Fri., 2/20	**18.8-10** Energy , Applications of the Theory	**Exp** 18,19,22-24
Spring Recess		
Mon., 3/2 Tues., 3/3 Wed., 3/4 Thurs., 3/5	**19.1-5** Capacitor Circuits **19.6-.14** Capacitor & Resistor Circuits **Quiz** Ch 18, **19.15-17,19** Meters and RC Circuits	**RE17, Exp** 29,30 **HW18:**RQ.38, 41, 44; P.49, 52, 56 (hint: consider V at spheres when L>>R,r) **RE18, Exp** 31-34 **Exp** 35-37

Need to finish these notes off, a candidate came this day, and I didn't actually run class.

Equipment

Announcements

Last Time

Surface Charge Density gradient causes electric field parallel to wire, necessary for constant i.

This Time

18.8 Energy in a Circuit

From before, we know that the electric potential difference (potential energy per charge) around any closed loop is zero. If a round trip passes through "elements" (battery, wire, resistor, etc.) 1, 2, etc., then:

Loop Rule: $\Delta V_1 + \Delta V_2 + \ldots = 0$ around any closed loop in a circuit

18.8.1 Potential Difference Across a battery

18.8.2 Internal Resistance

In this chapter, the book simply introduces the idea that the internal electric field must balance the charge's drive to move across the battery. If we represent the latter as a non-coulombic force, F_{NC}, then in equilibrium, F_{NC} = eE. When things aren't in balance, charge is flowing. The net force would be F_{NC} – eE. Using the idea of mobility, one would say, in this case it's the difference between these two forces that drives the drift of charges: v = u(F_{NC}/e – E).

The voltage drop across the battery is

$$|\Delta V_{\text{batt}}| = E_C s,$$

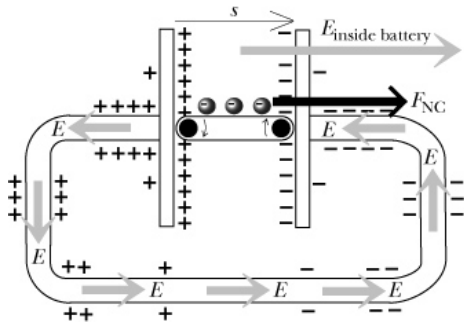
where *s* is the distance between ends of the battery. The change in potential energy associated with the noncoulombic force driving a charge across the battery is ΔU = FNCs, or dividing that e to get the energy per charge, we can define that as

emf = F_{NC}s/e

In the next chapter, we will learn how to model the internal resistance of batteries, which is a resistance to the flow of current. For an ideal battery, the internal resistance is negligible.

18.8.3 Field and Current in a Simple Circuit

The analysis of a simple circuit with a uniform wire is easy.



For a complete counterclockwise loop around the circuit:

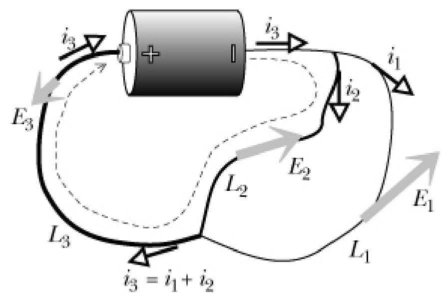
$$\Delta V_{\text{batt}} + \Delta V_{\text{wire}} = 0,$$

$$\text{emf} + (-EL) = 0,$$

$$E = \frac{\text{emf}}{L}..$$

18.8.4 A Parallel Circuit: two different paths

Consider the circuit below with multiple paths. The loop rule can be applied to any closed path.



For the clockwise path drawn (note the sign differences compared to above):

$$E_2 L_2 + E_3 L_3 - \text{emf} = 0$$

For a clockwise path through L_1, L_3, and the battery:

$$E_1 L_1 + E_3 L_3 - \text{emf} = 0$$

Together, those equations imply:

$$E_1 L_1 = E_2 L_2,$$

which we could also get with a loop through just L_1 and L_2 (if clockwise: $E_1 L_1 - E_2 L_2 = 0$).

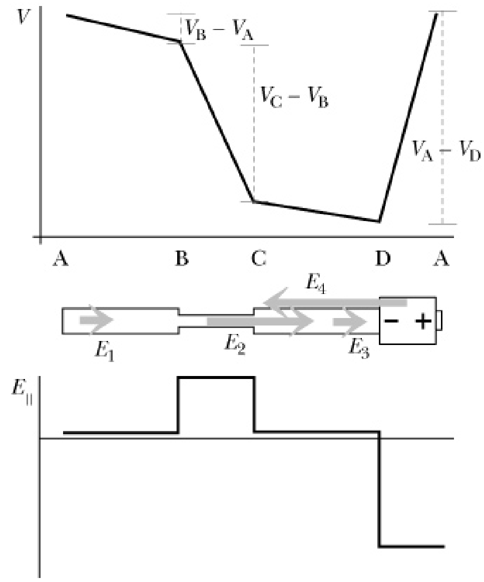
ADD A BETTER EXAMPLE WITH NUMBERS!

18.8.5 Potential difference across connecting wires

18.8.6 General use of the loop rule

18.9 Application: Energy in Circuits

Sometimes the textbook "flattens out" circuits to make graphs of electric potential and electric field like the following.



Note that the electric potential must return to the same value (not necessarily zero). Also, the magnitude of the electric field is minus the slope of the electric potential.

18.10 Application of the Theory

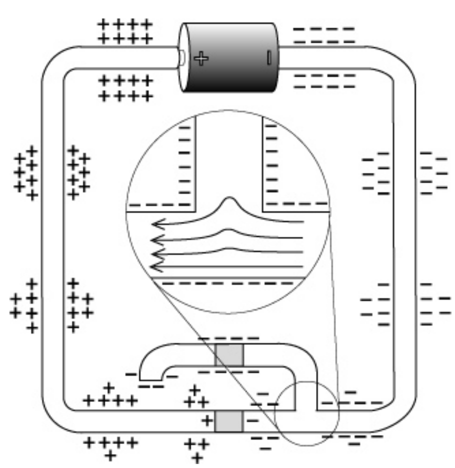
18.10.1 Application: doubling the length of a wire

18.10.2 Application: doubling the cross-sectional area of a wire

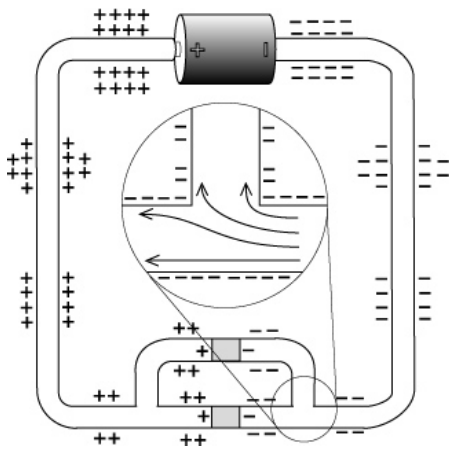
18.10.3 Quantitative measurements of current with a compass

18.10.4 How does current know how to divide between parallel resistors?

Before the second branch is connected at the second end, it becomes negatively charged and no current flows into it.



When the second branch is connected, the charges rearrange to guide current through it.

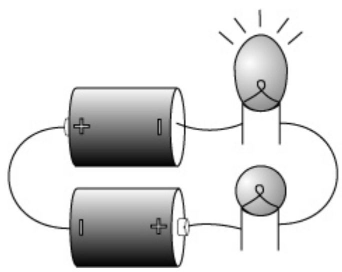


The potential difference (EL) must be the same size for each branch (loop rule), but the currents may be different. The one that conducts better will have more current ($i = nAuE$).

18.10.5 Application: round bulb and long bulb in series

Example: Round bulb and long bulb in series

If you try this, the long bulb will light up, but not the round one.



The current must be the same through both bulbs (node rule). Suppose the mobility u is the same for both bulbs, then:

$$nA_r uE_r = nA_\ell uE_\ell \quad \text{and} \quad E_\ell = \frac{A_r}{A_\ell} E_r$$

We know that the filament of the round bulb is thicker, $A_r > A_\ell$, so $E_r < E_\ell$.

We can also compare the electric field of the round bulb in this circuit with the field in a circuit with just the round bulb. The lengths of the filaments in the two bulbs are approximately the same, so the loop rule gives:

$$2(\text{emf}) - E_r L - E_\ell L = 0,$$

$$2(\text{emf}) = E_r L\left(1 + \frac{A_r}{A_\ell}\right),$$

$$E_r = \frac{2(\text{emf})}{L(1 + A_r/A_\ell)} < \frac{2(\text{emf})}{L},$$

because $A_r / A_\ell > 1$. The electric field in the round bulb when only it is connected is $E_{\text{r,bright}} = 2(\text{emf})/L$. The electric field in the round bulb (and the change in electric potential across it) is too small to make it glow.

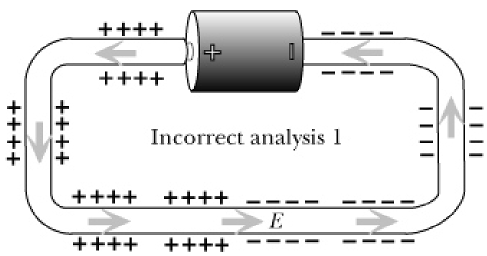
In addition, the round bulb is not as warm so its mobility is higher. That means an even smaller electric field than estimated above is needed to drive the current through it.

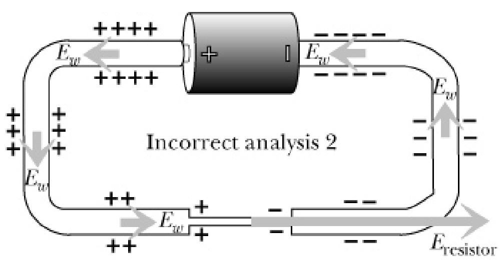
18.10.6 Application: Two batteries in series

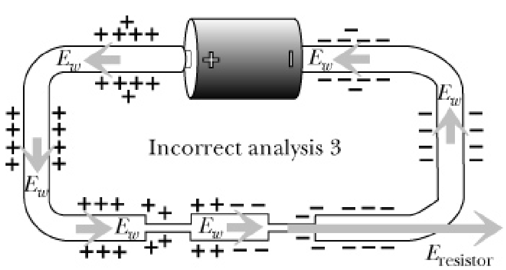
18.11 Detecting Surface Charge

Monday: Applications (5 Experiments!)

What is incorrect about the surface charge in each figure below?







Experiments: If the distance to the wire is the same, then $I \propto B_{\text{wire}}$. The magnetic field is found using $B_{\text{wire}} = B_{\text{Earth}} \tan\theta$, but the field is approximately proportional to the deflection angle is less than 15°.

Exp 18.18 – Twice the length of Nichrome wire should result in half the current. The resistance of the Nichrome is much more than the copper wire, so extra connecting wires don't matter much. The potential difference (EL) must be approximately equal to the *emf* of the battery in both cases. If the length L doubles, the current is half because $i = nAuE$ (the other properties don't change).

Exp 18.19 – The current with two bulbs is a little more than half (about 0.7) of the current with one bulb. With a single bulb and more current, the light bulb heats up and its electron mobility (u) decreases. Again, the resistance of the wires doesn't matter much.

Exp 18.22 – The current should be double when the cross sectional area is double. Since the length of the wire is the same, the electric field is the same size: $E = \text{emf}/L$. The electron current is $i = nAuE$ and the mobility u does not change much.

Exp 18.23 –

(a) The bulbs are brighter when they are in parallel than when they are in series, because they have the whole potential difference of the battery in that case.

(b) Unscrewing one of the bulbs in parallel has little effect on the other one. We'll worry about the slight difference in the next chapter when we have a better model of the battery.

(c) Predictions

(d) Should find that $i_A = 2i_B = 2i_C = i_D$. About half of the current goes through each of the identical light bulbs.

Exp 18.24 – Doubling the emf should result in double the current.

Resistance

This chapter, "A *Microscopic* View of Electric Circuits" has focused on building a solid, largely qualitative, fundamental picture of what's going on in circuits. If you've had physics before, and had an 'electronics' section, it probably didn't start off with a *microscopic* perspective, and thus it was presented as an independent science unto itself. Hopefully this chapter has helped to position electronics appropriately in the larger framework of physics. The next chapter will keep its fundamental, microscopic basis, but also scale up. Here's a little step in that direction.

Q: How does ΔV across a circuit element (stretch of wire, say,) relate to the electric field in it?

$$\Delta V = -EL$$

Q: How does the conventional current through a circuit element (stretch of wire, say,) relate to the electric field in it?

$$I = qnA\bar{v} = qnAuE$$

So, both voltage and current are proportional to field, solving for field in both and setting them equal to each other gives

$$\frac{\Delta V}{L} = E = -\frac{I}{qnAu} \Rightarrow \Delta V = -I\left(\frac{L}{qnAu}\right)$$

That's perhaps a familiar form. The stuff in brackets, how long the wire is, how thick it is, how mobile charge carriers are,… determines how much current flows when you've got a given voltage drop motivating it. The stuff in brackets defines the **Resistance** of the circuit element.

$$R = \left(\frac{L}{qnAu}\right)$$

$$\Delta V = -IR$$