Experiment

1

Electric measurements

1. Introduction

To find the resistance, one needs to measure the voltage across the resistor, V, and the current, I, flowing through the resistor. According to the Ohm's law the resistance, R, is given by the ratio:

$$R = V/I. \tag{1}$$

You will use a digital multimeter to find R, V and I. Our laboratory is equipped with first-rate instruments, which display 4 digits, see picture below. On the voltage scale you can measure 0.5×10^{-4} volts to 1999 volts; on the current scale you can measure 0.5×10^{-7} amperes to 10 amperes. Other multimeters used in this lab have different shapes but they all measure R, V, and I.

Typical analog (left) and digital multimeters (center and right).

As you look at the front panel of the multimeter, you notice that there are black and red jacks. Also on your workbench you may find red and black cables. It is a common practice to use a red wire for high voltage or positive signal and a black wire for low voltage or negative signal. We suggest that you should use this system in the laboratory since it is helpful in checking the wiring. [A different system is used in the wiring of buildings. White denotes the neutral wire; black is used to indicate wires under 120 volts AC; red is reserved for 240 voltage. Green is always used for ground wires.]

2. Procedure

Set the meter to measure resistance (ohm, Ω) by depressing the **HI Ω** function switch. Connect a black lead to the common jack of the multimeter and a red lead to the
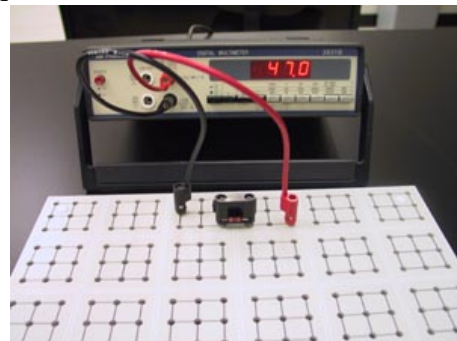
A-Ω jack. Select a 1000 range. Please note that HI Ω range is set to measure kiloohms, kΩ, combining it with the 1000 range this means that the maximum value to be measured is 1,000,000 ohm or 1 MΩ. Keep the leads apart and the display should flash. The flashing indicates that the measured resistance between two leads exceeds the maximum value of 1 MΩ. Next, grasp two exposed leads, holding one in your right hand and the other in the left hand. The meter will show the resistance of your body. Measure the resistance of your skin by touching two points on your skin about 2 inches apart. The resistance of the skin may vary greatly with the amount of moisture on the skin. If your skin is dry you may have to change the range from 1000 kΩ to 10 MΩ. If it is wet to display more significant digits, you may want to change the range to 100 kΩ.

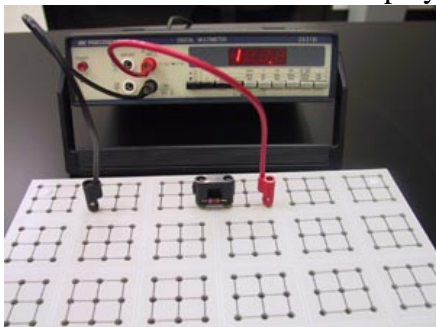## 2.1.   Resistor color code
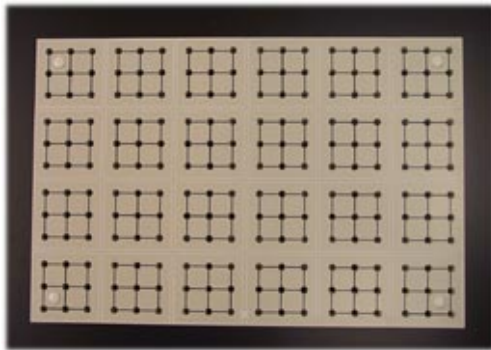
Determine the resistance of the 5 resistors provided. Each resistor to be measured must be connected between two posts on the "bread board". The breadboard shown in the photo allows you to built electrical circuits. The openings are designed to fit banana plugs and are arranged in the form of squares. There are nine openings per square.   They are all connected internally, but separate squares are isolated. To built a circuit you need to plug in one end of the resistor into any opening in one square and another end into another square. An example is shown in the photo to the right.

Here a resistor is mechanically attached to a banana plug, which is pushed into holes in adjacent squares. The leads are pushed into other holes in the same squares and a multimeter. You can read a measured value on the display.   An example of a BAD connection is shown below. In this photo the black lead is attached to a square with no resistor attached and the display is blank. This circuit is 'open' and the multimeter cannot measure anything.

For your convenience we attached the resistors to banana plugs. There are five different banana plugs with different resistors provided for each setup. The resistors are marked with four or five color bands. This is the resistor color code. The first two bands

indicate two significant digits, the third indicates the power of ten, and the fourth band indicates the precision of the measurements. The fifth band (if present) indicates reliability. The color code key for resistors is given in Table 1. Always orient the resistors so that the gold or silver band, the so called tolerance or precision band, be on your right side.

Attach the meter leads to the breadboard and record the displayed values. Change the range so that the display will show all four digits. For resistance values less then 10Ω depress the **LO** Ω and 10Ω switches. Clip the test leads together. You may observe a non-zero reading (a few tenths of an ohm). The reading is due to the resistance of the test leads, fuses, and jacks. You may adjust the **ZERO** control (available only on analog meters) until the display shows 0.00, or subtract the value from any readings in this range, if such accuracy is required.

Report the measured resistance values in Table 2.1 and compare the data with the values expected from the color code. Compare the difference with the estimated value from the fourth band of the color code.

DO NOT ATTACH ANYTHING TO THE 10A PLUG OF THE MULTIMETER.

2.2. Resistors in series

Select two resistors of similar values. Measure each resistance. Then connect them in series on the bread board as shown in Fig.1. Record the results. Compare the measured and expected values of two resistors connected in series. For the series combination, the theoretical value can be obtained from:

$$R_{series} = R_1 + R_2. \hspace{4cm} (2)$$

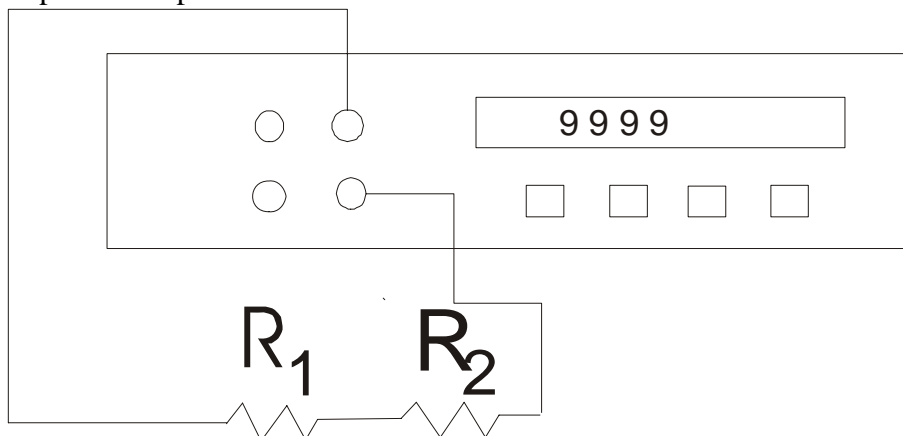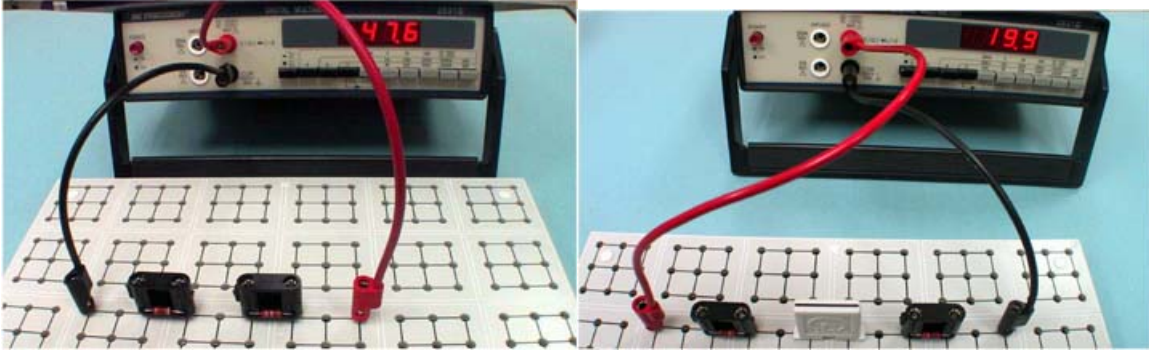Report the experimental and theoretical values in Table 2.2.

Fig. 1 Resistors in series.

The above photographs show two possible series combinations corresponding to the schematics in Fig. 1. In the left photo the resistors are plugged into adjacent squares, in the photo on the right the resistors are connected to distant squares and a white bridging plug is used to connect them. There are many other possible arrangements of resistors on the breadboard resulting in a series combination.

2.3. Resistors in parallel

Connect the same two resistors in parallel as shown in Fig. 2. Compare the readings of the meter with the theoretical value:

$$1/R_{parallel} = 1/R_1 + 1/R_2. \tag{3}$$

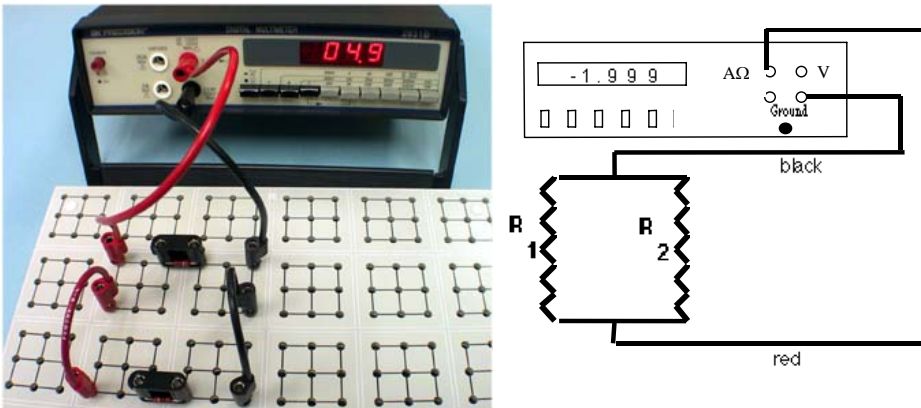Compute the percentage difference and report the experimental and theoretical data in Table 2.3.

Fig. 2. Resistors in parallel. The photo shows one of many possible arrangements of the resistors on the breadboard that give the parallel combination. You may want to explore and build your own connections. Note, that you may work with a different multimeter!!! Do not try to copy the arrangement in the photo.

2.4. Ohm's law. PHYS 20481 and PHYS 20484 only

Select a resistor of about 100 kΩ using the color code. <u>IMPORTANT: Use the multimeter to read its actual value and record it in Table 2.4 in the column labeled $R_{100K\Omega}$.</u>
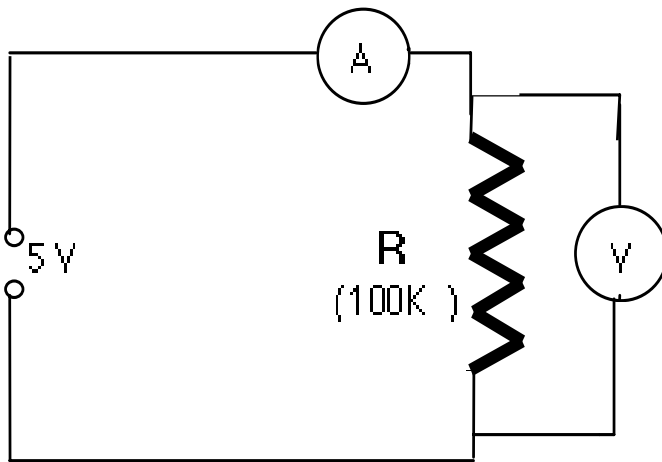
Fig. 3. Ammeter is always in series, voltmeter is always in parallel.

Set up the circuit on the breadboard as shown in Fig. 3. The voltmeter is connected in parallel, the ammeter in series. The 5 volts can be obtained from a power supply you will find on the desk. Make sure that the positive terminal is connected to the red jack on the meter. Use one digital multimeter for "A", the ammeter, and another digital mulimeter for "V", the voltmeter, in the circuit.
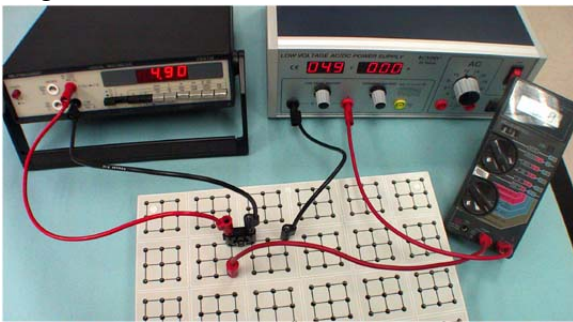
The photo shows the 100 KΩ resistor connected to a power supply (center) and an ammeter (right). The digital voltmeter (left) is connected in parallel to the resistor. Remember to depress the proper function and range switches. The same instrument may be used as a voltmeter or an ammeter, and selecting proper functions is very important. Remember that the ammeter must be connected in series and the voltmeter always in parallel. Since you will use a DC current, select **DCA** and the range of about 100 μA for current measurements, and **DCV** and 10 V range for the voltage measurements. Record the current, I, and potential, V. Compute V = I x R to verify your voltage measurements. The two values agree if the voltmeter has an *infinite* internal resistance.
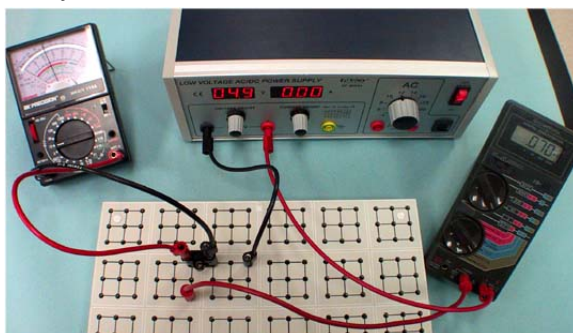
Replace the digital voltmeter with a standard voltmeter, as shown in the photo. Do not alter the power supply or the ammeter. The input input resistance of the standard meter is smaller then that of the digital meter and may affect the measurements. You can be read the value

of the input resistance on the meter's front panel. Adjust the meter scale appropriately and measure I and V. Compute V = I x R.

The difference in the readings can be explained as follows. The resistance of the ammeter, R_A, is essentially zero. The resistance of the voltmeter, R_B, acts as a resistor in parallel with R = 100 KΩ. This means that the equivalent circuit can be drawn as shown in Fig. 4. The goal of this part of the experiment is to find the input resistance of the standard voltmeter.
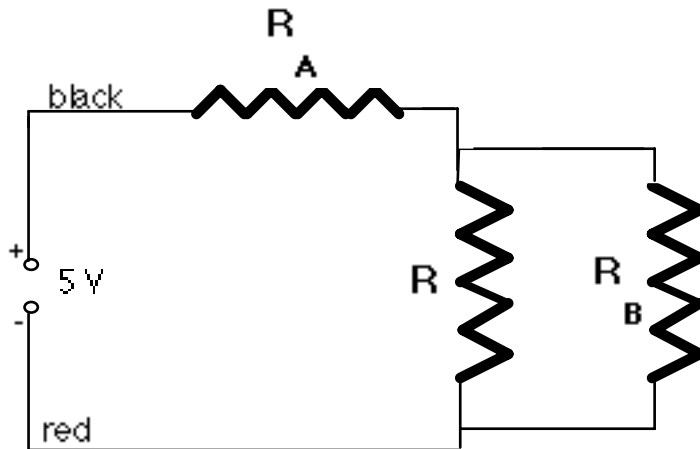

Fig.4. This is the same circuit as in Fig. 3.

The equivalent resistance can be found from the input voltage, which in this case is almost 5 volts, and the current in the system.

$$R_{equ} = V/ I \tag{4}$$

On the other hand the equivalent resistance can be written as (Eq. 3):

$$1/R_{equ} = 1/R + 1/R_B \tag{5}$$

From (4) and (5) one can find the resistance of the voltmeter:

$$R_B = R_{equ} \text{ x } R/(R - R_{equ}) \tag{6}$$

Report the calculated values of the input resistances for the digital and standard voltmeters. If you get a negative value for R_B it is probably because you did not measure with sufficient precision the value of R, the approximately 100 kΩ resistor.

Always remember to turn off the meters after the measurements. The meters use dry batteries with limited lifetimes.

3. Report

In your own words explain when it is practical to connect resistances in series and when in parallel.

Suggest when the internal resistance of a meter is important and how it may affect the measurements and when it can be ignored.

Which meter is a better one?

Table 2.1

No.	Measured resistance [Ω]	Color code value [Ω]	Difference [%]
1			
2			
3			
4			
5			

Table 2.2

R_1	R_2	Measured value	Calculated value $R_{series} = R_1 + R_2$	Difference

Table 2.3

R_1	R_2	Measured value	Calculated value $R_{parallel}=R_1R_2/((R_1+R_2)$	Difference

Table 2.4

	Potential [V]	Current [A]	$R_{100KΩ}$ [Ω]	R_{equ} [Ω]	R_B [Ω]
Digital meter					
Standard meter					

Remember to record the actual value of the 100KΩ resistor.

RESISTOR COLOR CODE

Resistance of common carbon resistors is usually indicated by three or four color bands. There can be extra bands, which may be ignored. The first two bands indicate two significant digits; the third band indicates the number of added zeros; and the fourth band, if present, indicates the tolerance or precision of the shown resistance value.

First digit

Second digit

Power of ten

Reliability, usually missing, not very important

Tolerance either silver or gold
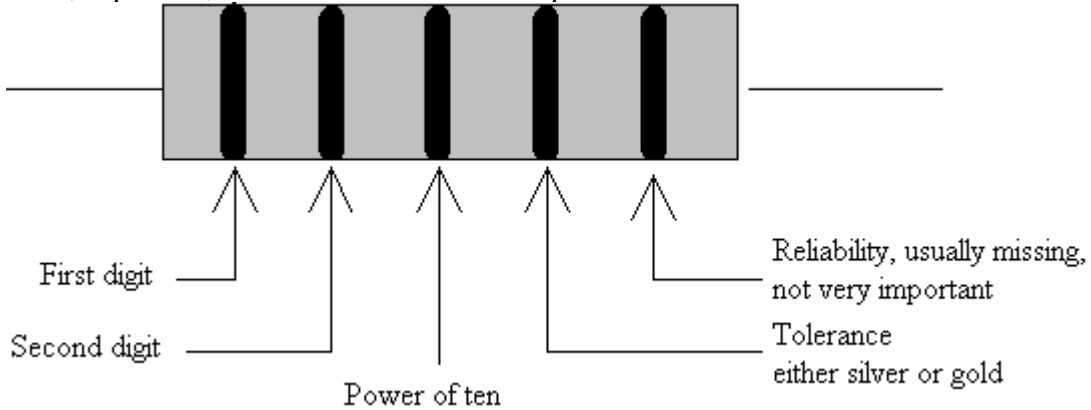
First two bands

Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

Tolerance band

Silver	10%
Gold	5%
No band	15%

Examples

brown – black – red - gold

   1   0   x 10^2 +/-5%= 10^3 Ω or 1,000 Ω +/− 5%.

   The actual resistance may be within the range from 950 Ω to 1,050 Ω.

red – red – yellow - silver

2   2   x 10^4 +/- 10%= 2.2 x 10^5 Ω +/− 10%

Actual resistance could be within the range from 1.98 x 10^5 Ω to 2.42 x 10^5 Ω.