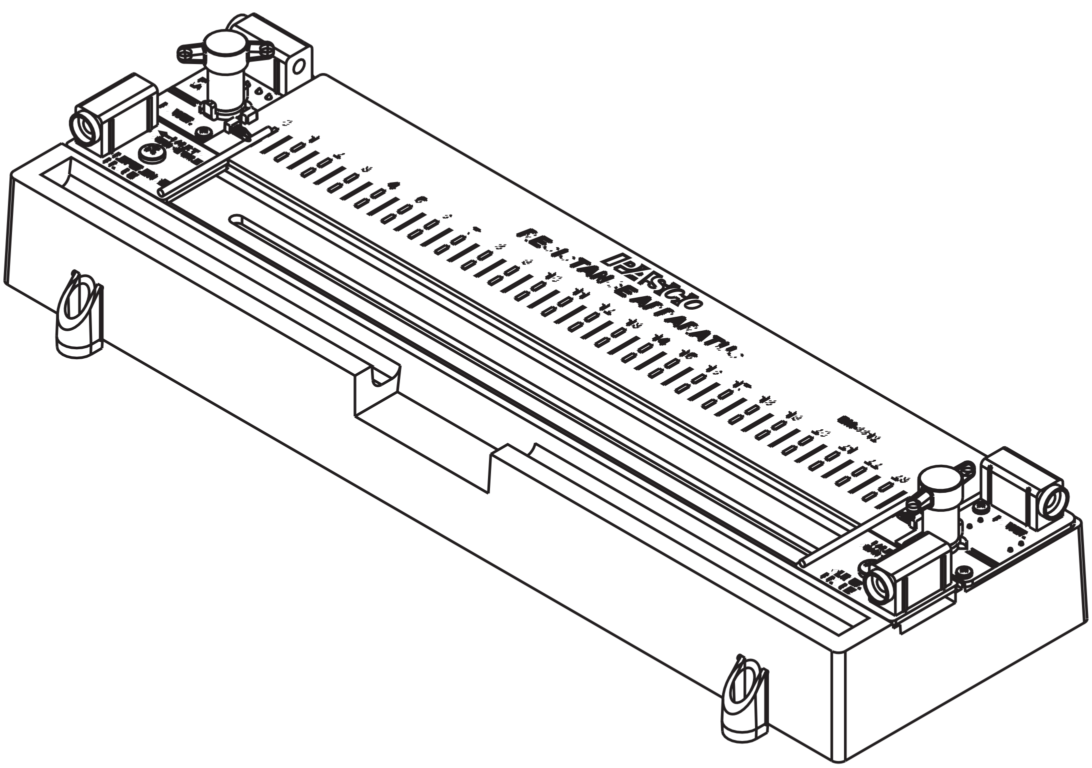
Instruction Manual with
Experiment Guide and
Teachers' Notes
012-09573A

Resistance Apparatus

EM-8812



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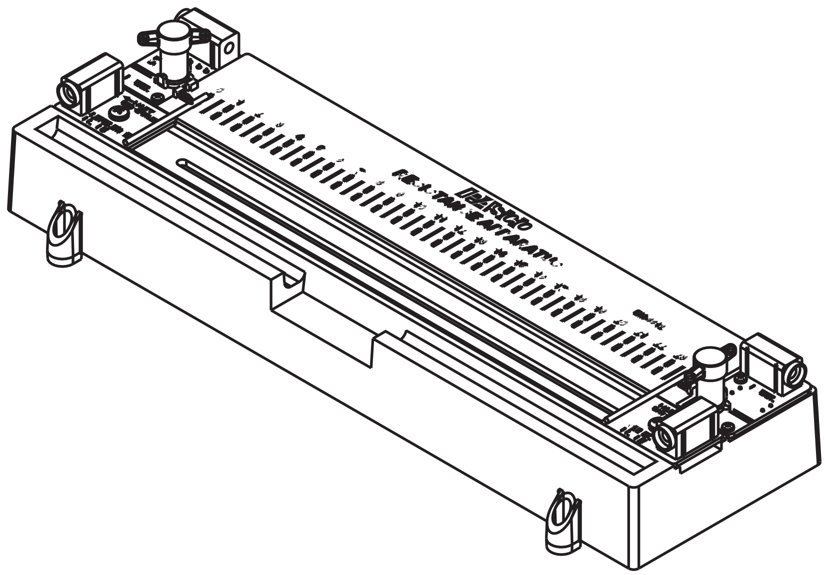


Included Equipment	**Part Number**
Resistance Apparatus	EM-8812
Two sets of wire (8 wires per set) in storage tube	EM-8813
Fuses (one installed and one spare), 2 A mini-blade	530-045
Other Equipment Recommended	
Voltage measurement:	
Galvanometer Sensor[1]	PS-2160
or Multimeter	SE-9786A *or similar*
Current measurement:	
Galvanometer Sensor[1, 2]	PS-2160
or Multimeter	SE-9786A *or similar*
or current meter of power supply	
Power Supply (capable of at least 1 A)	PI-9877 *or* SE-9720A
Patch Cords (4mm banana plug)	SE-7123

[1]Sensor requires a PASPORT interface such as Xplorer GLX (PS-2002).
[2]Two Galvanometer sensors can be used simultaneously to measure voltage and current. Second sensor requires a multi-port interface or two single-port interfaces.

Introduction

In the Resistance Apparatus, a current is established in a wire of known diameter, and the voltage drop across a section of the wire is measured. Students can calculate the resistance of the wire and the resistivity of the material.

Wires

The set of wires included with the apparatus contains two of each sample. Place one of each sample in the storage trough on the apparatus for immediate use and set the others aside as spares to replace lost or damaged wires. Order part EM-8813 for a new set of replacements with two of each wire.

The set includes wires of five different materials with the same diameter, and four different diameters of the same material (brass). Refer to the table to identify the wires.

Material	Color	Attracted to magnet?	Approximate Resistivity[1] ($\mu\Omega \cdot$cm)	Diameter(s) (inches)	Maximum[2] Constant Current (A)
Copper	Red	No	1.8 ± 0.1	0.040	2
Aluminum	Light gray	No	4.9 ± 0.1	0.040	2
Brass	Yellow	No	7.0 ± 0.5	0.020, 0.032, 0.040, and 0.050	2
Nichrome	Dark gray	No	105 ± 5	0.040	0.5
Stainless Steel	Dark gray	Yes	79 ± 1	0.040	1

[1] *All samples are alloys. The actual resistivity of a sample depends on its composition.*
[2] *Excess constant current will cause wires to heat up, changing their resistivities. Current up to 2 A can be applied briefly to all wires.*

Voltage Measurement

Measure the voltage drop along the wire with a model PS-2160 Galvanometer Sensor or a multimeter with a resolution of 0.1 mV or better. The maximum voltage measured will be less than 1 V.

Current Supply and Measurement

Current is established in the wire by an external power supply. Select a power supply capable of at least 1 A at 1 V. The apparatus contains a 2 A fuse to protect against excessive current (see page 6 for fuse replacement instructions). If you are using a current-regulated power supply capable of more than 2 A (such as model SE-9720A), set the current regulation to 2 A before connecting it to the apparatus. The apparatus contains a series resistance of 0.5 Ω, which makes it easier to tune the current through the wire by changing the applied voltage.

To measure current you can use a model PS-2115 V/I Sensor or a multimeter. If you are using a power supply with an accurate built-in current meter (such as model PI-9877), a separate meter is not necessary.

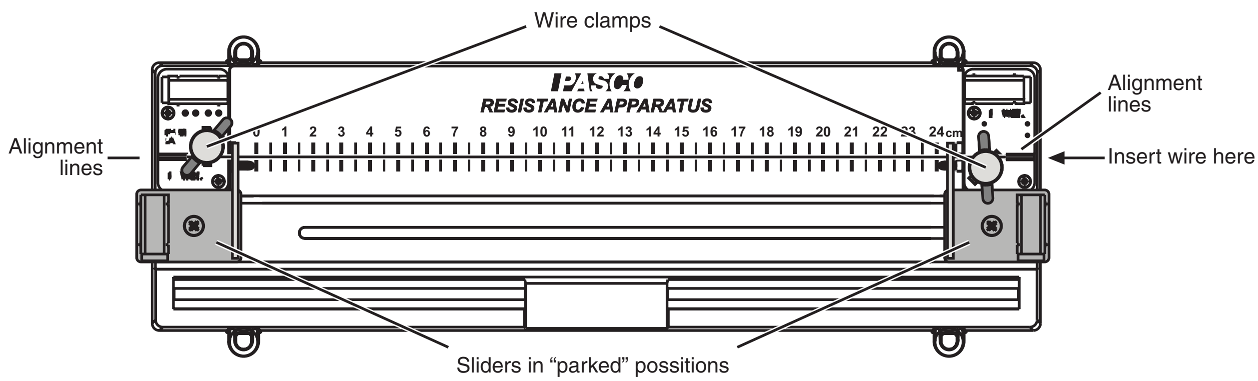
Four-wire Measurement

In the apparatus, the resistance of a length of wire is determined by applying a known current and measuring the voltage. This technique is known as a four-wire measurement. (The “four wires” are the two leads through which current is applied and the two leads of the voltmeter.) The voltage is measured only across the part of the wire under test (excluding the power supply leads), and virtually no current flows through the voltmeter leads (so there is no voltage drop in them). This technique allows a very small resistance to be measured even if the resistances of the four measurement wires are much higher, unknown, or variable.

Apparatus Setup

Wire Installation

1. Move the reference and slider probes to the extreme left and right positions so they are parked on the ramps that will hold them out off the wire.



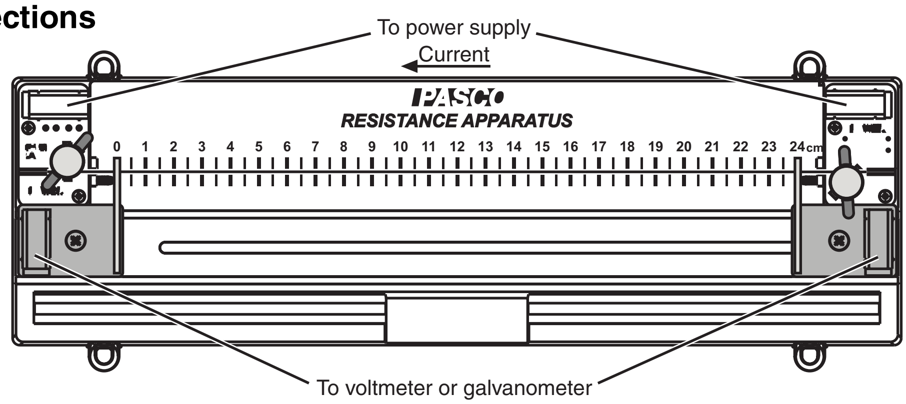
2. Loosen the wire clamps.

3. Insert the wire through the clamps and under the probes, as shown in the diagram. Observe the alignment lines marked near the wire clamps and note that the wire goes through the *front* of the left-hand clamp and through the *back* of the right-hand clamp. (This configuration causes the wire to be pulled tight when the clamps are closed.)

4. Tighten both clamps enough to secure the wire in place.

5. To remove the wire, park the probes and loosen the clamps.

External Device Connections

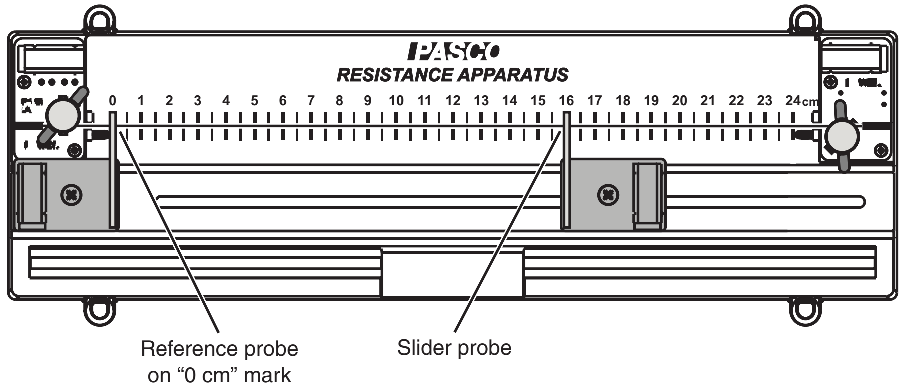


1. **Power Supply:** Set the voltage of the power supply to zero. Connect it to the power jacks of the apparatus (see diagram) so that the current will flow from right to left through the wire.

2. **Current Measurement:** If you plan to use a current sensor or meter, connect it in series with the apparatus.

3. **Voltage Measurement:** Connect Galvanometer Sensor or voltmeter to the jacks on the reference probe (-) and slider probe (+).

Measurement Procedure



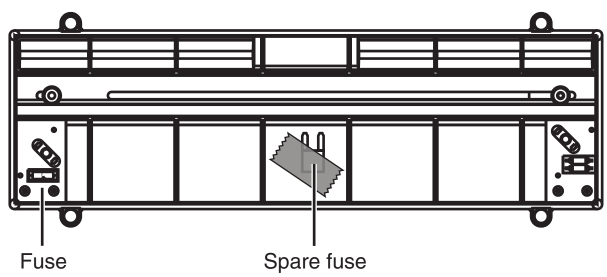
1. Turn on the power supply and adjust the applied voltage to established the desired current (I) through the wire.
2. Place the reference probe on the “0 cm” mark.
3. Move the slider probe to any point on the wire. Read the length (ℓ) in centimeters from the scale on the apparatus. This is the length of wire over which the voltage is measured.
4. Read the voltage (V).

In a typical experiment, you would make several measurements of V while varying one other parameter (such as I, ℓ, the wire diameter, or the wire material).

Fuse

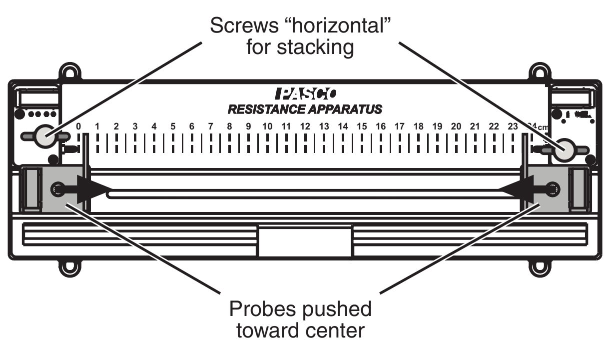
If current greater than 2 A is applied to the apparatus, the fuse will open and require replacement. The fuse is located on the underside of the apparatus. To remove it, pull it straight out. The apparatus includes a spare fuse taped to the underside.

The fuse is an 2 A mini-blade fuse, which can be purchased at automotive supply stores.

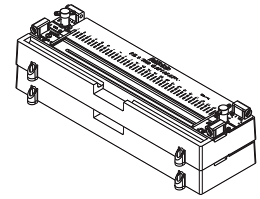


Stacking

To stack two or more apparatuses for storage, turn the clamp screws to be “horizontal” (as illustrated). Push the reference probe to the right as far as it will go (a little to the right of the “0 cm” mark) and push the slider probe to anywhere left of the “24 cm” mark.



About the Experiments



The experiments in the manual represent three examples of how the apparatus can be used, ranging from a simple exploratory lab (Experiment 1) to more advanced (Experiment 3). Teachers’ notes and sample data for all three experiments appear on page 15–17.

Experiments 2 and 3 refer to specific power supplies, sensors, and software; however variations of these experiments can be done with equipment available in most physics teaching labs.

Experiment 1: Exploratory Study of Resistance

Equipment Required	Part Number
Resistance Apparatus with wire set	EM-8812
Power Supply	PI-9877 *or similar*
Patch Cords (4mm banana plug)	SE-7123
Galvanometer Sensor or voltmeter (to measure voltage)	PS-2160, SE-9786A *or similar*
Current Meter (may be built into the power supply)	SE-9786A *or* similar
Micrometer (optional)	SE-7337

Theory

Ohm's Law describes the relationship between the resistance (R) of a wire, the voltage drop across it (V), and current through it (I):

(eq. 1-1)
$$R = V/I$$

In this experiment, you will apply a known current and measure V to determine R for wires of various lengths, diameters, and materials.

Setup

1. Select the next-to-smallest brass wire (about 0.081 cm diameter). If you have a micrometer, measure the diameter precisely.
2. Install the wire in the apparatus (see "Wire Installation" on page 5).
3. Connect the galvanometer sensor or voltmeter to the reference (-) and slider (+) probes of the apparatus.
4. Position the reference probe at the 0 cm mark and the slider probe at the 24 cm mark.
5. Connect the power supply to the power jacks of the apparatus so that current will flow from right to left through the wire.
6. If you are using a separate current meter, connect it in series with the power supply and apparatus.
7. Turn up the power supply's voltage until the current is about 1 A.

Part A: Resistance Versus Length

1. Measure V and I. Use Equation 1-1 to calculate R.
2. In a table, record R and ℓ, the length of the wire (or the distance between the probes).
3. Repeat steps 1 and 2 for ℓ equal to 20, 16, 12, 8, and 4 cm.

Make a graph of R versus ℓ. Is the relationship linear? Does the best-fit line pass (approximately) through the origin? What does this tell you about the relationship between R and ℓ?

Part B: Resistance Versus Diameter

Repeat step 1 above for the other diameters* of brass wires with ℓ = 24 cm.

*If you have a micrometer, measure the diameters; otherwise, use these values:
0.13 cm
0.10 cm
0.081 cm
0.051 cm

Make a graph of R versus diameter (D). Is the relationship linear? Try an inverse curve fit. Try and inverse-square curve fit. Which fits better? What does this tell you about how R is related to D?

Part C: Resistivity of Brass

The resistance of any wire is given by:

(eq. 1-2)

$$R = \frac{\rho\ell}{A}$$

where A is the cross-sectional area of the wire, and ρ is the resistivity of the material. Resistance depends on ℓ and A, but ρ is a function of the material only.

Calculate A for each brass wire. Use Equation 1-2 and the values of R and ℓ from Part B to calculate ρ for each brass wire. Do you get *about* the same value for each? What is the uncertainty of the calculated values? Compare your results to the accepted value.

Part D: Resistivity of Other Metals

Test the copper, aluminum, nichrome, and stainless steel wires. For each wire, measure D, ℓ, V and I. Calculate R, A, and ρ. Compare your values of resistivity to the accepted values.

Experiment 2: Resistance versus Length

Equipment Required	Part Number
Resistance Apparatus with wire set	EM-8812
DC Power Supply	PI-9877
Patch Cords (4mm banana plug)	SE-7123
Two Galvanometer Sensors	PS-2160
Resistor, 0.1 Ω, 3 W (included with Galvanometer)	
BNC-to-banana jack adapter (included with Galvanometer)	
PASPORT Interface (or interfaces)	See PASCO catalog
Micrometer (optional)	SE-7337

Theory

If a current (I) is flowing through a wire, the voltage drop (V) across a certain length of wire with resistance R is given by Ohm's Law:

(eq. 2-1) $$V = IR$$

On a graph of V versus I, the slope is equal to R. In this experiment, you will plot V versus I to measure R for various lengths of wire. You will then make a graph of R versus length (ℓ).

The resistance of a wire depends on ℓ, the cross-sectional area (A), and the resistivity (ρ) of the material:

(eq. 2-2) $$R = \rho\frac{\ell}{A}$$

Thus the slope of the R versus ℓ graph is equal to ρ/A.

Setup

1. Measure* diameter of the four brass wires and calculate their cross sectional areas.
2. Install the largest brass wire in the apparatus (see “Wire Installation” on page 5).
3. Position the reference probe at the 0 cm mark and the slider probe at the 24 cm mark.
4. Connect the power supply to the power jacks of the apparatus so that current will flow from right to left through the wire.
5. Connect both galvanometers to your PASPORT interface (or interfaces). If you are using a computer, connect the interfaces to it and start DataStudio.
6. Set up one of the galvanometers to measure voltage (V): Connect it to the reference (-) and slider (+) probes of the apparatus.

*If you do not have a micrometer, use these values of diameter:
0.13 cm
0.10 cm
0.081 cm
0.051 cm

7. Set up the other galvanometer to measure current (*I*):

a. Use the BNC-to-banana jack adapter to connect the 0.1 Ω resistor across the terminals of the galvanometer.

b. Press the tare button on the galvanometer.

c. Insert the resistor into the circuit *in series* with the power supply and apparatus.

d. Turn the power supply's function knob to Constant DC ( ).

e. On the power supply, press to display current. Turn the Fine knob slowly to set the current to about 1 A. Note the exact current on the display.

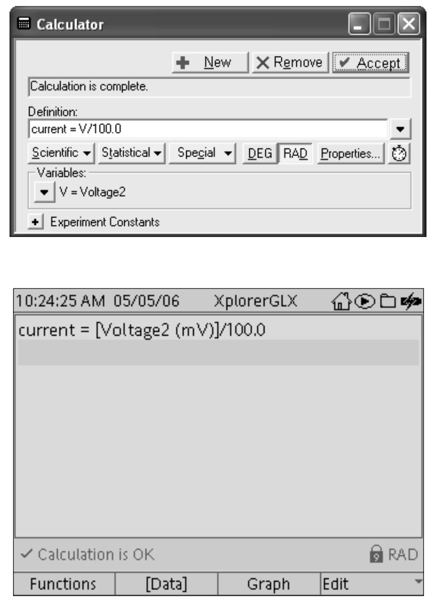
f. Collect a few seconds' worth of test data. Note the average voltage measured by the galvanometer (make sure you are looking at the current-sensing galvanometer, it should read about 100 mV).

g. Use the current (displayed on the power supply), the voltage (measured by the galvanometer), and Ohm's law to calculate the resistance of the resistor (it will be close to 100 mΩ).

h. Enter this calculation in the DataStudio or GLX calculator:

current = voltage/100.0

with your calculated resistance (in mΩ) in place of the "100.0". Define "voltage" as the voltage (in mV) measured by the galvanometer (again, make sure it is the current-sensing galvanometer). In this way, current is measured in amps.



Current calculation in DataStudio (top) and on the GLX (bottom)

8. Program the power supply for a 0 to 1 A ramp:

a. Turn the power supply's function knob to Constant DC ( ).

b. Press to display current (if it is not already displayed). Turn the Fine knob slowly to set the current to about 1 A.

c. Press again to display voltage and note this voltage.

d. Turn the function knob to Ramp ( ). Turn the Coarse and Fine knobs to set the height of the ramp (shown on the display) to the voltage that you noted in step *c*.

Note that the voltage measured by the galvanometer (*V*) is the voltage between the reference and slider probes, not the voltage output of the power supply. Also, the length (ℓ) is the distance between the probes, not the end-to-end length of the wire.

How to Measure Resistance

In this experiment, you will make several resistance measurements for various lengths and diameters of wire. Use this method to measure *R*:

Note: These instructions assume that you have set up the galvanometers and power supply as detailed above.

1. Set the reference and slider probes for the desired value of ℓ.
2. On the power supply, press ⇧ to start the applied voltage ramp. *At the same time*, click **Start** in DataStudio (or press ▶ on the GLX) to start data collection.
3. Watch the voltage reading on the power supply. Just *before* it reaches its maximum value (which you set in setup step 8), click **Stop** in DataStudio (or press ▶ on the GLX) to stop data collection.
4. On the power supply, press *and hold* ⇧ to turn off the applied voltage ramp.
5. In DataStudio (or on the GLX), open a Graph display. For the vertical axis, select **Voltage** in units of mV. (Make sure that this is the voltage measured by the galvanometer connected to the reference and slider probes, not the current-sensing galvanometer.) For the horizontal axis, select **current** (the calculation you defined in setup step 7).
6. Apply a linear fit to the *V* versus *I* data. The slope equals *R* measured in mΩ.

To make another measurement of *R* (for a different length or a different wire, for instance), repeat the steps above. However, you do not need to repeat step 5 because the new data will appear on the graph that you set up previously.

Procedure

1. With largest brass wire, measure the resistance for lengths of 24 cm, 20 cm, 16 cm, 12 cm, 8 cm, and 4 cm. (See “How to Measure Resistance” above.)
2. Make a graph of *R* versus ℓ.
3. Apply a linear fit to the graph.
4. Use the slope of the line, the cross-sectional area of the wire, and Equation 2-2 to calculate ρ.
5. Repeat steps 1 through 4 for the other three diameters of brass wire.

Questions

How do the values of ρ for the four brass wires compare to each other? How does your average value of ρ compare to the accepted value?

Further Study

Repeat the procedure to find the resistivities of the copper, aluminum, nichrome, and stainless steel wires.

Experiment 3: Voltage versus Length

Equipment Required	Part Number
Resistance Apparatus with wire set	EM-8812
Current-regulated Power Supply	SE-9720A
Patch Cords (4mm banana plug)	SE-7123
Galvanometer Sensor	PS-2160
PASPORT Interface	See PASCO catalog
Multimeter (to measure current)	SE-9786A
Micrometer (optional)	SE-7337

Theory

The resistance (R) of a wire depends on its dimensions and the resistivity (ρ) of the material. For a wire of cross-section area (A) and length (ℓ),

(eq. 3-1)
$$R = \rho\frac{\ell}{A}$$

If a current (I) is flowing through the wire, the voltage drop (across the measured length) is given by Ohm's law:

(eq. 3-2)
$$V = IR$$

Combining these two equations yields

(eq. 3-3)
$$V = \frac{\rho I}{A}\ell$$

Thus, the slope of a V versus ℓ graph is $\rho I/A$.

Setup

1. Measure* diameter of the four brass wires and calculate their cross sectional areas.

2. Install the smallest brass wire in the apparatus (see "Wire Installation" on page 5).

3. Position the reference probe at the 0 cm mark and the slider probe at the 24 cm mark.

4. Connect the power supply to the power jacks of the apparatus so that current will flow from right to left through the wire. Put the multimeter in series with the power supply to measure the current. Adjust the regulated current to about 1 A. (The current-regulated power supply ensures that the current will remain constant.)

5. Connect the galvanometer to the reference (-) and slider (+) probes of the apparatus.

6. Connect the galvanometer to your PASPORT interface. If you are using a computer, start DataStudio.

*If you do not have a micrometer, use these values of diameter:
0.13 cm
0.10 cm
0.081 cm
0.051 cm

7. Set up DataStudio (or the GLX) in Manual Sampling mode to graph V (measured by the galvanometer) versus ℓ (entered manually). See "Appendix: Manual Sampling Mode" below for detailed instructions.

Note that the voltage measured by the galvanometer (V) is the voltage between the reference and slider probes, not the voltage output of the power supply. Also, the length (ℓ) is the distance between the probes, not the end-to-end length of the wire.

Procedure

1. Note the current. Check it occasionally to ensure that it stays constant.
2. Click **Start** in DataStudio (or press or press ▶ on the GLX) to start data monitoring.
3. Set the probes for the desired value of ℓ (24 cm for the first point).
4. Click **Keep** in DataStudio (or press or press ⚐ on the GLX) to record a data point.
5. When prompted, manually enter the value of ℓ.
6. Repeat steps 3 through 5 for lengths of 20 cm, 16 cm, 12 cm, 8 cm, and 4 cm.
7. When you have finished collecting data, click **Stop** (■) in DataStudio (or press or press ▶ on the GLX).
8. Apply a linear fit to the V versus ℓ graph.
9. Use the slope of the line, the cross-sectional area of the wire, the current, and Equation 3-3 to calculate ρ.
10. Repeat this procedure for the other diameters of brass wire. It is not necessary for the current to be the same for each wire. Higher current (up to, but not over, 2 A) will give you better data, especially for the largest diameter.

Questions

How do the values of ρ for the four wires compare to each other? How does your average value of ρ compare to the accepted value?

Further Study

Repeat the procedure with the copper, aluminum, nichrome, and stainless steel wires to find their resistivities. Do not use a current over 1 A for the stainless steel wire, or over 0.5 A for the nichrome wire. Higher current in these wires will cause them to heat up, which will change their resistivities.

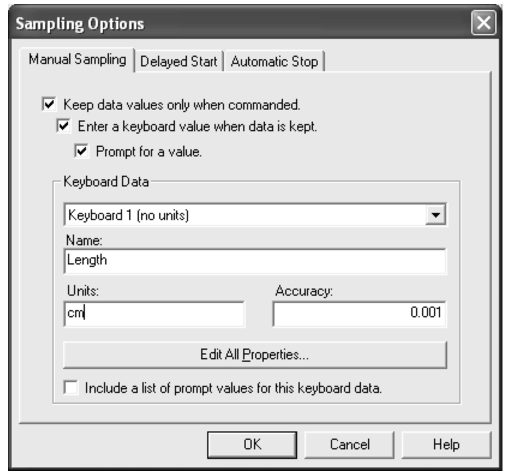
Appendix: Manual Sampling Mode

This experiment calls for manual sampling mode, in which the software or interface records a single voltage value when commanded by the user and prompts the user to type in the corresponding length measurement. After connecting the galvanometer to the interface, follow the instructions below to put DataStudio software or the Xplorer GLX (used without a computer) into manual sampling mode and setup a voltage versus length graph.

DataStudio

1. Click the **Setup** button (near the top of the screen) to open the Experiment Setup window.

2. In that window, click the **Sampling Options** button to open the Sampling Options window.



3. Click the check box to select **Keep data values only when commanded.**

4. Under the **Name** field, type “Length”.

5. Under the **Units** field, type “cm”.

6. The window on your computer should now appear as illustrated (right). If it does, click **OK**.

7. In the Displays list (on the left side of the screen), double-click **Graph** to open a graph display. (If prompted to select data, select **Voltage (mV)**).

8. The graph display typically appears with **Voltage (mV)** on the vertical axis. If it does not, click the vertical axis label and select **Voltage (mV)** from the pop-up menu.

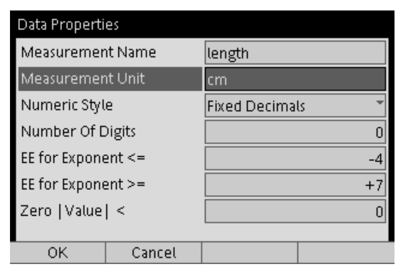
9. Click the horizontal axis label. Select **Length** from the pop-up menu.

Xplorer GLX (Without a Computer)

1. Press ⌂, F4 to open the Sensors screen.

2. Press F1 to open the Mode menu. Select **Manual** (press the down arrow to highlight it, then press ✓). The Data Properties dialog box will open.

3. With **Measurement Name** highlighted, press ✓ to edit it. Type “length”. Press ✓.



4. Press the down arrow to highlight **Measurement Unit**. Press ✓ to edit it. Type “cm”. Press ✓.

5. The GLX screen should now appear as illustrated (right). If it does, press F1 (OK).

6. Press ⌂+F1 to open the Graph screen.

7. Press ✓ to light up the graph fields. Press ✓ again to open the vertical axis data menu.

8. In the menu, use the arrow keys to highlight **Voltage**. Press ✓.

9. Press ✓ to light up the graph fields again. Press the down arrow to highlight the horizontal axis data label. Press ✓ again to open the horizontal axis data menu.

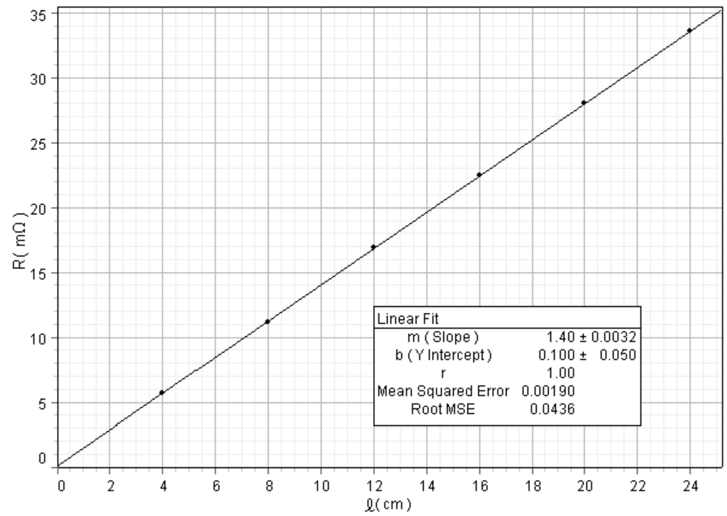
10. In the menu, use the arrow keys to highlight **length**. Press ✓.

Teachers' Notes and Typical Data

Experiment 1: Exploratory Study of Resistance

Part A

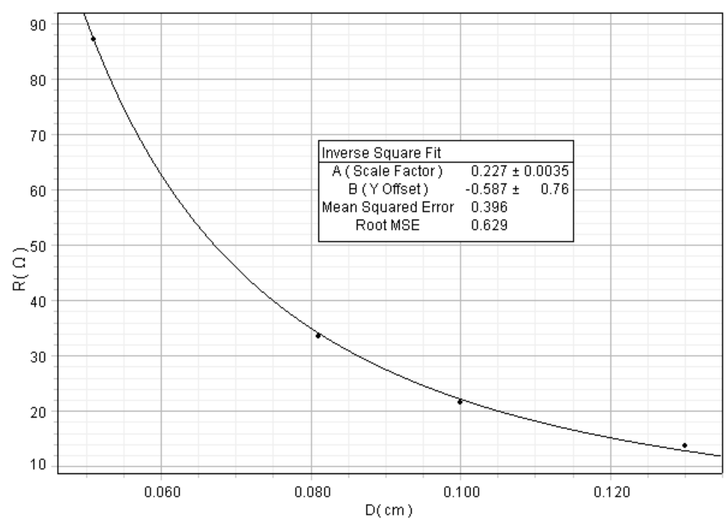
ℓ (cm)	V (mV)	I (A)	R (mΩ)
24	33.3	0.992	33.6
20	27.7	0.988	28.0
16	22.3	0.990	22.5
12	16.7	0.990	16.9
8	11.1	0.990	11.2
4	5.5	0.991	5.7



The relationship between R and ℓ is linear, and the line passes through the origin. This means that R is proportional to ℓ.

Part B

D (cm)	V (mV)	I (A)	R (mΩ)
0.13	13.7	0.992	13.8
0.10	21.3	0.990	21.5
0.081	33.3	0.992	33.6
0.051	86.9	0.998	87.1



The inverse-square curve fits best. This means that R is proportional to $1/D^2$, or that R is proportional to $1/A$.

Part C

The table below shows resistivities calculated using data from Part B and the formula $\rho = \frac{RA}{\ell}$.

D (cm)	ρ (µΩ·cm)
0.13	7.29
0.10	7.27
0.081	7.26
0.051	7.35
Average:	7.29

These data show that the resistivity is about equal (approximately 7.3 µΩ·cm) for all four brass samples.

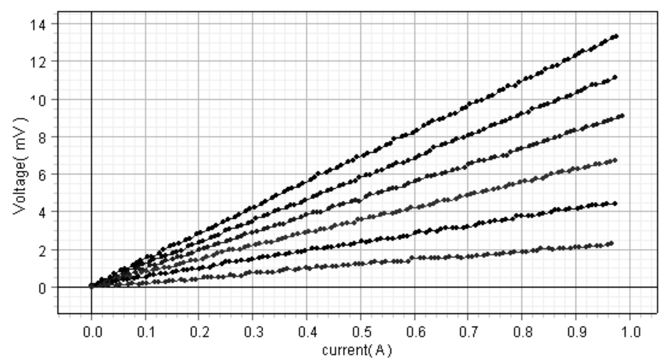
Part D

This table shows data for wires of other materials with ℓ =24 cm.

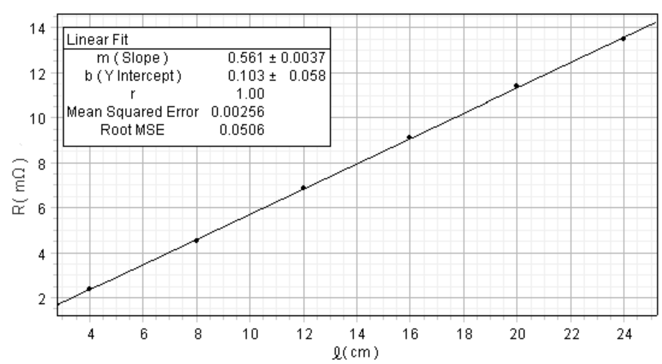
	D (cm)	V (mV)	I (A)	R (mΩ)	ρ (μΩ·cm)
Copper	0.10	5.19	0.997	5.21	1.76
Aluminum	0.10	14.5	0.994	14.6	4.93
Brass	0.10	21.3	0.990	21.5	7.27
Nichrome	0.10	161	0.504	319	108
Stainless Steel	0.10	232	0.994	233	78.8

Experiment 2: Resistance versus Length

This graph shows V versus I for the largest brass wire (A = 0.0127 cm^2) with ℓ = 24 cm, 20 cm, 16 cm, 12 cm, 8 cm, and 4 cm. The slope of each line equals R.



This graph shows R versus ℓ for the largest brass wire (where R was taken from the slopes in the first graph). The slope equals ρ/A; thus, ρ = 7.11 μΩ·cm.



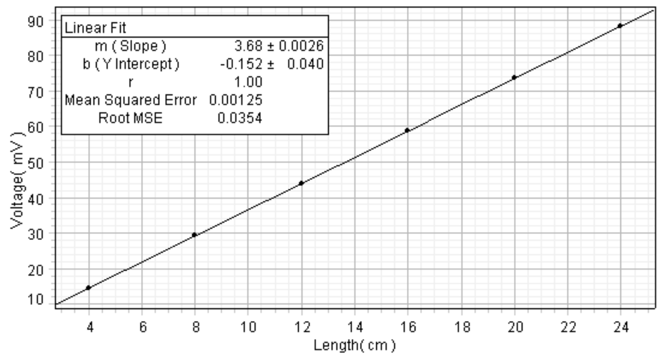
The table below shows ρ determined in this way for all wires. For the four brass samples, the average value of ρ is 7.21 μΩ·cm with a standard deviation of about 0.1 μΩ·cm (1.4%).

	A (cm^2)	slope = ρ/A (mΩ/cm)	ρ (μΩ·cm)
Brass	0.0127	0.561	7.11
	0.00811	0.886	7.18
	0.00519	1.39	7.21
	0.00203	3.62	7.34
Copper	0.00811	0.222	1.80
Aluminum	0.00811	0.595	4.82
Nichrome	0.00811	13.2	107
Stainless Steel	0.00811	9.70	78.6

The following refinements to the experiment setup can be used to improve the data and make the experiment easier:

- Increase the sample rate of both sensors (from the default of 10 Hz) to reduce the uncertainty of the slope of the *V* versus *I* graph.
- Set a stop condition in DataStudio (or on the GLX) to automatically stop data after slightly less than 10 s (the length of the applied voltage ramp).
- Set the DC Power supply to automatically stop after a single ramp.

Experiment 3: Voltage versus Length



The graph shows V versus ℓ data for the smallest brass wire (A = 0.00203 cm^2) with I = 1.00 A. The slope equals $\rho I/A$; thus ρ = 7.46 μΩ·cm. The table below shows ρ determined in this way for all wires.

	A (cm^2)	I (A)	slope = $\rho I/A$ (mV/cm)	ρ (μΩ·cm)
Brass	0.0127	2.00	1.15	7.28
	0.00811	2.00	1.80	7.30
	0.00519	1.00	1.42	7.37
	0.00203	1.00	3.68	7.46
Copper	0.00811	2.00	0.439	1.78
Aluminum	0.00811	2.00	1.23	4.99
Nichrome	0.00811	0.500	6.63	108
Stainless Steel	0.00811	1.00	9.78	79.3

For the four brass samples, the average value of ρ is 7.35 μΩ·cm with a standard deviation of about 0.08 μΩ·cm (1.1%).

Technical Support

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