ECE 109 - THE VERY BASICS - INVESTIGATION 2
VOLTAGE DROPS

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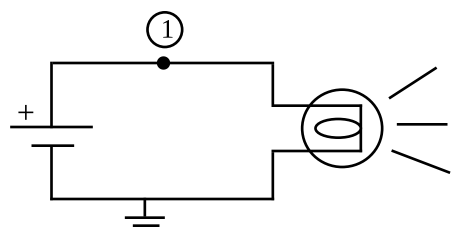
To do "well" on this investigation you must not only get the right answers but must also do neat, complete and concise writeups that make obvious what each problem is, how you're solving the problem and what your answer is. You also need to include drawings of all circuits as well as appropriate graphs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

We know from the last Investigation that if we could "look inside" our circuits we'd see negatively charged electrons flowing through the wires and circuit elements. This is of prime importance because as these charges flow through a circuit they take the energy they receive from the batteries and power supplies and *transfer* it to "circuit elements" like light bulbs and speakers which in turn convert the energy to "nice useful" things like light and sound.

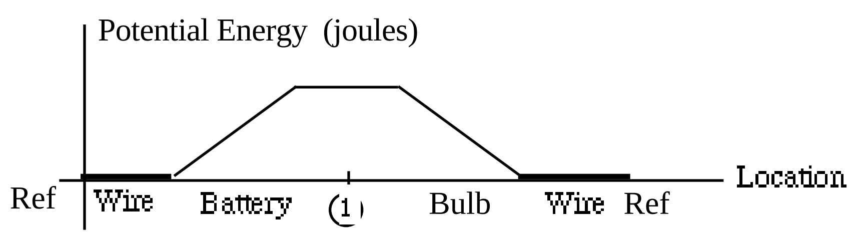
The objective of this Investigation is to show how we keep track of *energy transfer* in circuits by finding the **changes** in the potential energies of the equivalent positive charges as they flow through the circuit elements. Be sure to take a look at the **Computer Demos** on Voltage Reference Directions.

1. Let us begin with our flashlight circuit as follows



As equivalent positive charges starting from the **reference** - the node with the following (ground) symbol

flow clockwise around the circuit their *potential energies* are going to *increase* as they receive energy from the battery, *decrease* as they transfer energy to the filament of the light bulb and stay *constant* as they flow through the *ideal wires* as shown in the following graph

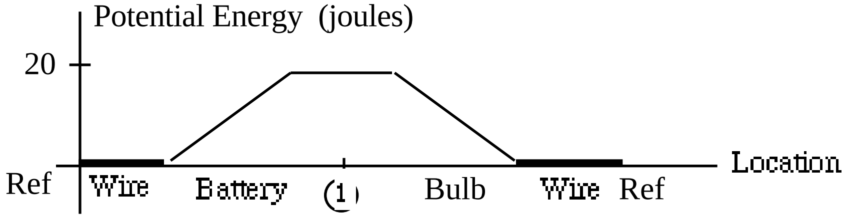


We refer to these potential energies as being *with respect to* the reference. They are the differences between the potential energies of equivalent positive charges at different locations in the circuit and the potential energies of equivalent positive charges at the reference.

a. Where in the flashlight circuit is the potential energy of the equivalent positive charges largest
b. Where in the flashlight circuit is the potential energy of the equivalent positive charges

smallest

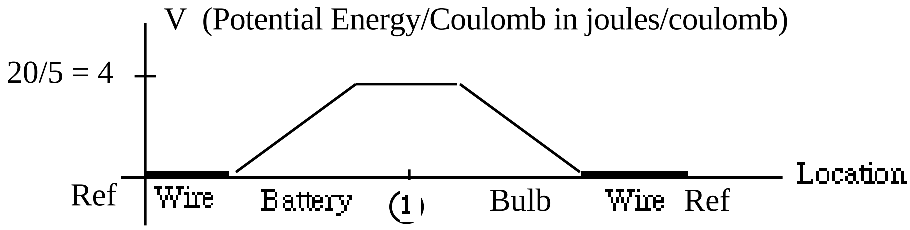
2. From Problem (1) we know that the potential energy of equivalent positive charge in a circuit varies as a function of its **location** with respect to the reference. Suppose in particular that the potential energy of $Q = 5$ coulombs of equivalent positive charge in a given flashlight circuit varies as follows



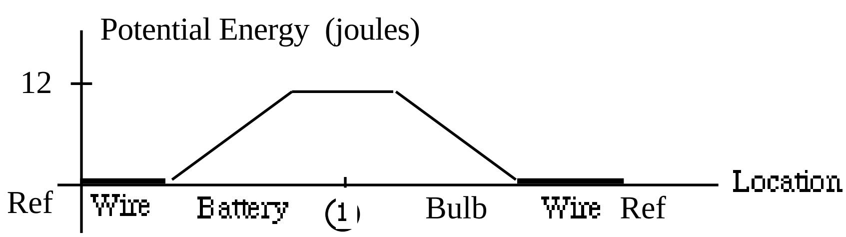
Graphs of potential energy are great but we have to draw a new one every time Q changes. One way to eliminate all this redrawing is to graph what we call the **potential** *V* as follows

$$\text{Potential } V = \frac{\text{Potential Energy}}{Q} = \text{Potential Energy per Coulomb of Charge}$$

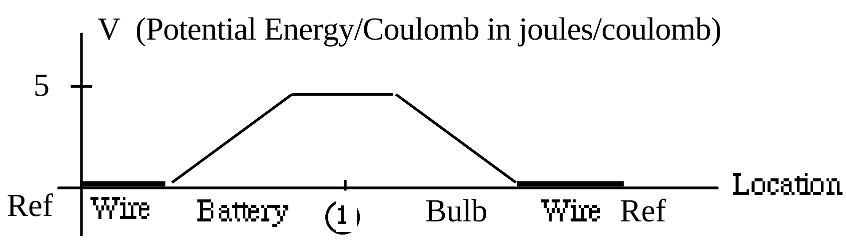
as follows



a. How are graphs of potential the same as graphs of potential energy and how are they different
b. Sketch a graph of the potential in a flashlight if the potential energy of $Q = 4$ coulombs of equivalent charge as a function of its location with respect to the reference is as follows

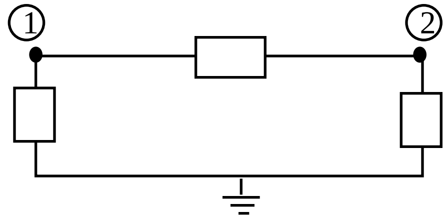


c. Sketch a graph of the potential energy in a flashlight circuit for $Q = 4$ coulombs of equivalent positive charge if the potential is as follows



3. The objective of this problem is to do some calculations with potentials V in a bigger circuit.

Suppose that in the following circuit with boxes containing batteries and light bulbs



the potentials at the nodes 1 and 2 with respect to the reference are $V_1 = 8$ joules/coulomb and $V_2 = 5$ joules/coulomb

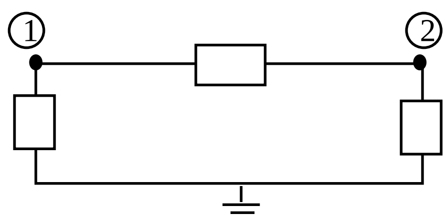
a. Find the potential energy of $Q = 4$ coulombs of equivalent positive charge at node 1 with respect to the reference
b. Find the potential energy of $Q = 4$ coulombs of equivalent positive charge at node 2 with respect to the reference
c. Find the potential energy of $Q = 4$ coulombs of equivalent positive charge at node 1 with respect to its potential energy at node 2

4. Instead of using the more cumbersome units joules/coul every time we want to work with potentials we define the unit **volt** as follows

$$1\,volt \equiv \frac{1\,joule}{coulomb}$$

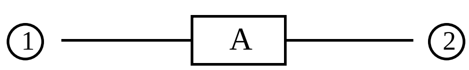
Express the potentials V_1 and V_2 at nodes 1 and 2 in Problem (3) in terms of volts

5. Up to now all our potentials have been positive numbers corresponding to the fact it's taken work to move the equivalent positive charges from the reference to the other nodes. When the potential energy at a given node is less than that at the reference we assign it a negative value. What are the potentials V_1 and V_2 at nodes 1 and 2 in the following circuit



if the potential at node 1 is 3 joules/coul more than the potential at the reference but the potential at node 2 is 5 joules/coul less than the potential at the reference.

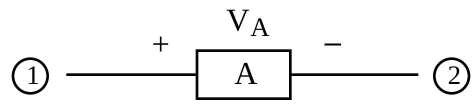
6. Now suppose 2 coulombs of equivalent positive charge is flowing from node 1 to node 2 through the following circuit element A



a. By how much will its potential energy change if the potentials at nodes 1 and 2 are $V_1 = 5$ volts and $V_2 = 2$ volts.
b. At which node do the equivalent positive charges have more potential energy

7. We refer to **differences** in potentials as **voltage drops**. We denote a voltage drop V_A from a

node 1 to a node 2 with a plus and a minus as follows

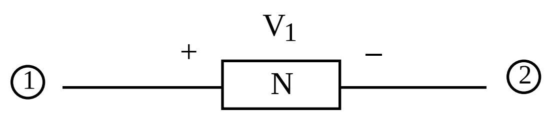


$V_A \equiv$ (Potential at the node with the **plus**) – (Potential at the node with the **minus**)

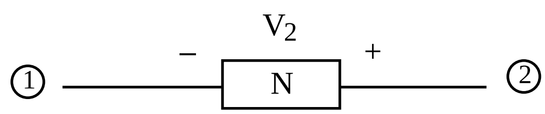
Memorize this expression for calculating voltage drops. Note, in particular, that the plus and the minus signs specify the **voltage reference direction** - they specify which potential to subtract from which for a given voltage drop V.

a. Find V_A if $V_1 = 5$ volts and $V_2 = 2$ volts
b. Find V_A if $V_1 = 3$ volts and $V_2 = 7$ volts
c. Label on the circuit diagram which side is at the higher potential and which is at the lower potential when $V_A > 0$. Justify
d. Repeat part (c) for $V_A < 0$

8. Suppose an engineer measures the voltage drop $V_1 = 3$ volts across the following circuit element N

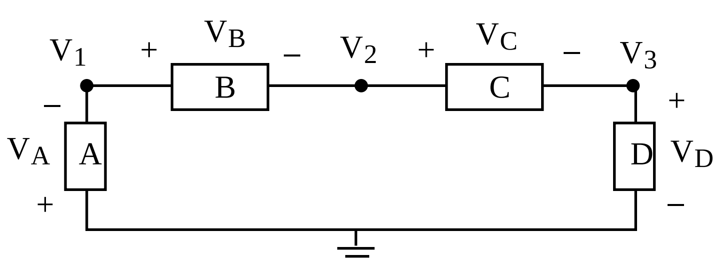


a. Now suppose a second engineer also measures the voltage across N but for the opposite voltage reference directions as follows



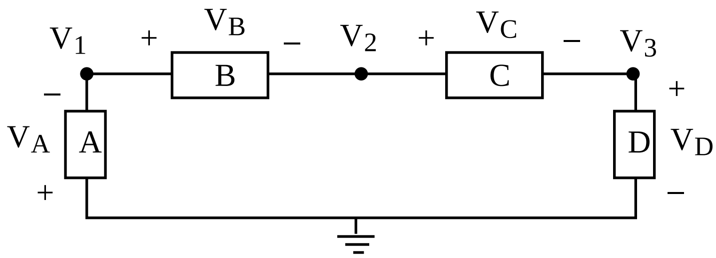
What will the second engineer measure.
b. Express V_2 as a function of V_1. Then describe in words how they're related.
c. How in general does reversing a voltage reference direction affect the value of the voltage. **Memorize** this result.

9. Now let's look at the following "whole" circuit



a. Find the voltage drops V_A, V_B, V_C and V_D across the circuit elements if the **node voltages** (the voltage drops from the nodes to the reference) are $V_1 = 10$ volts, $V_2 = 7$ volts and $V_3 = 2$ volts
b. Which circuit elements are transferring energy to the equivalent positive charges if they're flowing clockwise around the circuit

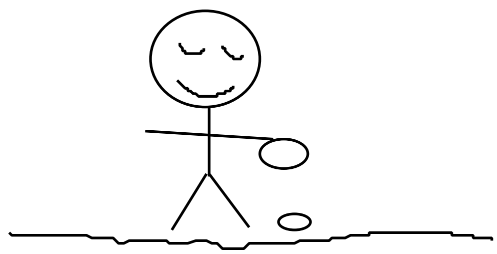
10. Given the following circuit



with voltage drops across the circuit elements equal as follows: $V_A = -5$ volts, $V_B = 2$, $V_C = -4$ volts and $V_D = 7$ volts.

a. Draw a graph like the one you drew in Problem (2) that shows the potential of equivalent positive charge in the circuit as a function of location.
b. Find the node voltages V_1, V_2 and V_3 with respect to the reference node.

11. And now, last but not least, explain how the operation of a flashlight is analogous to the cracking of nuts by lifting and then dropping rocks on them as illustrated by



12. Math Review: Sketch a graph of $V = -2 + 4000I$