

## Finding the Temperature of a Light Bulb Filament

**Introduction.** *Carbon resistors* are the kind typically used in wiring circuits. They are made from a small cylinder of graphite, surrounded by a protective plastic coating. (See fig. 1a.) Short wires, or *leads*, are attached to the ends of the graphite cylinder and held in place by the coating. [You have two carbon resistors at your station.] Other materials and devices can also act like resistors; a light bulb filament, for example, usually consists of a thin tungsten wire with its two ends connected to separate parts of the metal base.

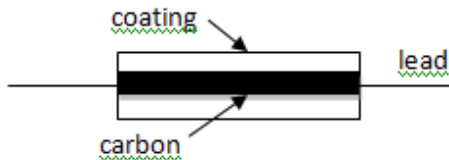


Fig. 1a



Fig. 1b

(See fig. 1b.) Like most (but not all) solid materials, graphite and tungsten are *ohmic*, which means that resistors made from them obey Ohm's Law,

$$V = IR.$$

Ohm's law applies to each resistor in a circuit – even a complicated circuit with many resistors.  $V$  in the formula is the voltage difference between the two ends of any one of the resistors,  $I$  is the current through that same resistor; and  $R$  is the resistance of that resistor. The unit for resistance is the Ohm, abbreviated by a Greek omega,  $\Omega$ ;  $1\Omega = 1V/1A$ . Carbon resistors typically range from about  $10\Omega$  to about  $10M\Omega = 10^7\Omega$ .

Since Ohm's Law says that  $V$  and  $I$  are proportional, one might expect that a graph of  $V$  (vertical axis) vs.  $I$  (horizontal axis) will be a straight line through the origin with slope equal to the resistance  $R$ . In some cases, however, such a graph will not be straight. One possible reason is that larger currents tend to heat up a resistor, and for most materials a change in temperature causes a change in resistance. This temperature-dependence of resistance appears as a changing slope in a  $V$  vs.  $I$  graph.

In this lab exercise, you will use the changing resistance of a light bulb filament to estimate its operating temperature.

## Resistors

*Resistor Color Codes.* Carbon resistors are often marked with colored stripes to indicate the value of resistance. A summary of the resistor color code is given on the accompanying sheet.

1. Examine one of the two “loose” resistors you have (they both have the same color code), record the colors of the stripes and the corresponding resistance value with tolerance. Record the range of resistances that lie within the tolerance of the resistor.

*Heat Dissipation in Resistors.* Although both of your resistors have the same color code, they are very different in size. The physical size of a resistor has little to do with its resistance value. Small resistors are made small so that they can be wired into small spaces. Large resistors are made that way because large resistors handle heat better and are less likely to “burn out” when carrying large currents.

## Digital Multimeter

Digital multimeters are electronic devices that can make a variety of electrical measurements. Examine the meters in a general way to see what features they have. The different receptacles or terminals with labels like  $V\Omega$ , COM, etc. are used for different kinds of electrical measurement, as explained below. Connections to the meter are usually made through wire leads or *patch cords* with *banana plug* connectors on their ends. The rotating dial may have settings marked V, A,  $\Omega$ , etc. for measuring voltage, current, and resistance.

*Using a Digital Multimeter to Measure Resistance.* Your digital multimeter can be used as an *ohmmeter* – a device for measuring resistance. You will use it to measure the resistance one of the loose resistors and a light bulb.

- 2a) Plug one patch cord into the COM receptacle of the meter and connect another into the  $V\Omega$  receptacle (use the ones with alligator clips on the ends). Now turn the rotating dial to the  $\Omega$  setting and connect the two cords to the two ends of one of the resistors. The number appearing on the meter is the resistance. Record this resistance, *taking care about the units* of the meter reading. Determine whether the ohmmeter value that you read lies within the tolerance range of the color code. Try using the other multimeter to measure the same resistance. That will give you an idea of how consistent the meters are.
- b) Now remove the light bulb from the circuit board, and use the ohmmeter to measure its resistance.

*Note: If the resistor you wish to measure with an ohmmeter is already wired into a circuit, it must be removed from the circuit before making the measurement.*

Record the value of resistance, and replace the light bulb to its original position on the circuit board. **You have now measured the resistance of the light bulb filament at room temperature, about 20 °C.**

*At this point ask your instructor to verify that the circuit is equivalent to Fig 2. An incorrectly wired circuit is likely to give spurious results and may burn out a fuse in the meter.*

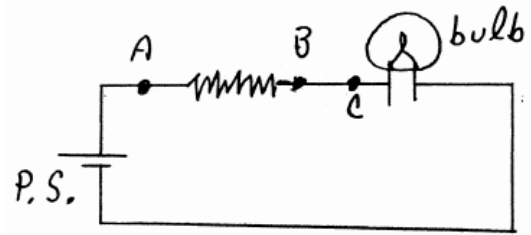


Fig. 2

*Using a Digital Multimeter as a Voltmeter.* A Digital multimeter can be used to measure voltage and current as well as resistance. To measure voltage, patch cords should again be attached to the COM and  $V\Omega$  terminals (this time use banana plug leads), and the meter dial should be rotated to the  $V$  setting. If the two leads are now connected to two different points in an active circuit, the number displayed by the meter will be the *difference* in voltage between those two points.

- 3a) Turn on the power supply and set it to read 5V. Now connect the digital multimeter to the circuit so as to measure the voltage difference between points A and B. That is, measure the voltage difference across the ceramic resistor. **Note: the ceramic resistor in this circuit may at times get hot. Handle it with care.**
- b) What do you think will happen if you reverse the leads to the meter? Try it and record.
- c) According to Ohm's Law, if a resistor were to have zero resistance, the voltage difference between its ends would also be zero, regardless of the current. Use the second multimeter to measure the voltage difference between points B and C. That is, measure the voltage across the wire between the resistor and the bulb. Be sure to get the units right. You are effectively measuring the voltage difference across a near zero resistance.

**Now turn off the power supply.**

*Using a digital multimeter as an ammeter.* An ammeter is a device for measuring electric current. Strictly speaking, an ammeter measures the current going through the meter itself, but it can be used to measure the current going through a resistor in a circuit by inserting the meter properly into the circuit. The basic idea is to insert the meter into the circuit in such a way that all of the current going through the resistor of interest also goes through the meter. For example, in the

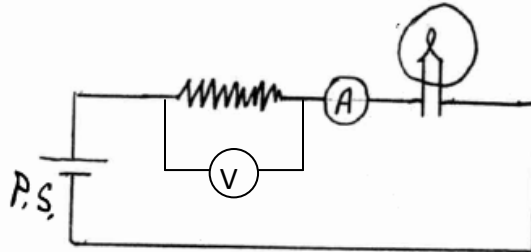
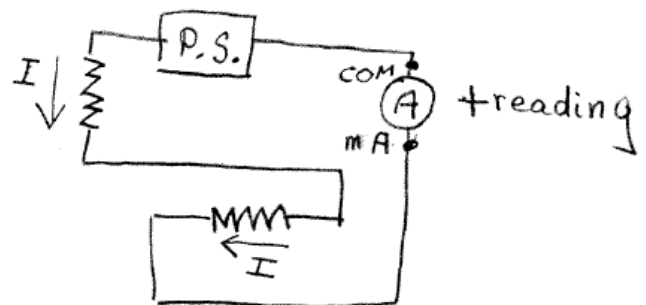


Fig. 3

circuit of fig 2, if the wire connecting B to C is removed and replaced by an ammeter (shown as an A in a circle in figure 3) then any current going through the resistor must continue on and also go through the meter. Similarly, all of the current that passes through the meter must continue on and go through the light bulb. By inserting the ammeter into the circuit in this way, we can measure the current through the resistor and also through the light bulb. They are the same.

4. To use your meter as an ammeter in this way, move the lead from the  $V\Omega$  receptacle to the mA receptacle and rotate the dial to the mA setting. Now remove the wire connecting B to C on the circuit board. The result is equivalent to figure 3. **Let your instructor check this.** Turn on the power supply and set it to 5 V. The number displayed by the meter is the current passing through the meter. If the number read on your meter is negative, reverse the leads to the meter. Record the size of the current through the resistor and light bulb.

*Direction of current.* The positive or negative reading of current in the multimeter indicates the direction of the current. The meter will give a positive reading if the current passes through the meter from the mA receptacle to the COM receptacle. Thus in the circuit below, if the ammeter reading is positive, the direction of the current through the resistors is as shown by the arrows. Be sure you understand the diagram below.



## Plotting an I-V curve for a resistor and a light bulb.

You will be varying the output of the power supply which in turn will change the voltage across the resistor and the current through it, as measured by your two meters. Open the Excel spreadsheet before recording the data below.

5. With the two multimeters in place, set the power supply to readings in roughly 3 V increments, from zero to 15 V (the voltage settings don't need to be exact). In each case record the voltage across the resistor and the current through the resistor in the Excel spread sheet. Plot a  $V$  vs  $I$  graph for the resistor ( $V$  on the vertical axis) and print out the graph.
6. Measure and record the slope of the resistor graph, including units. What resistance does it indicate in Ohms? How does the slope compare with the resistance value marked on the resistor? Calculate the percent difference between the two different values.
7. Now move the voltage measuring meter so that it reads the voltage across the light bulb instead of the resistor. Repeat step 5, but set the power supply to the values given in the table of your Excel spread sheet. Watch carefully and take note of the current when the bulb first begins to glow faintly red. Plot a graph of voltage vs current for the light bulb and print it out. What is the principle difference you see between these two graphs?
8. Add another column to your Excel table and calculate the resistance for the light bulb filament at each setting of the power supply. The formula for resistance is  $R = V/I$ . Plot a graph with current on the horizontal axis and resistance on the vertical axis. Mark an X on the graph where the bulb first begins to glow faint red. (Use value from 7 above.)

What is the approximate resistance of the filament when it cool (low current). When it first begins to glow faint red? When it is glowing brightly (maximum current)?

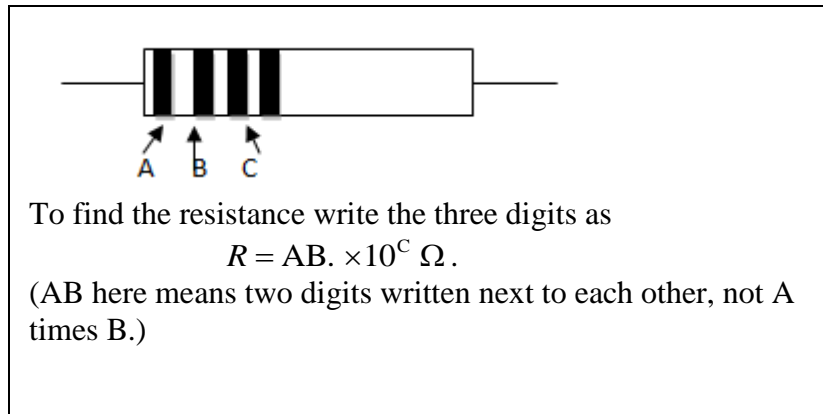
Let  $R_0$  be the resistance of the light bulb at room temperature [you measured that in 2c) above.] Let  $R$  be the resistance of the bulb when it is glowing brightly. Calculate the ratio  $R/R_0$ .

9. The temperature dependence of a resistance is given approximately by the formula  $R = R_0[1 + \alpha(T - T_0)]$ , where  $R$  is the resistance at temperature  $T$  and  $R_0$  is the resistance at temperature  $T_0$ . [This is equation 18-4 of your text.]  $\alpha$  is the *temperature coefficient of resistance*, which is tabulated for different materials on the attached sheet. In your case the filament is made of tungsten.
  - a) Show that the formula above is equivalent to  $T = T_0 + (R/R_0 - 1)/\alpha$ .
  - b) Using  $T_0$  as room temperature and  $R_0$  as the room temperature estimate the temperature of the light bulb filament when the bulb is glowing brightly.

## Reading Resistor Color Codes

A carbon resistor is usually marked with colored stripes to indicate its resistance in ohms. Begin with the stripe closest to the end of the resistor. The first three stripes correspond to digits as follow:

0	black
1	brown
2	red
3	orange
4	yellow
5	green
6	blue
7	violet
8	gray
9	white



Example: If the first three stripes are colored  
blue, gray, brown  
it corresponds to  $68 \times 10^1 \Omega = 680 \Omega$

The fourth stripe (if present) indicates the tolerance, as follows.

gold – 5%  
silver – 10%  
(absent) – 20%

Example: If the four stripes are colored  
blue, gray, brown, gold  
it corresponds to  $680 \Omega \pm 5\%$

The 5% tolerance means that the actual value of the resistance should be between .95(680) and 1.05(680). That is, the resistance of the resistor should be expected to be in the range

$$646 \Omega < R < 714 \Omega$$

**TABLE 18-1 Resistivity and Temperature Coefficients (at 20°C)**

<b>Material</b>	<b>Resistivity, <math>\rho</math> (<math>\Omega \cdot \text{m}</math>)</b>	<b>Temperature Coefficient, <math>\alpha</math> (<math>^{\circ}\text{C}</math>)<sup>-1</sup></b>
<i>Conductors</i>		
Silver	$1.59 \times 10^{-8}$	0.0061
Copper	$1.68 \times 10^{-8}$	0.0068
Gold	$2.44 \times 10^{-8}$	0.0034
Aluminum	$2.65 \times 10^{-8}$	0.00429
Tungsten	$5.6 \times 10^{-8}$	0.0045
Iron	$9.71 \times 10^{-8}$	0.00651
Platinum	$10.6 \times 10^{-8}$	0.003927
Mercury	$98 \times 10^{-8}$	0.0009
Nichrome (Ni, Fe, Cr alloy)	$100 \times 10^{-8}$	0.0004
<i>Semiconductors</i> <sup>†</sup>		
Carbon (graphite)	$(3-60) \times 10^{-5}$	-0.0005
Germanium	$(1-500) \times 10^{-3}$	-0.05
Silicon	0.1-60	-0.07
<i>Insulators</i>		
Glass	$10^9 - 10^{12}$	
Hard rubber	$10^{13} - 10^{15}$	

<sup>†</sup> Values depend strongly on the presence of even slight amounts of impurities.

## Data: Finding the Temperature of a Light Bulb Filament

Name \_\_\_\_\_

1. Colors of stripes: Brown Green Orange Silver  
                            A                    B                    C                    D

Corresponding resistance w/ tolerance and units: 15 kΩ +/- 10 %

Tolerance Range: 13500 Ω < R < 16500 Ω

2a) Resistance as measured with ohmmeter (w/ units): 16.3 kΩ

Are the color code and ohmmeter values consistent? yes  
Explain.

*The measured value lies in the  
tolerance range*

b) Resistance of light bulb filament at room temperature (20 °C). 1.1 Ω

3a) Record values with UNITS. Voltage across resistor = 4.65 V

b) Reading with reversed leads. -4.65 V

c) Voltage across BC. 1.4 mV

4. Current through resistor: 110.1 mA

Current through light bulb: 110.1 mA

5. Record data in Excel spreadsheet. Print out the data and the graph.



6. Resistance of resistor from slope: 41.1  $\Omega$   
Percent difference: 2.7%

7. Record data in Excel spreadsheet. Print out the data and the graph.

Describe the principle difference between resistor and light bulb graphs.

*The light bulb graph is not straight*

Current when bulb first begins to glow faint red. 130 mA

8. Print out graph.

Resistance when bulb is

Cool 1.13  $\Omega$

First begins to glow 4.28  $\Omega$

Glowing brightly 11.23  $\Omega$

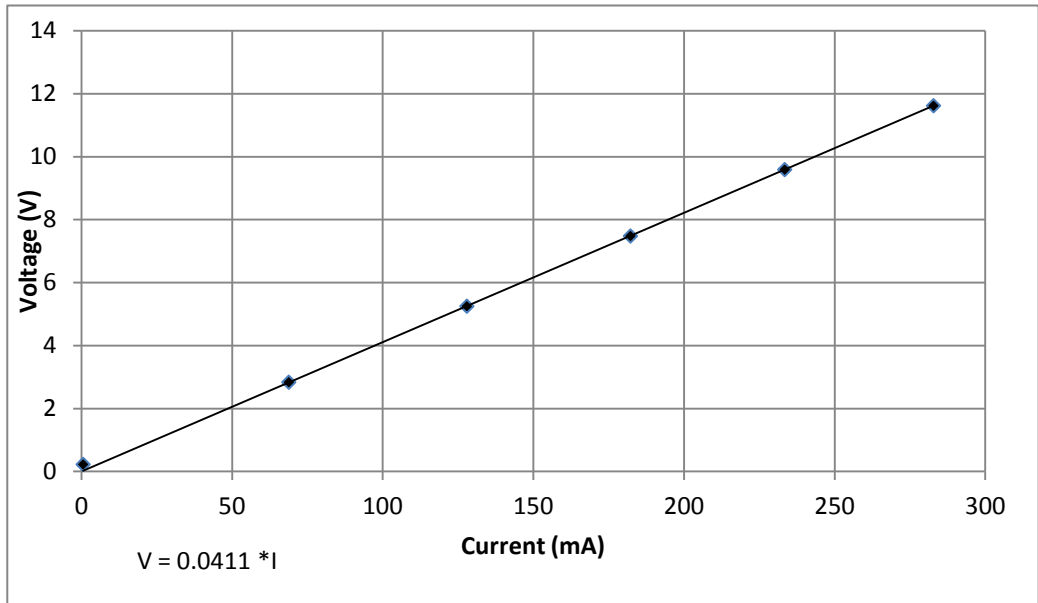
R/R<sub>0</sub> 9.93

- 9a) Derivation of  $T = T_0 + (R/R_0 - 1)/\alpha$

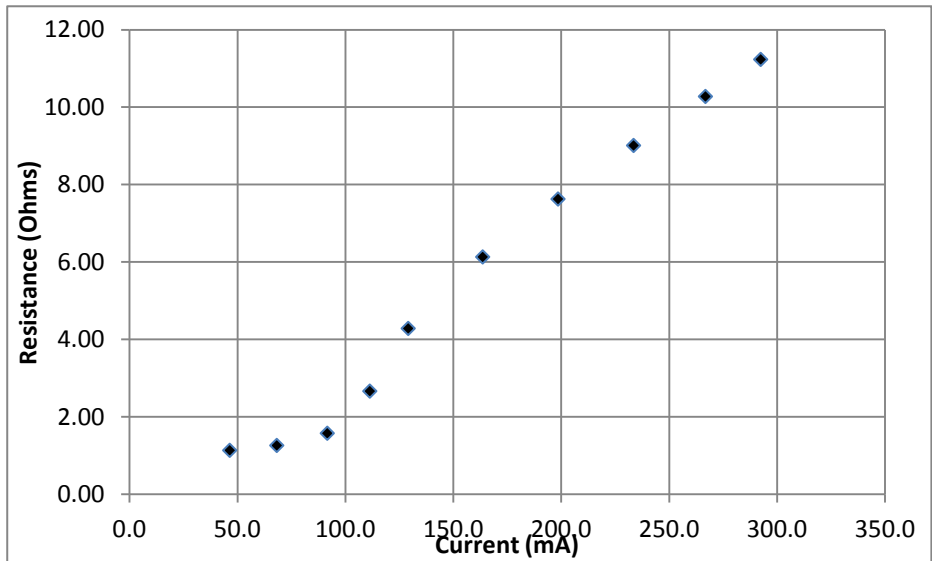
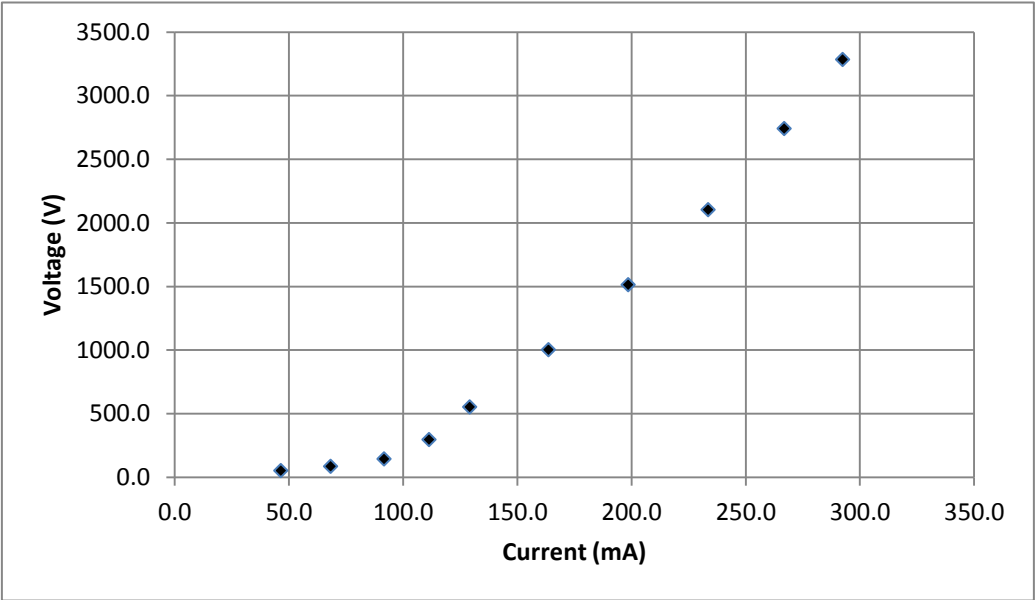
- b) Temperature when glowing brightly. 2004  $^{\circ}\text{C}$

Show your work

Power Supply Voltage	Resistor	
	Voltage (V)	I (mA)
0	0.224	0.54
3	2.836	68.8
6	5.25	127.9
9	7.48	182.2
12	9.59	233.4
15	11.62	282.8



Power Supply Voltage	Light Bulb		
	I (mA)	V (mV)	R (Ohms)
2	46.4	52.6	1.13
3	68.2	85.9	1.26
4	91.6	144.2	1.57
5	111.3	296.4	2.66
6	129.1	553.0	4.28
8	163.6	1003.0	6.13
10	198.5	1514.0	7.63
12	233.5	2104.0	9.01
14	266.8	2742.0	10.28
16	292.4	3285.0	11.23



# Homework for Finding the Temperature of a Light Bulb Filament

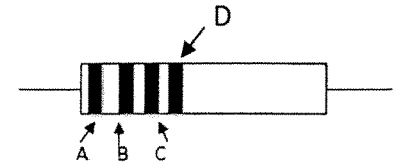
Name \_\_\_\_\_

- 1a) A certain resistor has colored stripes, as shown. What is the resistance value with percent tolerance?

Resistance 65 kΩ +/- 5% %

What range of resistances is consistent with this color code?

$$61.75 \text{ k}\Omega < R < 68.25 \text{ k}\Omega$$

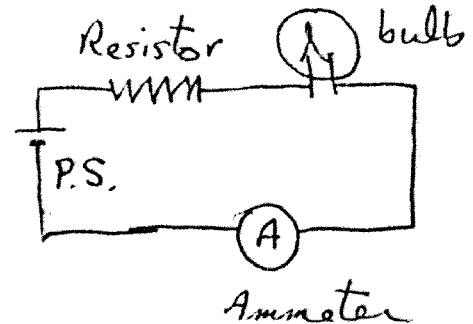


A - blue  
B - green  
C - orange  
D - gold

- b) Three resistors have the color codes shown in the table. Unfortunately, each resistor has had one of its stripes worn off (indicated by an X in the table). Which of the three resistors is the largest? Circle 1, 2, or 3.

	A	B	C	D
1	X	Red	Green	silver
2	Red	X	Red	silver
3	Blue	Red	Brown	X

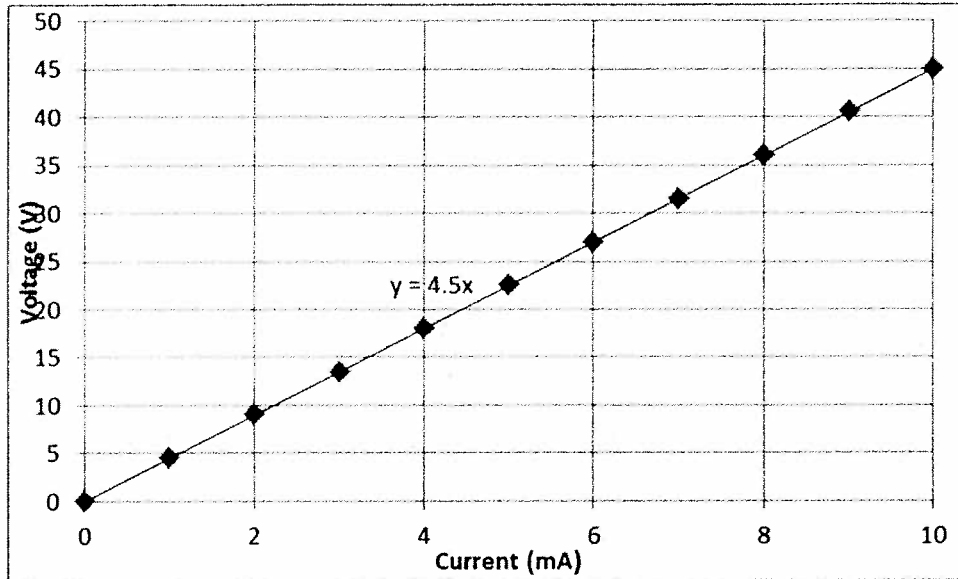
2. Instead of placing the multimeter where we did in lab to measure current, we could have placed it as shown at right. This figure should be compared with figure 3 of the lab handout. Write an explanation of why an ammeter placed as shown in the diagram will correctly read the current through the light bulb and the resistor.



Current is the same throughout a series circuit

3. The graph below show the voltage across a certain resistor as a function of the current through it. A best fit line has the formula  $y = 4.5x$ . What is the approximate resistance of this resistor? **Carefully note the units on the axes.**

Approximate resistance in Ohms 4500  $\Omega$



Is this resistor ohmic? Explain how you know.

(Circle one)

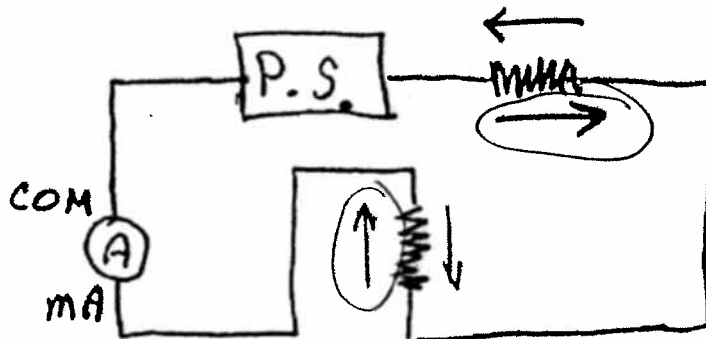
yes

no

Explain

*Graph is straight*

4. In the circuit below, the ammeter has a positive reading. Circle the arrows that indicate the direction of the current through the two resistors.



## Equipment

- 1 2W 10% 15kOhm resistor (loose)
- 1 ¼ W 10% 15kOhm resistor (loose)
- 2 Digital multimeter with (alligator clip leads available)
- 1 Circuit board
- 1 S 13 light bulb mounted for circuit board
- 1 40 Ohm 5 W resistor (this should be a high power resistor)
- 1 15 V power supply
- 2 long patch cords
- 4 medium patch cords
- 1 short patch cord

If the above resistor and a 15 V power supply are used, students can't burn out the light bulb.