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E84 Homework 1

1. Given the basic relationship between the voltage across and current through each of the three types of components R, C, and L,

Resistor R	$i = v/R = Gv$	$v = Ri = i/G$
Inductor L	$i = \int v\,dt/L$	$v = L\,di/dt$
Capacitor C	$i = C\,dv/dt$	$v = \int i\,dt/C$

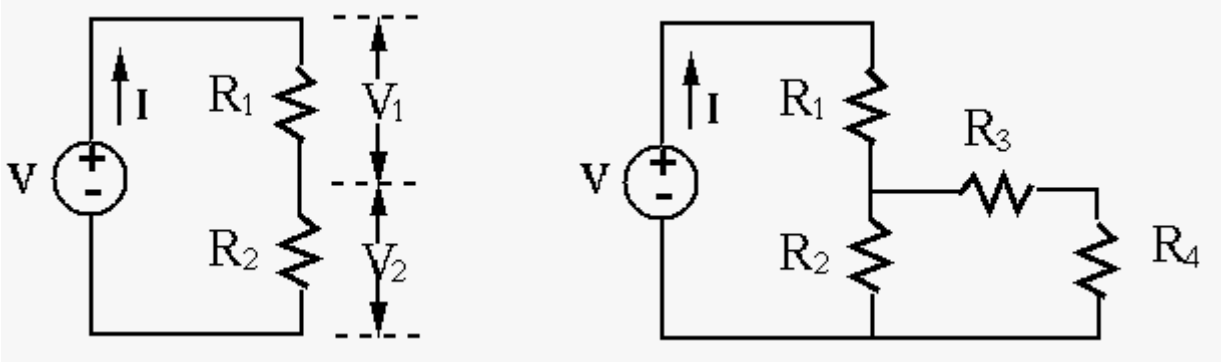
   - derive the expression for the equivalent resistance R_s of n resistors $R_1, \cdots, R_n$ combined in series. Then derive the expression for the equivalent resistance R_p of the n resistors combined in parallel.
   - Repeat the above for n capacitors $C_1, \cdots, C_n$.
   - Repeat the above for n capacitors $L_1, \cdots, L_n$.

2. (a) If two light bulbs both labeled as 110V and 40W in series are connected to a socket outlet of 190V, what is the power consumption of each of the bulbs?

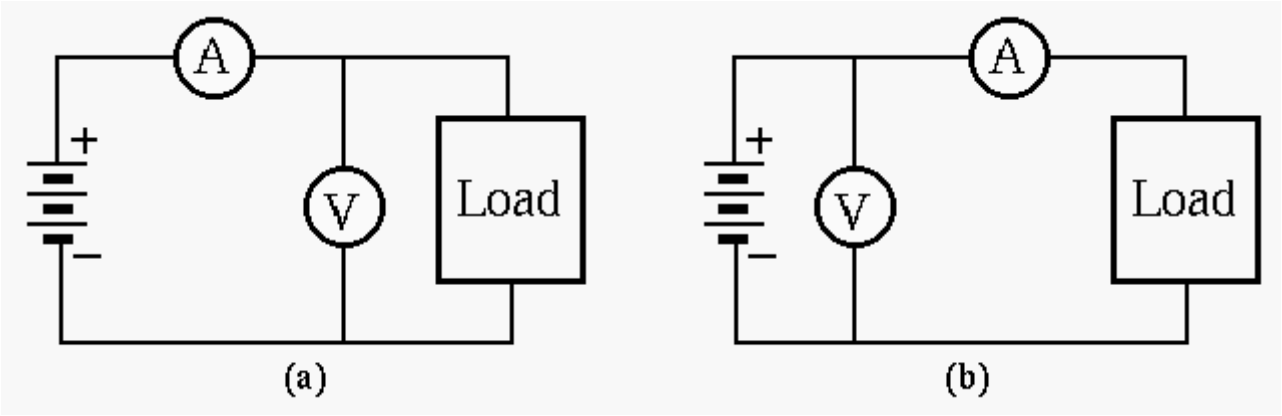
   (b) Replace one of the two bulbs by another bulb labeled as 110V 15W, and find the power consumption of each of the bulbs. What will happen to each of the two bulbs? (Note that when the power consumption by a bulb is larger than the specified wattage, it will be burned out!)

3. Consider the circuit on the left. Give the expressions of voltage V_1 and V_2 across R_1 and R_2, respectively, in terms of R_1 and R_2 as well as the voltage source V.

   In the circuit on the right, give the expressions of the voltages across R_2 and R_4 in terms of the circuit parameters (R_1 through R_4 as well as the voltage source V).



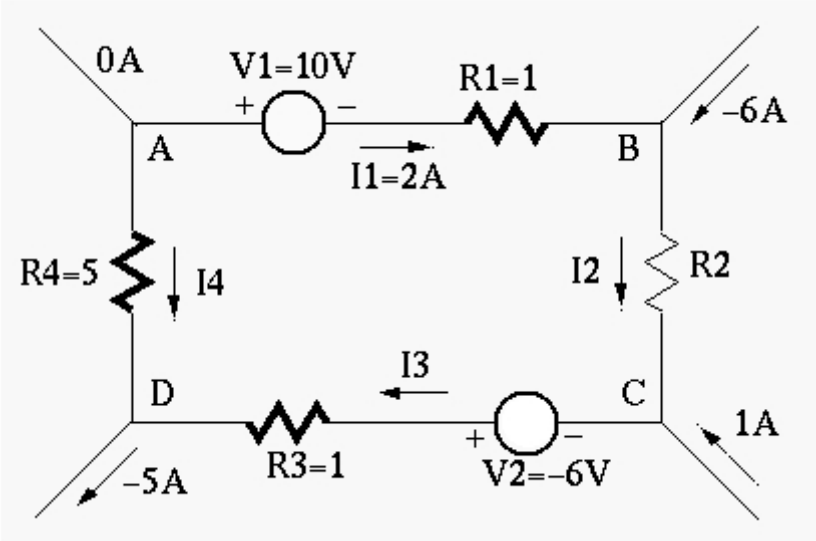
4. Measurement of a physical process by instruments may be tricky due to the inevitable interfere on the process being caused by the instruments (remember what you learned in quantum mechanics?). The figure below shows two possible configurations for the measurement of the voltage across and the current through the load.



   1. What are required of the ammeter and the voltmeter to minimize their influences on the measurements?

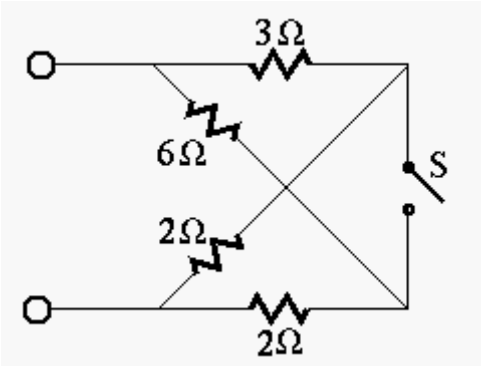
   2. How would the ammeter and the voltmeter affect the measurement of the current and the voltage in either of the configurations (a and b)?

5. Use Kirchhoff's voltage and current laws to find voltage V_{BD} and resistance R_2 in the circuit shown below:



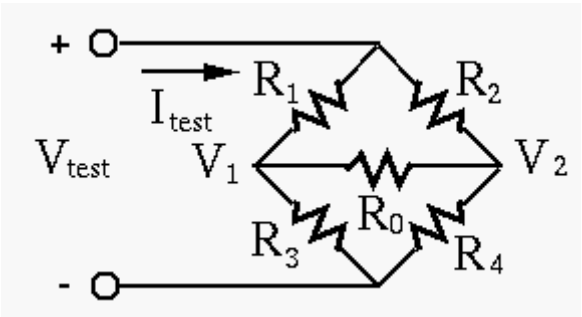
   (Note: The direction of a current and the polarity of a voltage source can be assumed arbitrarily. To determined the actual direction and polarity, the sign of the values also should be considered. For example, a current labeled in left-to-right direction with a negative value is actually flowing right-to-left.)

6. Find the equivalent resistance between the two terminals before and after the switch is closed. (Note, the two diagonal branches are NOT connected to each other in the middle.)



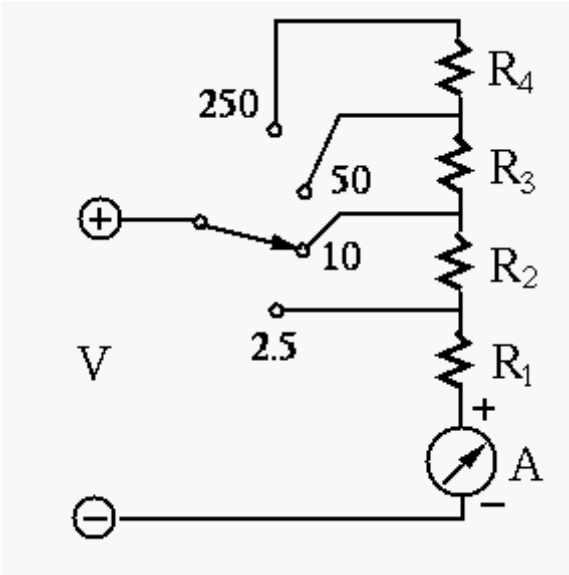
7. (Optional, extra credits) Find the equivalent resistance R_{eq} between the two terminals in the figure, where $R_0 = 3\Omega,\ R_1 = 4\Omega,\ R_2 = 2\Omega,\ R_3 = 2\Omega,\ R_4 = 1\Omega$. What is R_{eq} if $R_0 = 5\Omega$?

   (Hint: apply a test voltage V_{test} across the terminals and the equivalent resistance can be found to be $R_{eq} = V_{test}/I_{test}$. The circuit can be solved by applying KCL to V_1 and V_2.)

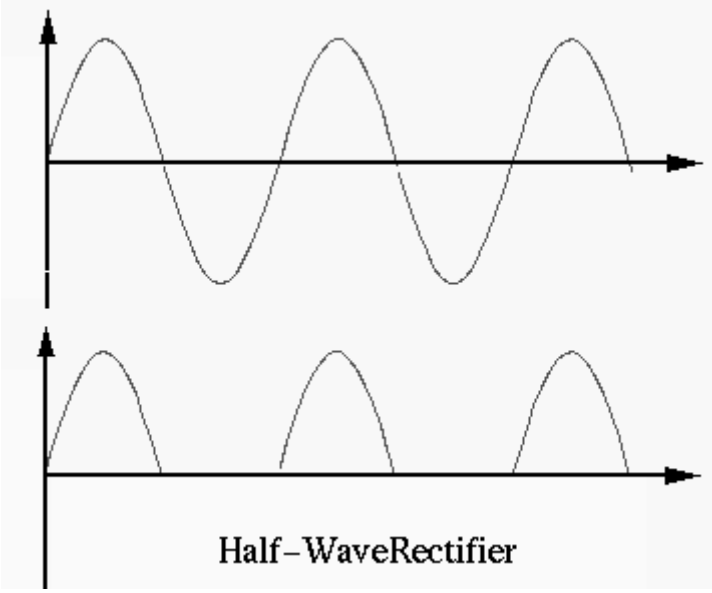


8. Design a multimeter that can measure both DC and AC voltage, DC current, and resistance with different scales. Specifically, you are given an analog meter A with a needle display, which reaches full scale when a DC current of $I = 100\ \mu A = 10^{-4}\ A$ goes through it. The internal resistance of the meter is 10 Ohms. In addition, you need some multi-position rotary switches to select different scales for each of the three types of measurements, and resistors with any values needed in your design.

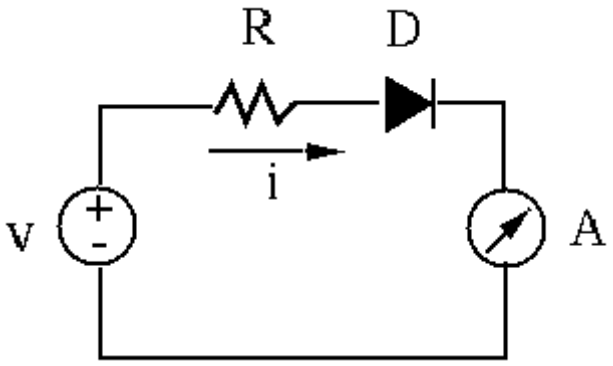
   - DC Voltage measurement: DC voltages in these ranges can be measured 0-2.5, 0-10, 0-50, and 0-250 (all in volts). Use a 4-position rotary switch to select one of the four ranges as shown in the figure below. For example, when the range of 0-10 is selected, the needle display will reach full scale when the voltage being measured is 10 V. The circuit is shown below. Determine all resistances labeled.



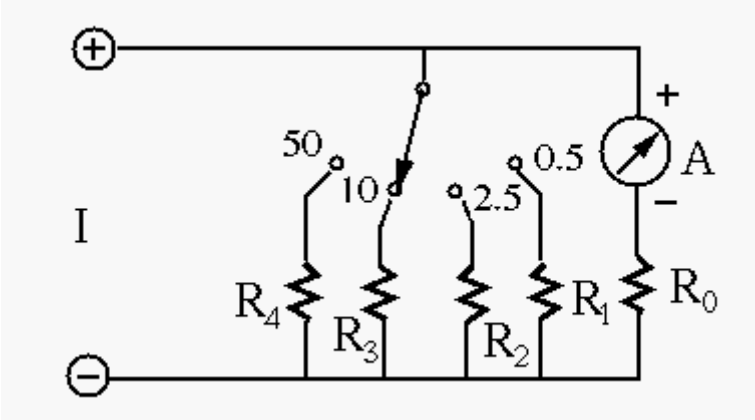
- AC Voltage measurement: To measure an AC voltage (in terms of its RMS value), it first needs to be converted into a DC voltage. This can be achieved by a diode which only allows the current to pass in one direction (along the arrow) but not the other. This process is called rectification.



The diode will also cause a voltage drop of 0.7 volt along the direction. The actual reading of the meter reflects the average value of the rectified current. Find the resistance R so that when the incoming AC voltage is $V = 10$ volt (RMS), the meter shows a full scale display.

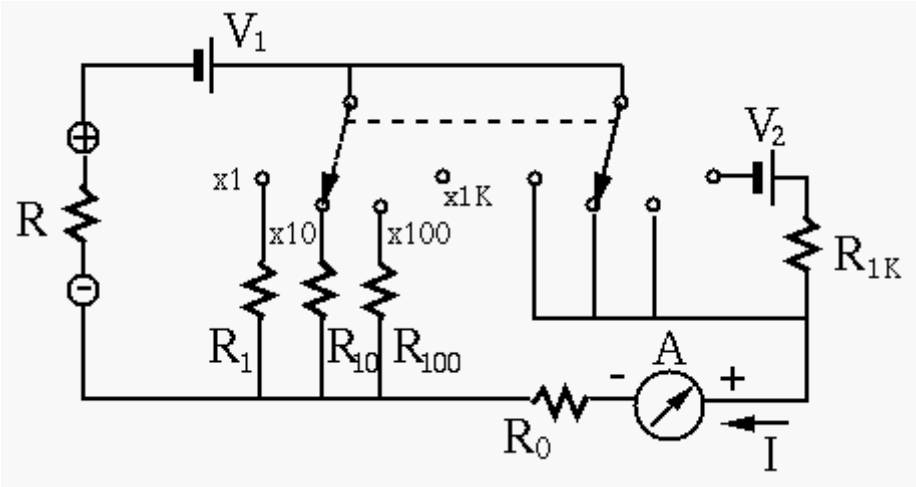


- DC current measurement: measure currents in these ranges (all in mA): 0-0.5, 0-2.5, 0-10, 0-50. Use a 4-position rotary switch to select one of the four ranges as shown in the figure below. For example, when the range of 0-10 is selected, the needle display will reach full scale when a 10 mA current is measured. Determine all resistances labeled. Use $R_0 = 1\ K\Omega$.



- Resistance measurement: The circuit for resistance measurement is provided as shown below, where $V_1 = 1.5V$. Determine the values for the resistors labeled as R_0, R_1, R_{10}, R_{100} and R_{1000} and V_2 so that the needle display of the meter is full scale ($I = 100\ \mu A$) when the resistor $R = 0$ being measured (between the two leads labeled + and -) is zero, or half scale ($I = 50\ \mu A$) when the value of R and the position of he two synchronized rotary switches are given in each of the four case shown in the table:

positions	$\times 1$	$\times 10$	$\times 100$	$\times 1K$
R values	20 Ω	200 Ω	2000 Ω	20 $K\Omega$



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Ruye Wang 2016-09-02