# Lab 3 : Electric Potentials

**INTRODUCTION:** When a point charge is in an electric field a force is exerted on the particle. If the particle moves then the electrical work done is $\Delta W = F\Delta x$. In general, $W = \int dW = \int_a^b F(x)\, dx$. Like gravity, the electric force is a conservative force. The work done, therefore, depends only on the difference in an electric potential at the initial and final position, not the path taken to move the charge So if we know the potentials V at points a and b, we know the energy $W = \int_a^b F(x)\, dx = \int_a^b q\, E(x)\, dx = \int_a^b q\,(-dV/dx)\, dx = -q\,(V_b - V_a)$. Referring back to Lab 1 can help you to understand electric potential. You felt the electric force due to the charge of the balloon tugging at the hairs on your arm or head. This force was related to the difference in electrical potential between your head and the balloon. The electric potential at any point in an electric field is the work per unit charge required to bring one coulomb of positive charge from infinity to that point. With charges, the question is often, "How much energy is required to put the charge at that point?" In this lab, we will look at the simplest device - a capacitor – to measure how charge, potential and energy are related. The energy of an electron at a point in space is $U = qV$ and the force on a particle in the x direction is $F = qE = -q\, dV/dx$. When you finish, you should be able to answer the following questions:

- How are electric potentials and the Coulomb force related?

- What is the relationship between energy and the electric potential at which a charge is positioned?

- How are these concepts related to electric cars?

**EQUIPMENT:**

- Half dozen AA batteries
- Electric motor LEGO car
- Capacitor and charging circuit
- Two channel, time dependent electrical measurement

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## Experiment 1: Calculating Electric Potential

When putting charge on an object, the potential V changes. For example, the first charge on a neutral object goes for free, since E=0 and no force is required to put the charge there. Now the later charges will not have it so easy. They approach an object with a charge on it and so the force from Coulomb's law will require energy for their transport to the object. The energy required to move them onto the charged object is obviously $W = \int F(x)\, dx = q\, \Delta V$ where $\Delta V$ is the relative electric potential of new position. The analogy with mass is very close. If you are assembling a planet, for example, the first piece of mass feels no gravity and goes for free. But the second piece of mass feels the force from the first mass by the law of gravity. The more mass (charge) on the planet (object), the larger the gravitational (electrical) potential.

In this lab, you will analyze the energy required to move charge onto a simple object – a capacitor. By measuring the electrical potential (i.e. the voltage) of the capacitor and the flow rate of the charge to the capacitor, i.e. the current, you should be able to determine how much energy was required to put the electrons on the capacitor and therefore how much work is stored on the capacitor. Step one of this lab is to put charge on a capacitor while measuring the flow of electrons (current) and the potential of the capacitor. A simple box has been setup to allow you to do this safely and record the voltages and current for the capacitor. You can record the measurements of V and I as you like. A computer program is available to assist in recording these voltage and current measurements.
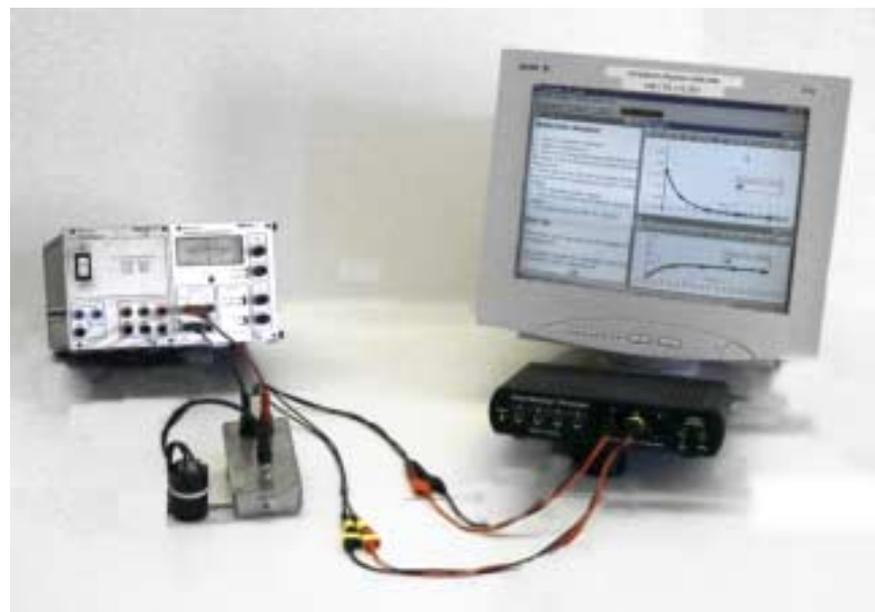


Figure: Example of charging circuit with measurements of voltage and current on capacitor over a time span of 30 seconds. You may zoom into the picture to check out the setup more carefully. Also note that the capacitor should be discharged to make sure it is neutral before starting each measurement.
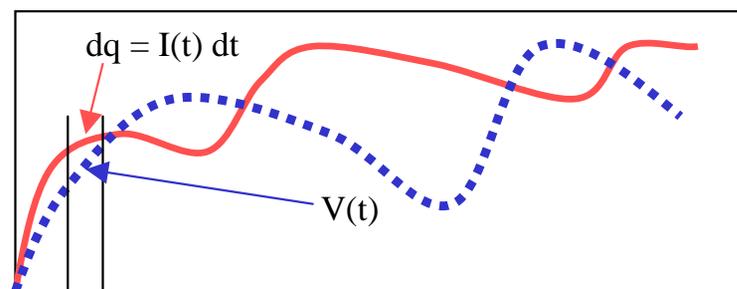


Figure: For a small section of time t, the amount of work done at that time is $\Delta W(t) = V(t)\, dq = V(t)\, I(t)\, dt$. The total work is obtained by summing, i.e. integrating, over all $\Delta W$.

Part two of this experiment is testing out your calculation of how much energy is stored on the capacitor you just charged. The energy stored in the charge at a electric potential should be able to power a LEGO car. When connecting the car, see how far the energy you put in the capacitor can move the car.

Now, repeat the charging of the capacitor with different voltages or disconnect the capacitor from charging before the 30 seconds is up. Measure the distance the car moves again. Check if the energy used to move the car is proportional to the energy stored in the capacitor by graphing the distance as a function of your calculated electrical energy. You should have at least 5 measurements of partial charging at a fixed voltage and full charging at various voltages. These should be plotted together on the graph since both can be converted to electrical energy.
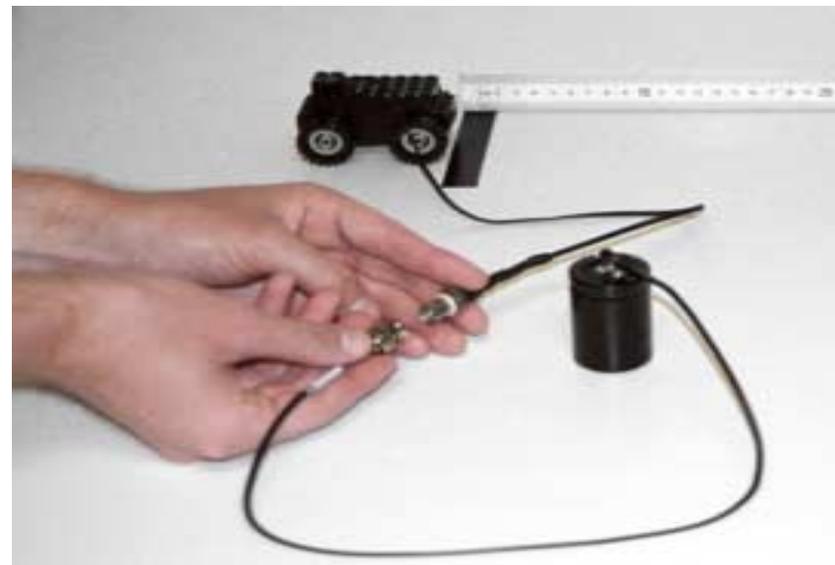


Figure: Ready, Set, Race…See how far the energy stored by putting the charge at a potential can move the car. An analogy could be water at a higher gravitational potential flowing downhill like the electrical current to do work.
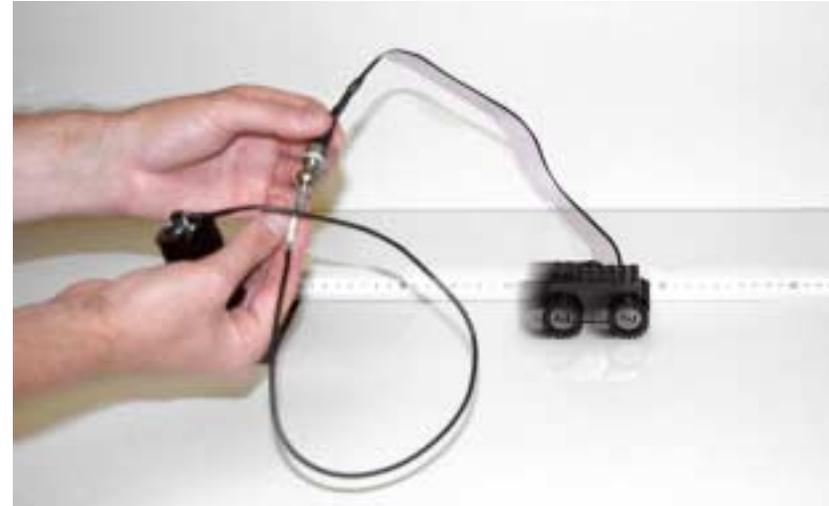


Figure: Make sure you do not hinder the motion of the car with the cable or add other variable energy loss mechanisms during your measurements.

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# Experiment 2: The Electric Vehicle

Like capacitors, batteries are able to store energy by holding charge at an electrical potential.

•Why are the terminals at different potentials, i.e. what is the mechanism by which the battery gives power?

•There are many different types of batteries due to the different materials and respective potentials, electron affinities, etc. Research on the web some of the different types of batteries.

Now that you have determined some important characteristics, you will run some tests with AA batteries.

•Measure the voltage of a single battery and connect the battery to the car using electrical tape.

Like a mass going up rungs on a ladder, a sequence of batteries can be used to increase the potential energy of charge.

•Repeat the above procedure combining batteries to get more voltage. Connect two batteries in series, simply tape the positive terminal of one to the negative of another, and then use one end of each to connect to the car. Also measure the voltage across the combined batteries.

Now that you understand electrical energy, electrical potential and electrical charge, consider the problem of the electric car. Experts have predicted that the world's oil energy supplies will be depleted as early as 2040. 60% of oil consumed in the United States is used for transportation, and a large portion of that in automobiles. As oil energy diminishes clearly an alternate mode of transportation will have to be developed to deal with the coming crisis. Some have proposed the idea of cars which run on electrical energy stored in batteries.
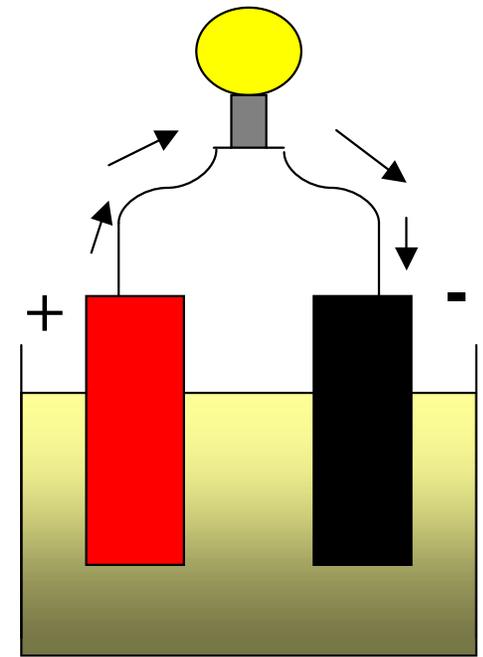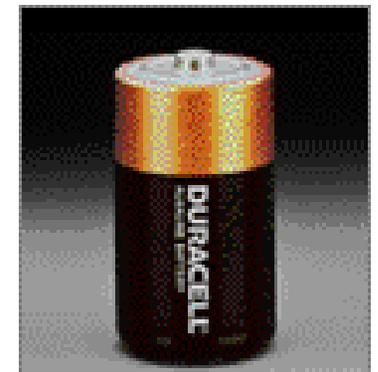


Figure: In a battery, current flows from plus terminal to the minus terminal, which is at a lower potential. They light up the bulb along the way.

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Consider how your small electric LEGO car could model the performance of a real electric car. You already have the distance the car can travel given a certain amount of electrical energy. The energy used for travel can be assumed to be linear in mass so you will need to correct for the 3000lbs of a typical car compared to the 0.5lb mass of your LEGO car. **Using your model LEGO car, estimate how much energy is required to by a "typical" driver who drives 200 miles/week.**

When considering the true energy efficiency and green house gas emission of an electric car vs. a gasoline powered car, one must include the energy wasted by sending the electricity over the power lines from the power plant to the home, the efficiency of generating the electricity at a power plant, and the electric motor efficiency in the vehicle. Typical transmission losses can be in the range of 20% or more, the efficiency of generating the electricity by burning oil at an electrical power plant is typically 45%, and 75% of the energy stored in the car battery can be converted by the motor in an electric vehicle. **When comparing all the facts, which car (electric or internal combustion) most efficiently uses our energy resources?**

Try out www.fueleconomy.gov/feg/atv.shtml to help with this problem.



The GM Gen II EV1 is available now. It runs on 312 volts of lead acid batteries, or 343 volts of Nickel Metal Hydride batteries. With a weight around 3000 lbs, it can transport two passengers up to 130 miles. At 136 horsepower it can do 0-60 in 9 seconds, and has a top speed of 80 mph.



Many production cars are now being made electric, such as the Nissan Hypermini, Ford Ranger, Nissan Altra, and the Toyota RAV4. These cars have zero emissions and are nearly silent.

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