

DAY 11

Summary of Topics Covered in Today's Lecture

Kirchoff's Two Common-Sense Rules

The key to understanding electric circuits (be they circuits in a home's wiring system, circuits on a circuit board, circuits in the human nervous system, or circuits in energetic astrophysical phenomena), is two simple rules. These are called Kirchoff's Laws:

**Kirchoff's
Voltage Law or
"The Loop Law"**

In any system, if you follow a closed loop (your ending point is the same as your starting point), then the potential where you started is the same as the potential where you ended.

(DUH! It has to be the same if you ended up where you started!).

Therefore, all increases in potential along your path are matched by decreases in potential.

(DUUUUHHHH! Since you ended at the same place you started, then however much you went up, that's how much you had to go down. Contrary to what grandpa said about his walk to school, you can't go uphill both ways!)

Σ Voltage Rises = Σ Voltage Drops

**Kirchoff's
Current Law or
"The Junction
Law"**

Charge cannot be created or destroyed. Therefore, if you have a junction in a system, the total current flowing into the junction must be the total current flowing out of the junction.

Σ Current In = Σ Current Out

Kirchoff's Laws always hold true. Between Kirchoff's Laws, Ohm's Law, and the Power law, you can deal with almost any circuit.

Magnets

We've all encountered magnets in our lives - you probably have a bunch on your refrigerator.

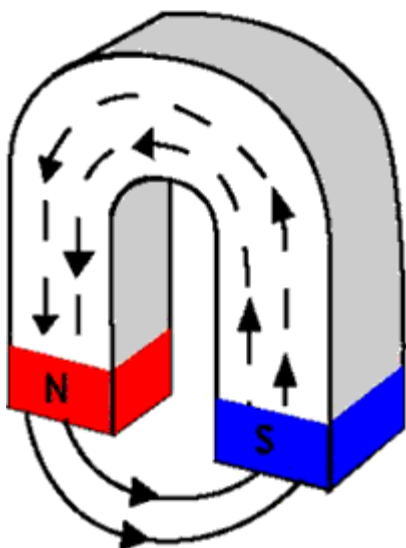
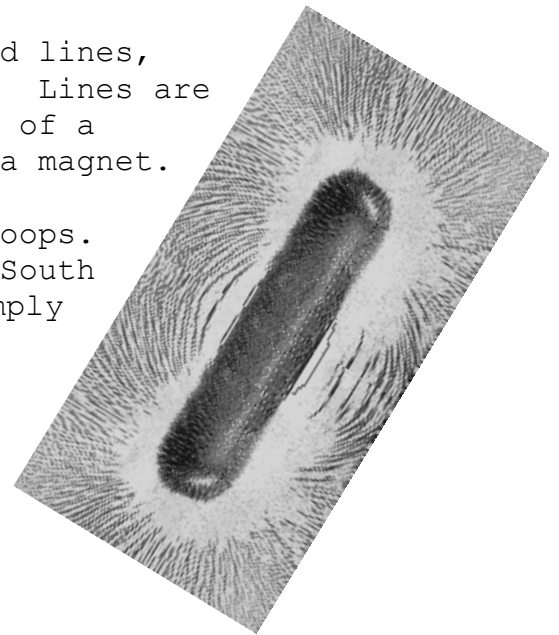
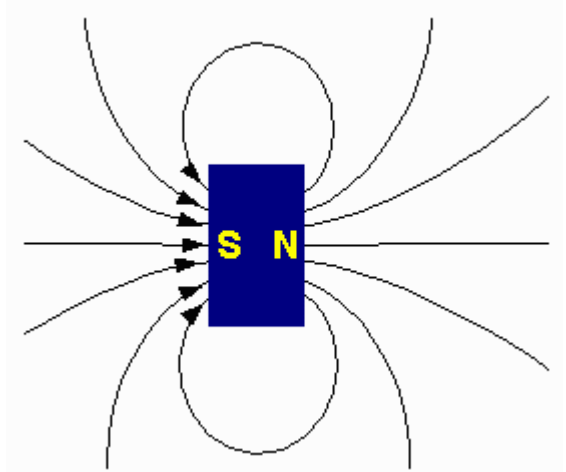
A magnet, if hung freely on a string, will orient itself roughly North-South. The end of the magnet that points toward the North is called the magnet's *North Pole*. The other end is called the *South Pole*. If you play with a couple of magnets you will find that *like poles repel each other, while opposite poles attract one another*. Either pole of a magnet will attract certain metal objects such as paper clips or staples.

Magnetic Field

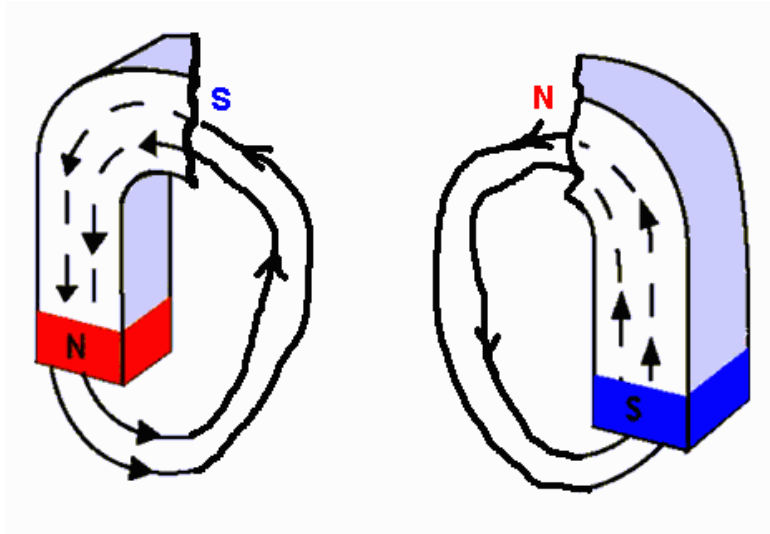
A magnet produces a *magnetic field* (**B**). The magnetic field of a simple bar magnetic (a rectangular magnet with N and S poles at opposite ends) looks something like the figure at right.

Unlike Electric fields, Magnetic fields can be seen fairly easily. The usual demonstration involves sprinkling iron filings around a magnet. The filings line up with the field.

Magnetic fields can be represented with field lines, just like gravitational and electric fields. Lines are typically shown emerging from the North Pole of a magnet, and converging at the South Pole of a magnet. Magnetic field lines actually do not have a beginning or an end - they form continuous loops. Thus you can never get an isolated North or South pole. A North Pole is simply a point from which field lines emerge.

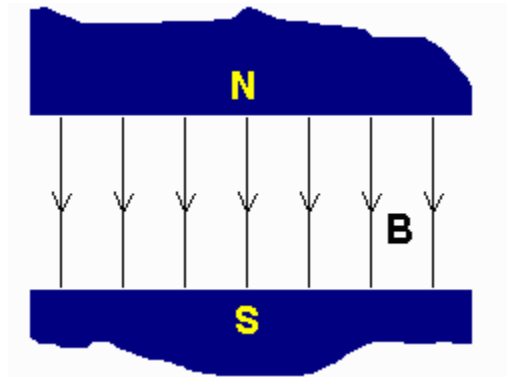


If you break a magnet in half, you get two smaller magnets, each with a North and South pole, because the field line loops simply emerge now from the broken spots:



Pictures from <http://www.ndt-ed.org/EducationResources/CommunityCollege/MagParticle/Physics/MagneticFieldChar.htm>

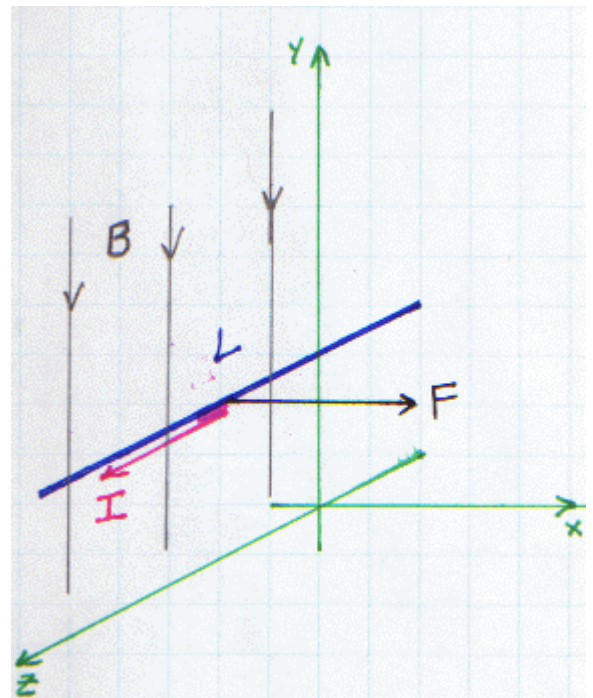
A fairly uniform B-field can be established between the poles of a large magnet as shown below.



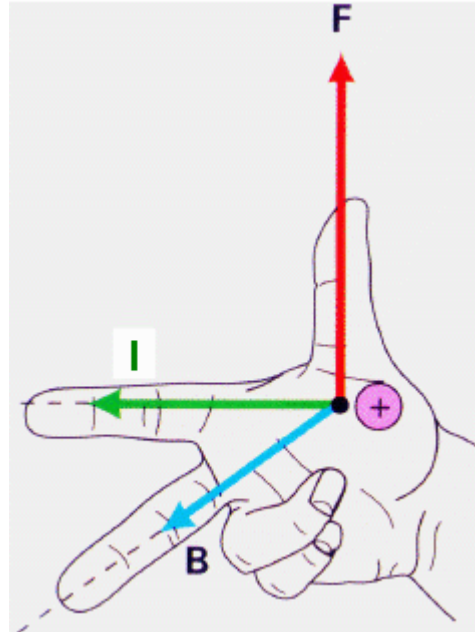
Magnetic Fields Exert Forces on Moving Charges

If a wire of length L , carrying current I , is placed in a uniform magnetic field of strength B , the field will exert a force on the wire that is given by

$$\vec{F} = \vec{I}L \times \vec{B}$$



This is a vector cross product (remember this from torque in Physics I?), so the direction of F is given by the right-hand-rule (RHR). Your index finger points in the direction of the current flow (positive charge motion). Your middle finger points at 90° to your index finger, in the direction of the magnetic field. Your thumb is then fully extended.



<http://www.physics.brocku.ca/faculty/sternin/120/slides/rh-rule.html>

If the current flow is perpendicular to the B field, this equation becomes simply $F = ILB$. $B = F/(IL)$, meaning that B has units of $N/(Am)$. This unit is called a Tesla.

$$1 \text{ T} = 1 \text{ N}/(\text{Am})$$

We can also write this in terms of the speed of moving charges. If the current I is formed by a charge q moving at speed v , then if we remember that $I = q/t$ and $v = L/t$ we can make a few substitutions and get a different form of the same equation:

$$\vec{F} = \frac{q}{t} L \times \vec{B} = q \frac{L}{t} \times \vec{B} = q\vec{v} \times \vec{B}$$

As when we dealt with torques, we will represent vectors that point directly at us with this symbol:

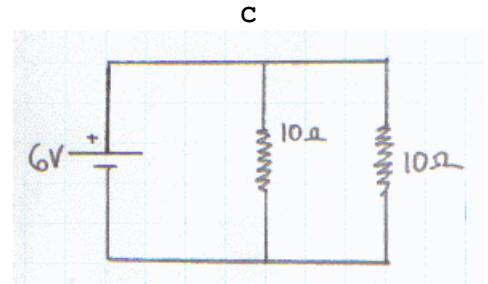
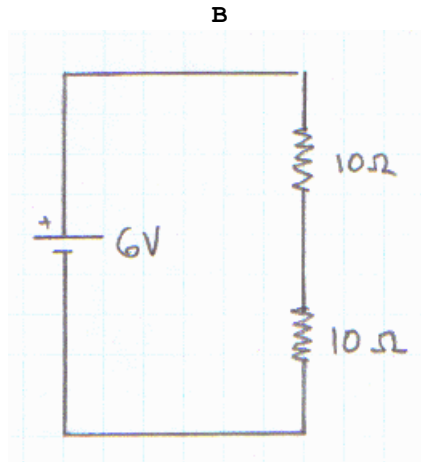
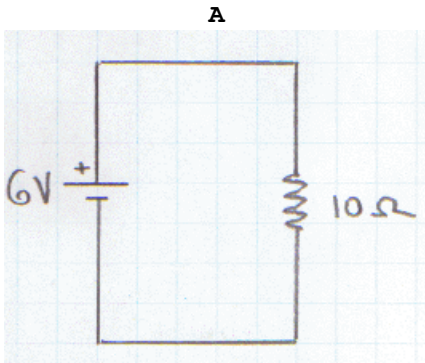


Vectors that point directly away from us we represent with this symbol:



Example Problem #1

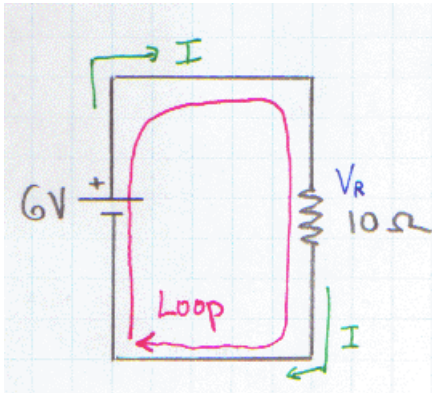
Determine the current through each branch of the circuits below and calculate the power supplied by the battery in each circuit.



Solution:

In each circuit I will apply Kirchoff's Laws, Ohm's Law, and the Power equation. I start by drawing in loop-paths to follow with Kirchoff's Loop Law. I also label the current in each branch of the circuit. Then I apply Kirchoff's Laws.

1st circuit—



Loop Law:

$$\sum V_{\text{rises}} = \sum V_{\text{drops}}$$

$$6V = V_R$$

$$6V = I(10\Omega)$$

$$6V = I(10\frac{V}{A})$$

$$.6A = I$$

$$V_R = IR$$

(Ohm's Law)

Junction Law says this is the same current as the battery generates

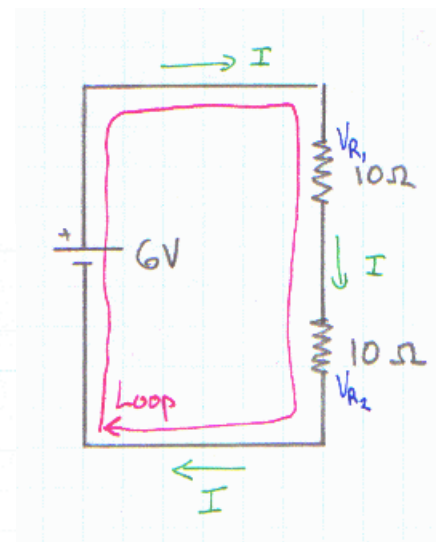
Power from battery: $P = IU$

$$P = .6A(6V)$$

$$= .6\frac{C}{s}(6\frac{J}{C})$$

$$= 3.6\frac{J}{s} = 3.6W$$

2nd circuit – a “series” connection in which each element in the circuit shares one point of connection. The two resistances are connected at one point only.



Using Loop Law

$$\Sigma V_{\text{Rises}} = \Sigma V_{\text{Drops}}$$

$$6V = V_{R_1} + V_{R_2}$$

$$6V = I(10\Omega) + I(10\Omega)$$

$$6V = 20\Omega (I)$$

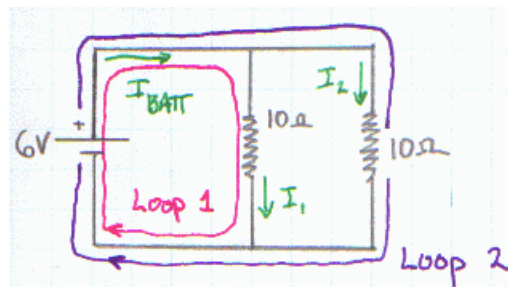
$$I = .30A$$

Junction Law says
current through
 $R_1 + R_2$ is same

This is the same current as is drawn from the battery.

$$P = IU = .30A (6V) = 1.8 \text{ Watts}$$

3rd circuit – a “parallel” connection in which elements in the circuit share two points of connection. The two resistors are connected at each end.



Loop 1

$$\sum V_{\text{rises}} = \sum V_{\text{drop}}$$

$$6V = I_1 (10\Omega)$$

$$I_1 = .6A$$

Loop 2

$$\sum V_{\text{rises}} = \sum V_{\text{drop}}$$

$$6V = I_2 (10\Omega)$$

$$I_2 = .6A$$

JUNCTION LAW SAYS

$$I_{\text{BATT}} = I_1 + I_2$$

$$I_{\text{BATT}} = .6A + .6A = 1.2A$$

Power from battery is

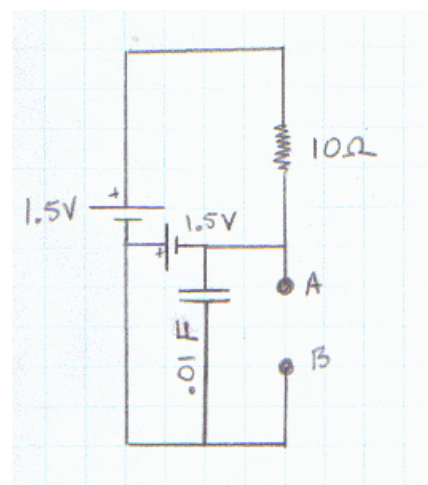
$$P = 1.2A (6V) = 7.2W$$

Example Problem #2

In the circuit shown, determine the charge on the capacitor, the current through the resistor, and the potential difference between points A & B

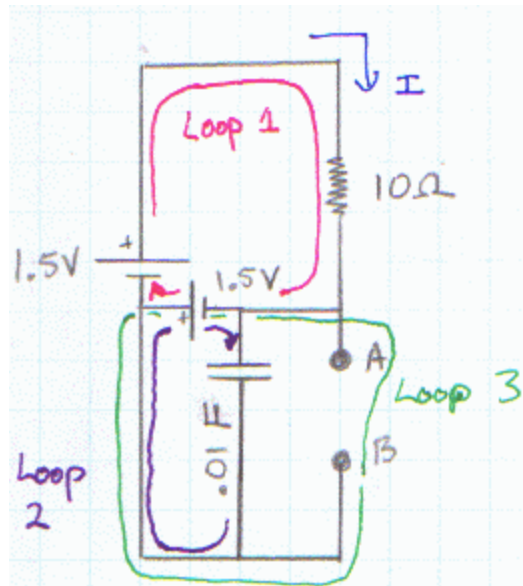
Solution:

Again, I will apply Kirchoff's Laws, Ohm's Law, and the Power equation. I start by drawing in loop-paths to follow with Kirchoff's Loop Law. I also label the current in each branch of the circuit – there is only one branch with a resistance so there is only one with current. I am assuming the capacitor is fully charged.



Here is my drawing...

... and now I apply Kirchoff's Laws...



$$\text{Loop 1}$$
$$\Sigma V_{\text{rise}} = \Sigma V_{\text{drop}}$$
$$\text{Rises} = \text{Drops!}$$

$$1.5V + 1.5V = I(10\Omega)$$

$$3V = 10\Omega I$$

$$I = .3A$$

Loop 2

$$\Sigma V = \Sigma V$$

$$1.5V = \text{Voltage on Capacitor}$$

$$U_c = 1.5V$$

$$C = \frac{Q}{U_c}$$

$$Q = C U_c = .01F(1.5V)$$
$$= .01 \frac{C}{V}(1.5V) = .015C$$

Loop 3

$$\Sigma V = \Sigma V$$

$$1.5V = U_{AB}$$

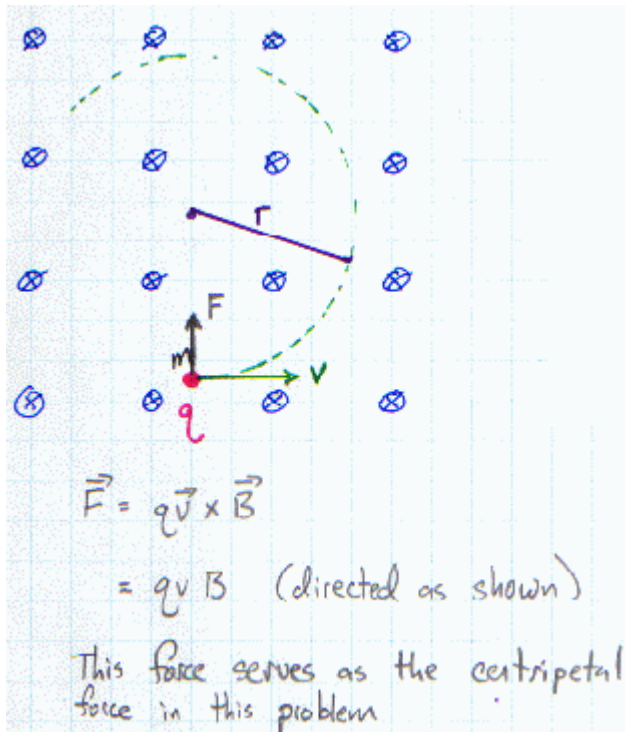
The cell and AB are the only elements in the loop, so U_{AB} must equal the cell voltage. One is a rise, the other a drop.

So the current is 0.3 A, the charge on the capacitor is 0.015 C, and the potential difference between A & B is 1.5 V.

Example Problem #3

Show that a charged particle moving freely in a magnetic field, and moving perpendicular to the field lines, will move in a circular path. If the particle has mass m , charge q , and speed v , and the magnetic field has strength B , determine an equation for the radius of the circle. Show that the units in the equation work out.

Solution:



$$F_c = ma_c$$
$$a_c = \text{centripetal accel} = \frac{v^2}{r}$$
$$qvB = F_c = ma_c$$
$$qvB = m\frac{v^2}{r}$$
$$r = \frac{mv}{qB}$$

I'll use the equation

$$\mathbf{F} = q \mathbf{v} \times \mathbf{B}$$

By the RHR, F must always be perpendicular to v . That is the hallmark of a centripetal force. A centripetal force means circular motion.

Now I'll find the equation for the radius.

My equation is $r = mv/(qB)$.

Now let's figure out the units:

$$\begin{aligned}
 r &= \frac{mV}{qB} \\
 &= \frac{[\text{kg}] [\text{m/s}]}{C \left[\frac{\text{N}}{\text{Am}} \right]} \\
 &= \frac{[\text{kg}] [\text{m/s}]}{\cancel{C} \left[\frac{\text{N}}{\cancel{\text{A}} \text{m}} \right]}
 \end{aligned}$$

$$\begin{aligned}
 &= \frac{[\text{kg}] [\text{m/s}]}{\left[\frac{\text{N}}{\text{m/s}} \right]} \\
 &= \frac{\text{kg m/s m/s}}{\text{N}} \\
 &= \frac{\cancel{[\text{kg m/s}^2]} [\text{m}]}{\cancel{[\text{N}]}}
 \end{aligned}$$

So my equation for r works out in meters units. That looks good.