_5			

Resistor	Digital Resistance Measurement (Ohms)		Systematic $*R$ (Ohms)
R_1			
R_2			
R_3			
R_4			
R_5			

Question: Do the two instruments give the same values of resistance within the limits of uncertainty? If not, can any differences be explained by resolution limitations of the meters? If measurement inconsistencies cannot be explained by either resolution or systematic errors, what can you conclude about the manufacturers' claimed accuracy of their instruments?

Data Sheet - Experiment 1

B. Voltage Measurements

Instrument	Measured Voltage (Volts)	Range	Systematic *V (Volts)
VOM			
Digital Meter		-----------	

C. Current Measurements

1. Battery and resistor in series.

Resistor (digital values)	I (mA) measured with the VOM	V (Volts) measured with the digital meter	V (volts) computed using $V = IR$
$R_1 =$			
$R_2 =$			
$R_3 =$			
$R_4 =$			
$R_5 =$			

2. Power supply and resistor in series.

   (Remember, set the voltage of the power supply to the same value as the battery from part B.)

Resistor (digital values)	I (mA) measured with the VOM	V (Volts) measured with the digital meter	V (volts) computed using $V = IR$
$R_1 =$			
$R_2 =$			
$R_3 =$			
$R_4 =$			
$R_5 =$			

3. Battery and resistor in series.

Resistor (digital values)	I (mA) measured with the digital meter	V (Volts) measured with the VOM	V (volts) computed using $V = IR$
$R_1 =$			
$R_2 =$			
$R_3 =$			
$R_4 =$			
$R_5 =$			

4. Power supply and resistor in series.

(Remember, the power supply voltage is supposed to be set to the same value as the battery above.)

Resistor (digital values)	I (mA) measured with the digital meter	V (Volts) measured with the VOM	V (volts) computed using $V = IR$
$R_1 =$			
$R_2 =$			
$R_3 =$			
$R_4 =$			
$R_5 =$			

Data Sheet - Experiment 1

D. Ohm's Law

   1. Voltage as a function of current.

I (mA)	V (Volts)
1.50	
1.25	
1.00	
0.75	
0.50	
0.25	
0	
-0.25	
-0.50	
-0.75	
-1.00	
-1.25	
-1.50	

   2. Plot of voltage as a function of current.

   Resistance determined from the slope of the line = _____ kΩ

   Resistance determined with the digital ohmmeter = _____ kΩ

   Are the two values consistent? If not, please check your results.

   Do not forget to attach your graph.

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