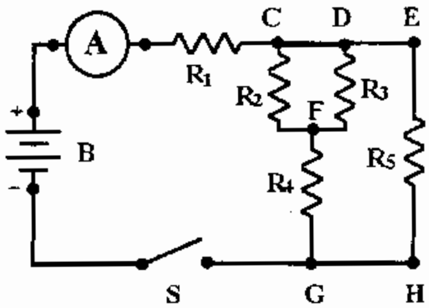
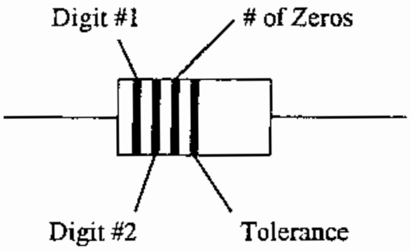
Apparatus: Packet of color-coded resistors (see below for recommended values). 3-volt battery, switch, connector clips and leads, milliammeter (0-50 ma), and a voltmeter of high internal resistance (0-5 volt, 1000 ohm/volt). A test set for checking resistor values will be available. <u>CAUTION.</u> <u>Never connect an ammeter directly to any battery; it could be damaged even by a single dry cell.</u>

Explanation: The circuit to be assembled and tested is shown in the schematic diagram. B is a battery of 3 volt EMF and small internal resistance, A is a milliammeter (0-50 ma), and S is a switch. The resistors form the network. It is to be assembled from five carbon resistors, using the pinch clips and lead wires to make connections. Note that points C, D, E are common (same clip may be used) and that G, H are common.



The resistors are selected by using the following color code:



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

Gold	- 5%
Silver	- 10%
No band	- 20%

To read, start at the end where the colors start. Then the first two bands give the first two digits while the third gives the number of zeros following these digits. The fourth band gives the tolerance. Example: Grey-Green-Red-Silver means 8500 ohms, approx. 10% tolerance. The final parameter which defines a resistor is the amount of power it can dissipate. This is determined to a large extent by its physical size.

Circuit Analysis: For this experiment you will need to calculate the voltage and current across each resister. To compute these values we need the equivalent resistance across the entire network. To compute this network resistance proceed as follows. R_2 and R_3 are in parallel, so $1/R_{eq1} = 1/R_2 + 1/R_3$ where R_{eq1} is the net resistance between CD and F. (If you are unfamiliar with calculating the equivalent resistance of resistors in series or parallel, see the "Addition to Ohm's Law" section at the end of these instructions.) The circuit can now be analyzed as if one resistor of resistance R_{eq1} has been put in place of the parallel combination of R_2 and R_3. Draw this new equivalent circuit in your notebook. From this new circuit diagram you can see that, R_{eq1} and R_4 are in series, so $R_{eq2} = R_{eq1} + R_4$. Draw this equivalent circuit where R_{eq2} is now the net resistance between CD and G, via F. The circuit can now be analyzed as if one resistor of resistance R_{eq2} has been put in place of the series combination of R_{eq1} and R_4. From this new circuit you can see that R_{eq2} and R_5 are in parallel, so find R_{eq3}, the net resistance between CDE and GH. Draw the equivalent circuit. Finally, R_{eq3} and R_1 are in series, so find the net resistance, R, of the entire network.

During the experiment you will measure directly the voltage V across the battery and the current I through the ammeter A. The potential difference across R_1 can be obtained from $V_1 = I\ R_1$. The Voltage at junction C, D, E is $V_{CDE} = V - V_1$. Next, V_{CDE} can be use to find the current I_5 in R_5 from $I_5 = V_{CDE}/ R_5$. At junction C, D, E it must be true that $I = I_5 + I_{eq1}$ where I_{eq1} is the current across R_{eq1}. Then the Voltage

V_{eq1} across R_{eq1} (voltage between CD and F) is found from Ohm's law. I_2 and I_3 can be determined using V_{eq1} and Ohm's law. Next, V_4 (the voltage across R_4) is $V_{CDE} - V_{eq1}$. I_4 is equal to I_{eq1} because the same current that flows through R_{eq1} flows through. R_4.

Numerical Example of Network Calculation: Suppose the resistances of R_1 to R_5 are 30, 200, 50, 160, 1000 ohms respectively, instead of the values used. Then $1/R_{eq1} = 1/200 + 1/50 = 0.005 + 0.020 = 0.025$, so $R_{eq1} = 40$ ohm. $R_{eq2} = 40 + 160 = 200$ ohm. $1/R_{eq3} = 1/200 + 1/1000$, so $R_{eq3} = 167$ ohm. You may now verify that R is 197 ohm. Next, if B is a 3.0 volt battery the current would be $I = V/R = 3.0/197 = 0.0152$ amps. The voltage across R_1 would be $V_1 = I_1R_1 = 0.457$ volt. $V_{CDE} = 3 - 0.457 = 2.54$ volts. Next, $I_5 = V_{CDE}/R_5 = 2.54/1000 = 0.00254$ amps. $V_{eq1} = (I - I_5)R_{eq1} = 0.506$ volts. $I_2 = V_{eq1}/R_2 = 0.00253$ amps. $I_3 = V_{eq1}/R_3 = 0.0101$ amps. $V_4 = V_{CDE} - V_{eq1} = 2.05$ volts. . $I_4 = I_{eq1} = I - I_5 = 0.0127$ amps.

Experimental Procedure: By referring to the code, assemble the network to provide values of R_1 to R_5 as follows. $R_1 \approx 30$, $R_2 \approx 100$, $R_3 \approx 50$, $R_4 \approx 200$ to 300, $R_5 \approx 500$ to 1000 ohms. To protect the milliammeter from possible damage, omit it at first and connect the free terminal of R_1 to the positive battery terminal. Then connect point GH to the negative terminal through switch S. Connect the high-resistance voltmeter across R_1. After approval by the instructor, close switch S and read the voltage across R_1. If it is less than one volt, the milliammeter, A, may be inserted. Note: Inserting A will not appreciably alter the current, provided the resistance of A is small compared to R. Because of their low resistance, ammeters are very easily damaged unless used with forethought. Record the current read on A and compare with the current computed from I = V/R, where V is the battery voltage as read with the voltmeter. Recall that most of the resistances have 10% tolerance.

Measure the voltage across each resistor with the voltmeter and write the results in the table. Note. If use of the voltmeter is not to alter I_2, for example, the current through the meter must be small compared to I_2. Hence the resistance of the meter must be large, compared to R_2. Accordingly, most voltmeters have high internal resistances as compared to ammeters.

Draw the circuit diagram in your notebook and write in the actual values of resistance as given by the color code. Calculate the expected voltages across each resistor and put them in the table. Finally, compute the power (P=VI where, V is output voltage of the battery under load and I is the ammeter reading) delivered by the battery. Then determine the power for each resistor and compare the sum with VI. The power dissipated by a resistor R_1 is given by the following equivalent expressions:

$$P_1 = I_1V_1 = I_1^2R_1 = V_1^2/R_1.$$

Report: Fill out the table below.

Table

V = Voltage across entire circuit = ________ I = Current from the amp meter = ________

Resistor	R Measured	T	Δ	V_m	V_c	i	P
R_1							
R_2							
R_3							
R_4							
R_5							

P = Power through circuit = VI = ________ Total Power = $P_1 + P_2 + P_3 + P_4 + P_5$ = ________

Note: See the next page for the definitions of the table symbols.

R = Measured resistance in ohms
T = The tolerance of the resistor (%)
Δ = Numerical uncertainty in the resistance = T x (color coded resistance)
V_m = Measured voltage
V_c = Calculated voltage
i = Current (amps)
P = Power (watts) = i^2R

Questions:

1. Recompute the network resistance, R, with omission of R_5. By what percent would omission of R_5 decrease the current I? In view of this calculation, comment briefly on the effect of a large resistance connected in parallel with a low resistance.

2. In terms of the color code what is the equivalent resistance of a red-green-brown resistor in series with a parallel combination of brown-green-red and orange-black-red resistors.

3. Referring to the computation of the power, it was mentioned that "the battery must be under load." Why should this matter?

Addition to "Ohm's Law"

1. Measure the resistance of the 10Ω and 33Ω resistors with the digital multimeter. Do your measured values fall within each resistor's uncertainty?

2. **<u>Resistors in series:</u>** The equivalent resistance of several resistors connected in series is equal to the sum of their individual values. For two resistors;

$$R_{equivalent} = R_1 + R_2$$

- Calculate the equivalent resistance of a 10Ω and 33Ω resistor connected in series.

- Measure the resistance of the 10Ω and 33Ω resistors connected in series.

- How does your measured value compare with your calculated value? Calculate the percent difference.

$$\text{Percent Difference} = 100\% \text{ X } \frac{|R_{calculated} - R_{measured}|}{R_{calculated}}$$

3. **<u>Resistors in Parallel:</u>** The equivalent resistance of several resistors connected in parallel is always less than the smallest resistor. For two resistors;

$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2}$$

- Calculate the equivalent resistance of a 10Ω and 33Ω resistor connected in parallel.

- Measure the resistance of the 10Ω and 33Ω resistors connected in parallel.

- How does your measured value compare with your calculated value? Calculate the percent difference.