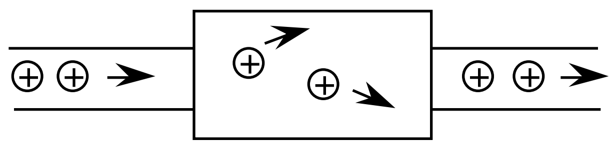
ECE 109 - THE VERY BASICS - INVESTIGATION 4
LINEAR RESISTORS

FALL 2006 **A.P. FELZER**

To do "well" on this investigation you must not only get the right answers but must also do neat, complete and concise writeups that make obvious what each problem is, how you're solving the problem and what your answer is. You also need to include drawings of all circuits as well as appropriate graphs and tables.

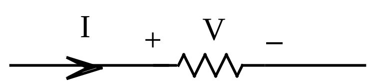
In the last Investigation we found how V and I are related in ideal voltage and current sources. The objective of this Investigation is to determine the relationship between V and I for linear resistors. As you undoubtedly know linear resistors are simply pieces of material like carbon with wires connected to them as follows



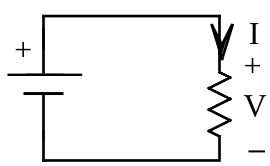
that we represent with the following symbol

The equivalent positive charges flow easily through the wires but it takes work to push them through the carbon (or other resistive material). As a result, there has to be a nonzero voltage drop across a resistor to get the charges flowing. Be sure to take a look at the **Computer Demos** on Ohm's Law.

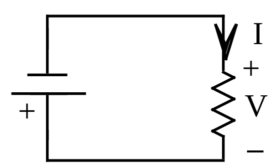
1. To find out how the voltage V (in volts) **across** and current I (in amps) **through** a given resistor as follows



are related we have to do as the first investigators did. We have to go into the lab, connect up different batteries (or voltage sources) as follows



and



and then measure the corresponding currents I. Suppose we do this for a **particular** resistor and obtain the following data

V (volts)	I (ma)
-4	-2
-2	-1
0	0
2	1
4	2

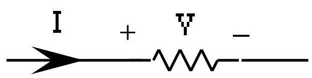
where **ma** is shorthand for milliamp = 10^{-3} amps. Our goal in this problem is to get an equation for V as a function of I for **this** particular resistor

a. First plot a graph of the data points with V in **volts** as a function of I in **amps** (**not ma**).

Then draw a curve through your data points. Describe your curve

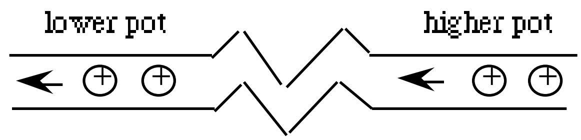
b. Find an equation for your curve with V (in **volts**) as a function of I (in **amps**)
c. Why would you say that we refer to such resistors as **linear** resistors
d. What does your **model** for this resistor - your equation - predict for the voltage V when I = -2 ma.
e. What do you predict for V when I = 2.5 ma

2. The objective of this problem is to see what happens to the potential energies of equivalent positive charges as they flow through the resistor in Problem (1) with **reference directions** as follows



a. First draw pictures like the following

V = – 4 volts
I = – 2 ma

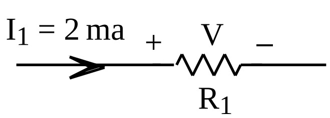


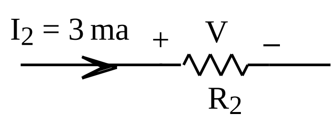
for **each** of the data points in Problem (1) - pictures that show

(1) Which way the equivalent positive charges are flowing and
(2) Which node is at the higher and which at the lower potential

b. Now make use of your pictures in part (a) to set up a Table that indicates - for each data point - whether the equivalent positive charge flowing through the resistor is going from higher to lower or lower to higher potential.
c. What does your Table in part (b) tell you about the transfer of energy in the resistor - are the equivalent positive charges flowing through this resistor always losing potential energy, always gaining potential energy or sometimes gaining and sometimes losing potential energy.
d. Are your results in part (c) what you expected - are they consistent with your understanding of what's going on inside resistors. Why

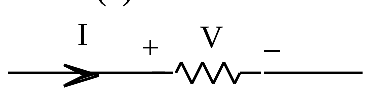
3. Now suppose we apply the same voltage V across two resistors R_1 and R_2 as follows





and obtain the currents I_1 and I_2 as shown. Which resistor would you say has the higher **resistance** - most **resists** the flow of charge when a voltage is applied across its terminals. How can you tell

4. We know from our results in Problem (1) that V and I for linear resistors like the following



are related by equations like V = 1000 I and V = 2000 I where V is in *volts* and I is in *amps*. We refer to the coefficient of I as the resistor's **resistance R** with V = RI

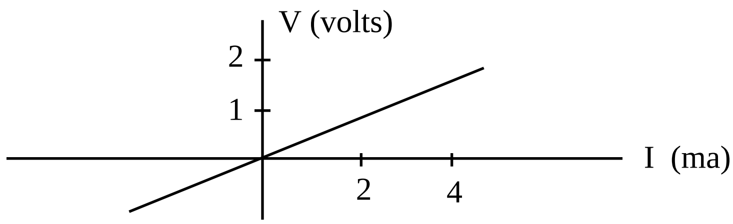
a. Verify that the units of R are volts/amp
b. How does increasing the size of the resistance R affect I for a given V
c. Make use of your result in part (b) to explain why we call the coefficient of I the

resistance of the resistor.

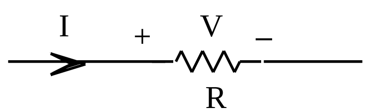
5. Engineers and scientists usually use the term **ohm** (Ω) instead of the more cumbersome volts/amp with

$$1 \text{ ohm} = \frac{1 \text{ volt}}{\text{amp}}$$

when specifying resistances. We also make use of the shorthand 1K for 1000Ω. Now express the resistances of the following resistors in volts/amp as well as ohms
   a. A resistor characterized by $V = 4000\,I$
   b. A resistor characterized by the following curve (Be sure to note that the current on this graph is in milliamps)

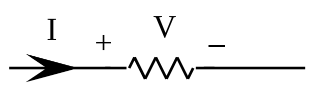


6. Find the current I in the following circuit

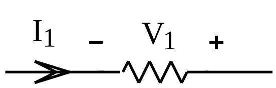


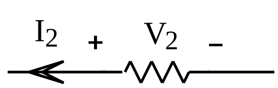
if the resistance R = 1K ohms and the voltage V is
   a. V = 2 volts
   b. V = –2 volts

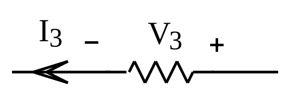
7. Up to now the reference directions of our resistors have all been **associated reference directions** - reference directions with the current reference arrow pointing from the plus to the minus of the voltage reference direction as follows



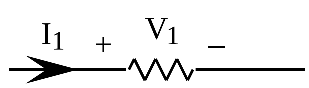
Memorize this definition. Then make use of it to determine which of the following resistors have associated reference directions and which do not

a.


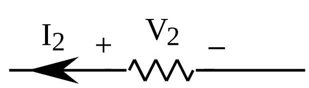
b.


c.


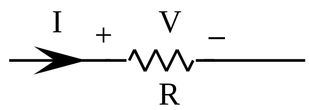
8. Suppose Engineer 1 measures $V_1 = 3$ volts and $I_1 = 2$ ma for a resistor with associated reference directions as follows



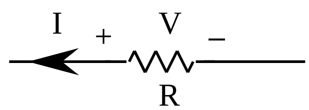
Then what will Engineer 2 measure for the same resistor if the reference directions are not associated as follows



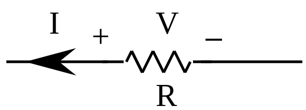
9. Now whenever we go into a lab and measure V and I of a resistor with *associated* reference directions as follows



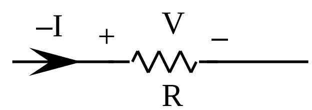
we always find that V = RI. The objective of this problem is to find the relationship between V and I when the reference directions are *not associated* like the following



The trick is to make use of the fact that non-associated reference directions can be turned around to make them associated as follows

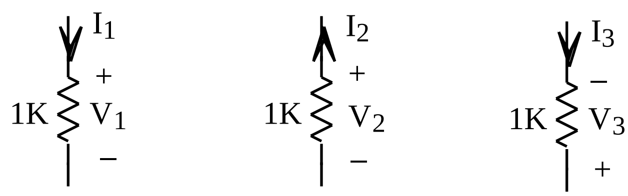


is equivalent to



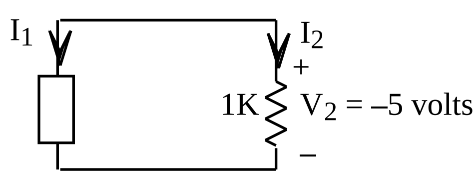
Make use of this equivalence to find V as a function of I for this resistor.

10. Generalizing on the result of Problem (9) we have that whenever the reference directions of a resistor are associated then $V = RI$ but when they're not associated then $V = -RI$. **Memorize** this result. Then make use of it to express each of the following voltages in terms of the corresponding currents

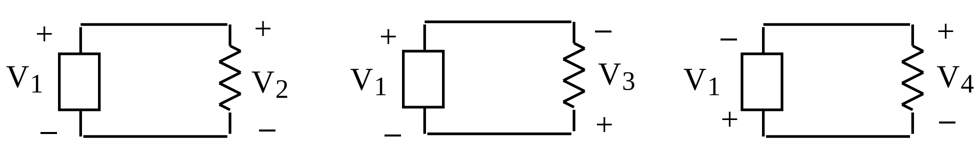


11. Now as you surely know **V = RI** is known as **Ohm's Law**. What was Ohm assuming about the reference directions of V and I when he wrote Ohm's Law.

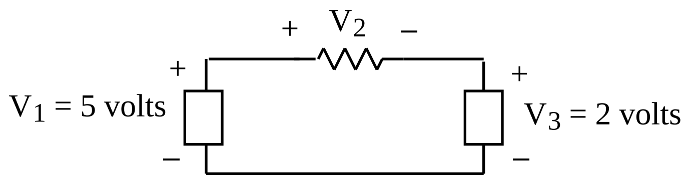
12. Find I_1 and I_2 in the following circuit



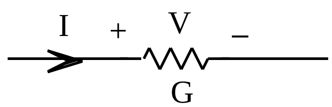
13. Find the voltage drops V_2, V_3 and V_4 across each of the following resistors assuming the wires are ideal with no voltage drops and $V_1 = 5$ volts



14. Find V_2 across the resistor in the following circuit



15. When we take our equation V = RI for a linear resistor as follows



and solve for I we obtain I = (1/R)V = GV where **G = 1/R** is defined to be the **conductance** of the resistor. Conductance is measured in **siemens S** with 1 siemen = 1/ohm. Find the current through the resistor above with V = 5 volts and conductance $G = 10^{-3}$ S

16. Math Review - Sketch $V = \dfrac{R}{1000 + R}$ for $R > 0$