1. We have talked about motion in terms of forces. In fact, physicists have boiled down all of the basic ways in which matter interacts with things into four forces:

- Gravity
- Electromagnetism
- Strong Nuclear
- Weak Nuclear

We have already talked some about gravity, and fortunately, the nuclear forces are not on the agenda for this course. Today, we pick up the tale of Electromagnetism.

The basic phenomena of Electricity and Magnetism, the kinds of things you explored in lab yesterday, have been studied since Ancient Greece. The systematic study really began in the 1700's.

2. The idea of there being positive and negative charges, and them acting on each other by a force that gets weaker with increased distance is summed up in Coulomb's Law shown on the right.

$$F_E = k\frac{q_1 q_2}{r^2}$$

- Attraction (– force) and Repulsion (+ force) are given numerically by the product of the charges q_1 and q_2.
- The $1/r^2$ drop-off with distance r is similar to what is seen in gravity, or sound intensity, light intensity, or other cases of something getting weaker as it spreads out into 3-dimensional space.

There are similar, but more complicated, force laws for magnets.

3. Eventually, people figured out that electricity is responsible for most of what we encounter in day-to-day life. That is to say, the chemical bonds between atoms and molecules that are at the heart of chemistry and biology, the friction that keeps your shoe in contact with the floor, the power that drives the light in the room, and so much more are all electric interactions.

4. First, some basic terminology. When charges move, we keep track of two things:

- Current (how many charges per time), **I** in Amperes or Amps.
- Voltage (how much energy each charge carries), **V** in Volts.

5. This was enough as various 19th century scientists made systems of batteries and wires that carried currents to do certain things. Then, Oersted discovered that an electric current can produce a magnetic field (you saw that with your battery-coil combinations yesterday). A little later, Faraday found that moving a magnet and a coil near each other cold produce an electric current in the coil.

6. The grand synthesis was due largely to Maxwell, a theorist who showed that we don't have the separate forces of Electricity and Magnetism, they are actually a united force we call Electromagnetism. As a bonus, Maxwell discovered that it was possible to have electromagnetic waves, and that they would travel at the speed of light. We now understand that visible, Ultraviolet and Infrared light, X-rays, cosmic rays, radar, radio, microwaves, and many more waves are all electromagnetic, all traveling at c.

7. Another world-view-changing aspect of the work of Faraday and Maxwell was the proper way to look at electromagnetism was that the space around us is imbued with *fields*, waiting there to interact with anything that comes along.

8. An alternate way of looking at physical interactions also took hold in the 19th century, that of *energy*. This tried to capture the idea of what properties a body has when it is in a certain state. We think in terms of *energy conservation*, that is, the total amount of energy in a system is constant, but it can change forms during a process.

For instance, consider a ball rolling downhill. It starts with a certain amount of *gravitational potential energy*, energy stored up in the interaction between the ball and the gravitational field set up by the earth. As it rolls downhill, more and more of the potential energy gets converted to *kinetic energy*, which is energy of motion. Also, the friction with the ground means the ball loses *dissipative energy*, energy which becomes heat and, unlike potential energy, is hard to recover.

9. I would like to rethink the mass-spring system in energy terms, and bring into comparison a system made of the *capacitor* and *inductor* that we discussed in lab. I will be ignoring the friction/dissipation energy for the moment.

Potential Energies

A spring stores tension energy. The more it is stretched, the more energy.
Likewise, a capacitor stores electric energy. The more charge on it, the more energy.

Kinetic Energies

A moving mass has motion energy. The faster it moves, the more energy.
An inductor has magnetic energy. The more current, the more energy.

The drawing below captures the parallels between the two systems and their energies as they go through a complete oscillation cycle. Code: ++ = Large. + = Small.

Spring: Fully compressed → Compressed → Equilibrium → Stretched → Fully Stretched → Stretched → Equilibrium Compressed → Fully Compressed

Capacitor: Full +charge → +charge → Uncharged → –charge → Full –charge → –charge → Uncharged → +charge → Full +charge

Kinetic energy of motion is largest at the center of the oscillation.

Stage	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Potential	++	+	0	+	++	+	0	+	++
Kinetic	0	+	++	+	0	+	++	+	0
Total	++	++	++	++	++	++	++	++	++

A B C D E F G H I