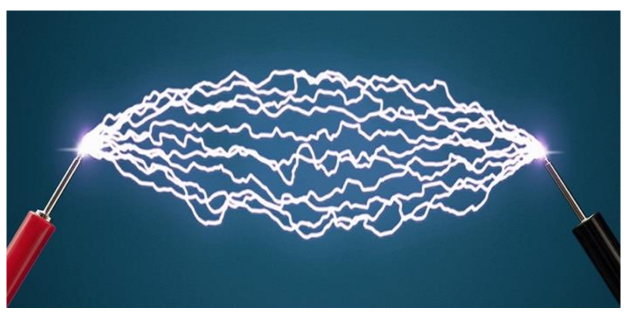
PHYS 40C: Lab 2
Electricity Generation
(Includes Pre-Lab Assignment)

Objectives

In physics, we talk a lot about different kinds of energy – gravitational, kinetic, thermal, nuclear, etc. In a lot of cases, though, it's hard to really grasp how we can harness that energy to work for us. Today's lab will be an exploration into transferring some of these different kinds of energy into electricity, which is easy to store, move, and transfer into useful mechanical work.

1. Mechanisms of Electricity Generation

By generating and/or storing charge in different configurations, we are able to efficiently move energy across vast distances – this is the purpose of electricity. Energy is harvested from some source via some physical mechanism and then transferred into electricity, which makes it easy to transport the energy across large distances. We then use our electronic devices to transform electricity back into some other kind of useful energy (mechanical, light, heat, etc.).

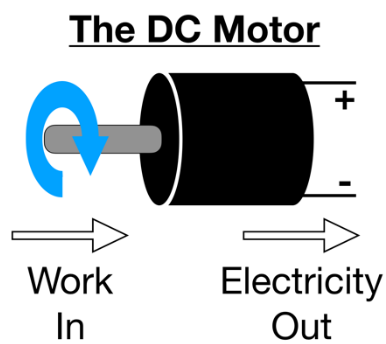


We can define electricity very simply as *moving charge*. That's it. Electricity only becomes complicated when we want to use it – that means we have to make charges move where we want them to, when we want them to, and at a consistent rate. You know from last week's lab a few different ways electricity can be transferred between various objects, and how objects with different charges repell and attract each other. From lecture you should be familiar with how static (non-moving) charges interact with each other by Coulombic force. In this week's lab, you will study different mechanisms by which we can use different sources of energy (work, heat, light, *etc.*) to force charges to move in a controlled manner.

In this section, you are presented with different mechanisms that can be used to convert non-useful energy into electricity. For each mechanism, answer the four questions below. If you don't know the answer, think critically and form a logical hypothesis. You are encouraged to collaborate with your colleagues.

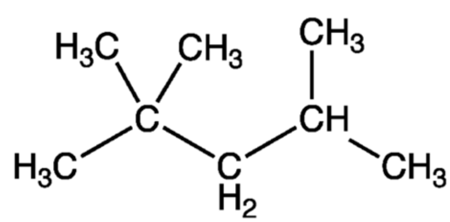
1. What is the source of potential energy that this mechanism utilizes to generate electricity? Explain where that energy comes from.
2. What is an example of this mechanism in a real-life application, or what would be a good application of this mechanism?
3. How efficient do you think this mechanism is at generating electricity? What limits this efficiency?
4. In what ways could you increase the overall electricity output of this mechanism? How might you be able to increase the efficiency of output?

Mechanical:



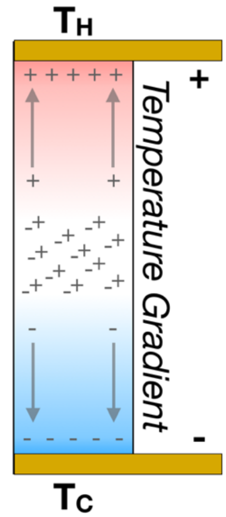
In this mechanism, something does mechanical work on a system, and the system produces useable mechanical work in return. One example is riding a bike: you do mechanical work on the bicycle pedals, the pedals turn a chain, the chain drives the wheel, and you and the bike are moved forward. That mechanical work that you do to pedal the bicycle can also be converted into electricity via a DC motor. You haven't yet learned the tools to be able analyze how a DC motor converts rotational energy into electricity, though you will later on in lecture. For now, you can just think of the DC motor as a 'black box' – spinning the axle of the motor generates electricity. All you need to worry about is how to get the axle to spin.

Combustion:



In this mechanism, some kind of fuel is combusted (burned) to produce a large amount of thermal energy in a gas mixture. The thermal energy then drives a heat engine, which can be used to transfer heat into electricity in a similar manner to the mechanical mechanism. This mechanism is very commonly utilized in our society not because it is particularly efficient, but because there is so much energy stored in the fuel that even an inefficient process will yield a significant amount of useful electricity. An example of a hydrocarbon fuel molecule is diagramed at right.

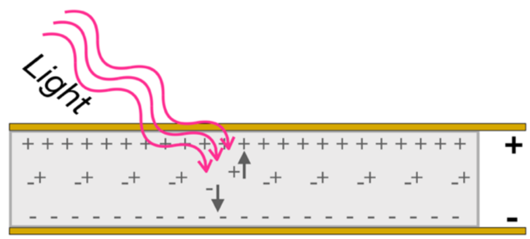
Thermoelectrics:



Thermoelectrics belong to a class of devices that function via "solid state" processes. Solid state devices leverage the electronic properties of specially-designed materials to move charges around within a solid material. When the material is exposed to specific conditions, opposite-signed charges are separated within the material. When those separated charges are collected outside of the material, electricity will flow from one side to the other, and it can be used along the way.

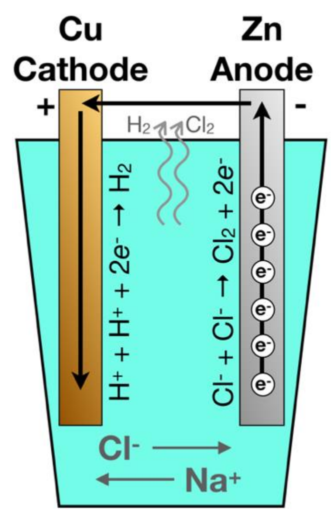
Fundamentally, thermoelectric materials generate this charge separation when a temperature gradient is applied across the material. In other words, if you heat one side of a thermoelectric material relative to the other side, charge motion within the material will be initiated. This mechanism again resembles the functionality of a heat engine, except that thermal energy is *directly* converted into electricity rather than being converted to mechanical work as an intermediate step – there are no moving parts in thermoelectric devices.

Photovoltaics:



Photovoltaics are another class of solid state devices. Photovoltaics, however, generate electricity from the absorption of light. Charge motion is initiated within a photovoltaic material when light is absorbed to push opposite-signed charges apart opposing the Coulombic attraction force.

Electrolytics:



An electrolytic cell relies on an oxidation-reduction reaction between metal electrodes and dissolved ions in a solution to drive the separation of charges. We will leave the intricacies of such reactions to the Chemistry Department, but we can talk about the flow of charge in such a process. A basic cell consists of two electrodes, a cathode and an anode, that are submerged in an electrolyte solution. The electrolyte solution (salt-water, in the diagram at right) consists of positively charged and negatively charged ions, cations and anions respectively. In short, the anion is oxidized and donates electrons to the anode, and the cation consumes two electrons to be reduced.

2. Defining and Measuring Electric Potential

We know how single charges interact with each other via Coulombic force. But just one AA battery contains around >10^{22} electrons! We could certainly do some Coulomb's Law analysis of all those point charges, but that sounds like a lot of work! To make it easier for ourselves, we introduce a term called *electric potential*. We will refer to it as just 'potential' from here on.

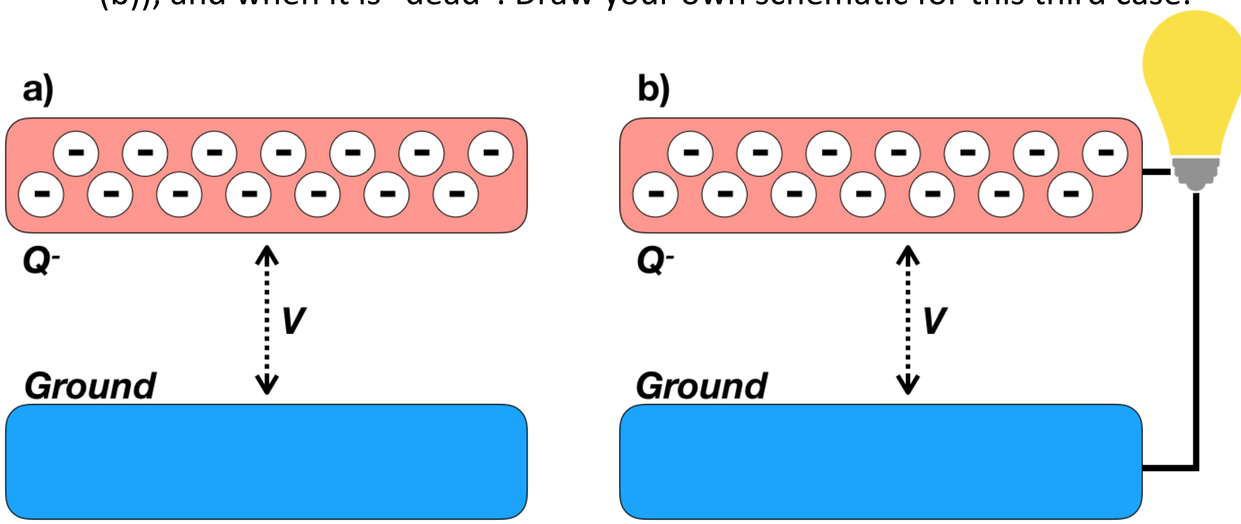
The *potential* at a given location determines the potential energy that a charge would have if placed there. Electric potential is caused by the *separation of charge*. You can think of it as a generalization of the effect of Coulomb's Law for a continuous distribution of charges, like, for example, in an electric circuit. Potential is denoted 'V' and is measured in Volts (abbreviated also as 'V').

A Digital Multi-Meter (DMM) (pictured at right) can be used measure many properties of electric circuits including, crucially, electric potential. You will use DMMs in several labs, but today we will use only the "DC Voltage" function on the meter ('V—').

The meter has 2 probes that plug into terminals on its front surface. **When the dial is set to "voltage" the meter measures the electric potential between the tips of the two probes.** Use the 2V scale to start. This is a few clicks clockwise from the "OFF" position. The multi-meter reading implicitly assumes the "negative" or black colored probe is at 0V (zero volts), referred to as "Ground". *Note that the DMM can only measure the potential difference between the two probes, it cannot measure absolute potential values*.

2.1: Use the multimeter provided to you to measure the potential across the two terminals of the battery at your station. The battery should have a label on it stating the stored potential – does your measurement compare to the labeled value?

2.2: What happens to the battery's potential when it "dies"? Recreate the schematic diagrams below and describe the distribution of electrons in the battery when it is brand new (schematic (a)), when it is in use (schematic (b)), and when it is "dead". Draw your own schematic for this third case.



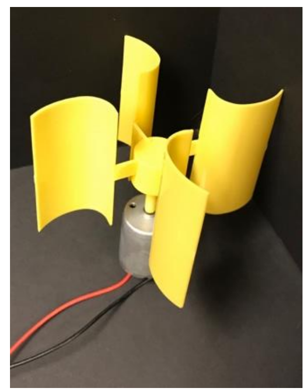
3. Generating Electricity

In this section, you finally get to do some experiments to test your answers to the questions for the electricity generation mechanisms from Part 1 (you will not test combustion…). You will analyze each mechanism using simple apparatus for each. This is intended to be an open-ended exploration, but follow the general guidelines listed out below. Feel encouraged to share ideas with your colleagues!

1. For each mechanism, your first task is figure out how to get the apparatus to generate a potential, which you will measure using the DMM. Describe how the potential you generate with each apparatus compares to the battery you measured in 2.1 with regard to magnitude, convenience, and consistency.
2. You may also take measurements of potential over a period of time. To do this, use the voltage probes attached to the 850 interface along with the *Capstone* template for this week's lab.
3. Once you have figured out how to generate and measure potential, reflect on your responses to questions 3 and 4 from Part 1. You are also provided with some extra equipment with which you may modify the apparatus or to modify the conditions under which potential is generated. Think (and

write!) about how to test what limits the efficiency (how completely energy is transferred from one form into electricity) and what limits the output of each apparatus (how much total potential can be generated).

4. Test your ideas! You may come up with some design that requires some equipment not already provided to you – if you do, present your idea to your TA and they may be able to acquire it for you!
5. Discuss how the different things you tried affected the charges within the system – it will be useful to draw some schematics similar to those in 2.2.
6. At the end of the lab, experiment with all apparatus together (including the battery) to see who can generate the largest potential measurement on their DMM! Explain your thought process. You can link the leads to different apparatus together using the provided wires with alligator clips.



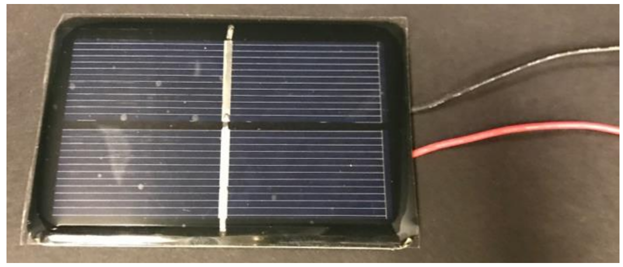
Mechanical Apparatus:

- 4-blade turbine attached to DC motor
- Cardboard sheets + tape
- Compressed air source
- **Safety Precautions:**
  - Avoid getting the DC motor wet at all costs! The blades can get wet, but the motor cannot!

Thermoelectric Apparatus:

- Two-legged thermoelectric apparatus
- Liquid containers
- Hot water, room temperature water, ice water
- **Safety Precautions:**
  - Handle liquids carefully – spilling them haphazardly may cause damage to some of the apparatus.
  - The legs of the thermoelectric apparatus are made of aluminum, which means they conduct heat very well, which means they take on the temperature of the liquid in which they are submerged. Handle the apparatus only at the top near the probe plugs.

Photovoltaic Apparatus:



- Small photovoltaic cell
- Desk-lamp
- Various other light sources
- **Safety Precautions:**
    - Handle the photovoltaic cell with care – the cell is fragile and smudges/fingerprints on the absorbing area of the cell will reduce the amount of light that can be absorbed.
    - Do not get the photovoltaic cell wet!

Electrolytic Apparatus:

- Liquid container with lid
- Water
- Salt
- Stirring rod
- Copper and zinc electrodes
- Connecting wires

Make the electrolytic cell by mixing 0.5 g of salt with 90 mL of water in the container provided and stir until all the salt is dissolved. Check to see if your copper and zinc electrodes are clean and capable of a good electrical contact. If not, ask your TA to replace them with a fresh set. Insert the zinc anode (negative terminal) and copper cathode (positive terminal) into the lid.

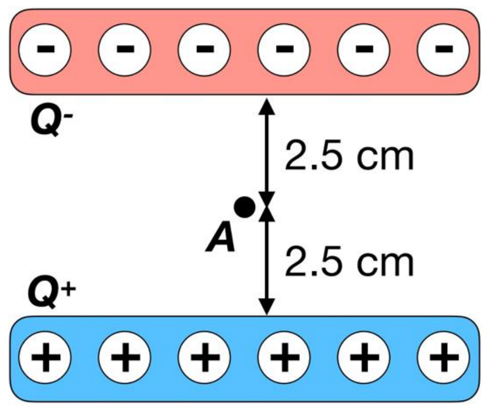
- **Safety Precautions:**
    - Handle liquids carefully – spilling them haphazardly may cause damage to some of the apparatus.

Pre-Lab Assignment (1 point)

1. Use Coulomb's Law (equation below) to calculate the approximate force felt by an electron at point *A* in the schematic below. For the sake of simplicity, assume that the charge reservoirs, Q^- and Q^+, can be treated as point charges each 2.5 cm away from point *A* and 5.0 cm away from each other. Make sure to denote which direction the force will act. The red and blue regions indicated in the schematic are conductors. Here, Q^- is equal to the charge of six electrons, and Q^+ is equal to the charge of six protons.

Coulomb's Law: $|F| = \frac{1}{4\pi\epsilon_0}\frac{Qq}{r^2}$

$e = 1.6 \times 10^{-19} C$



2. If we were to connect the Q^- and the Q^+ charge reservoirs with a conducting wire, as shown below, describe what you would expect to happen regarding the movement of the charges. Note that the negative charges are *electrons* and the positive charges are *protons* and cannot freely move.