

Introduction

In this lab we will examine the concepts of electric current and potential in a circuit. We first look at devices (like batteries) that are used to generate electrical energy that we can use in circuits. Then we consider how the current through certain circuit elements depends on the voltage across them. Finally we show how the electrocardiogram can give information about electrical activity inside the human heart. You should review chapter 17 of Serway and Faughn before coming to lab.

Pre-lab questions:

Suppose you have a circuit consisting of four 1.5 V D-cell batteries in series, some wires, and a light bulb. The bulb is lit and the current flowing through the bulb is 4.0 A. You may assume that all of the voltage drop occurs in the light bulb.

- What is the resistance of the bulb?
- Taking the negative terminal of the first battery as 0.0 V, what is the electrical potential energy of an electron leaving the negative battery terminal? What is the electrical potential energy of the electron as it re-enters the fourth battery at the positive terminal? How much energy has the electron gained or lost as it moved around the circuit? In which part of the circuit did it lose the energy? (Hint: Where does the voltage of the electrons change?)
- How many electrons enter and leave the light bulb every second?
- What is the total gain or loss of energy for all the electrons in the light bulb in one second? Calculate this by comparing the energy of an individual electron as it enters the lightbulb vs. its energy as it leaves.
- Using power $P = I(\Delta V)$ for the bulb, what is the power consumed by the bulb?
- Compare the energy change per second of the electrons and the power consumed by the bulb. Should they be the same?
- Where does the energy that is delivered to the bulb come from?

A. Group Activity:

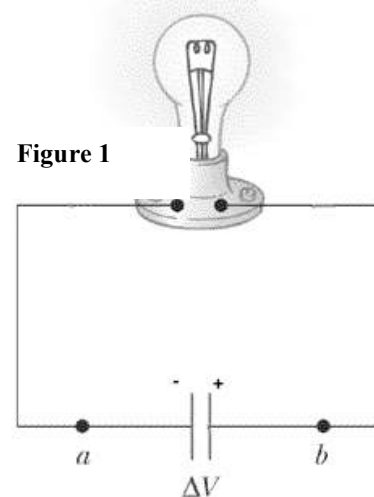
After your group has answered each of these questions, call your TA over to discuss them.

A1. Your TA gives you a capacitor and tells you it is charged. How can you determine if this the capacitor really is charged? What equipment would you need and what measurements would you need to make?

A2. Now suppose you connect a wire between the two terminals of the charged capacitor. Does the charge in the wire flow (a) from the positive plate to the negative plate, (b) from the negative plate to the positive plate, or (c) both of these? Have you done any experiments in this lab to demonstrate this?

A3. Describe a situation in which both positive and negative charge carriers are responsible for an electrical current.

A4. Suppose you connect one plate of a charged capacitor to one terminal of a light bulb. Then connect the other terminal of the bulb to the other capacitor plate. Figure 1 shows the circuit.



Compare the charge flow at points a and b on each side of the light bulb? Does charge accumulate inside the light bulb? Does the light bulb “use up” the current?

A5. Taking the negative plate as a reference voltage of 0 V and a potential difference across the capacitor plates of 1.5 V, what are the potentials at points a and b?

A6. What is the potential energy of a single electron before it passes through the lamp, and just after it emerges from the lamp? How much energy does a single electron lose as it passes through the lamp? If the current flowing is 1 A, how much energy do the electrons lose in 1 second?

A7. Where does the energy to heat the light bulb filament come from?

B. Sources of voltage

The first battery was created in 1799 by Alessandro Volta . Today batteries provide the power for an amazing variety of devices, everything from flashlights to robots, computers, satellites and cars. Inventors and researchers continue to improve batteries, designing batteries that store more energy, are lighter in weight, and friendlier to the natural environment.

Understanding how batteries work requires knowledge of chemistry. The most important factor in battery design is the electrical relationship between the two metals used in the battery. Some metals more readily give electrons away while other metals accept extra electrons.

Batteries are made of chemicals called electrolytes sandwiched between electrodes made of different metals. Chemical reactions in the electrolytes separate charges by moving positive ions to one electrode and negative ions to the other. The chemical reactions provide the energy of the battery. Some, but not all batteries can be “recharged” by forcing a current backwards through the battery and reversing the chemical changes made during discharge.

B1. The Vinegar Battery:

A very simple battery can be made with vinegar (acetic acid), and strips of aluminum foil and copper foil. Vinegar batteries have some drawbacks for everyday use. Name some practical problems you would have if you had to use these for your cell phone for example.

- Using equipment available, make a vinegar battery.
- Use the DMM to test which terminal is positive and measure the potential across the terminals.
- Can you light the light bulb with this battery? What is the potential across the battery when the light is connected?

B2. Alkaline Batteries:

The D-cells that we use in flashlights are usually alkaline batteries. The two electrodes of the alkaline battery are zinc and manganese dioxide. Zinc is the anode, or the electrode that becomes negatively charged due to the electrolyte. Manganese dioxide is the cathode, or the electrode that becomes positively charged. The electrolyte (providing the ion transport mechanism between the anode and cathode) of an alkaline cell is a strong alkali solution of potassium hydroxide.

- Measure the potential drop across a D-cell.
- Can you light the light bulb with this battery?
- What is the potential across the battery when the light is connected?

Why would a battery have a lower potential across its terminals when a current is flowing?

B3. Power supplies:

Many items of electronics use power supplies to provide the electrical power they need to operate their circuitry. For example, the big screen TV set you just purchased needs to be plugged into a wall socket to work. From the wall socket it gets electrical energy from the big power station through the distribution grid. The wall socket delivers 110 V alternating current (more about AC later). The “power supply” inside the box provides the appropriate voltages from this AC supply. For large electrical appliances, this is a more convenient and cheaper source of energy than batteries. For use in the lab we have units, called power supplies, that also plug into regular “mains supply”. You can set the voltage at the output with a dial and read the voltage (and sometimes also the current) on meters on the front of the unit.

- Use the power supply provided to light the bulb. Set the voltage initially to zero, connect the bulb to the terminals, raise the voltage SLOWLY and note how the bulb changes in brightness. DO NOT USE more than 4 V across the light bulb as this will exceed its power level and burn out the filament.

C. Measuring Current and Voltage for a Resistor and Light Bulb

In this exercise, you will use the power supply and a resistive element in a circuit. You will vary the voltage that the power supply creates across the resistor and measure the current flowing through it. The resistor you will use is a combination of five resistors soldered together in parallel. This type of configuration of resistors will be studied in detail next week.

C1.Setup:

- Open the file in the Experiment 25 folder of *Physics with Computers*. A graph of potential vs. current will be displayed. The vertical axis is scaled from 0 to 6 V. The horizontal axis is scaled from 0 to 0.6 A. The “meter window” displays potential and current readings.
- Connect the Voltage Probe to Channel 1 and the Current Probe to Channel 2 of the LabPro. In the Logger Pro program, click on Setup and then Sensors. Click on the CH 1 button and in the Sensors drop-down menu, scroll down and select “Voltage Probe – Differential” (if it is not already selected). Then click on the CH 2 button and in the Sensors drop-down menu, scroll up and select “Current Probe” (if it is not already selected). These probes are different from the file defaults and should be manually set.
- With the power supply turned off, connect the power supply, resistor, wires, and clips as shown in Figure 1. Take care that the positive lead from the power supply and the red terminals from the Current & Voltage Probes are connected as shown in Figure 2.

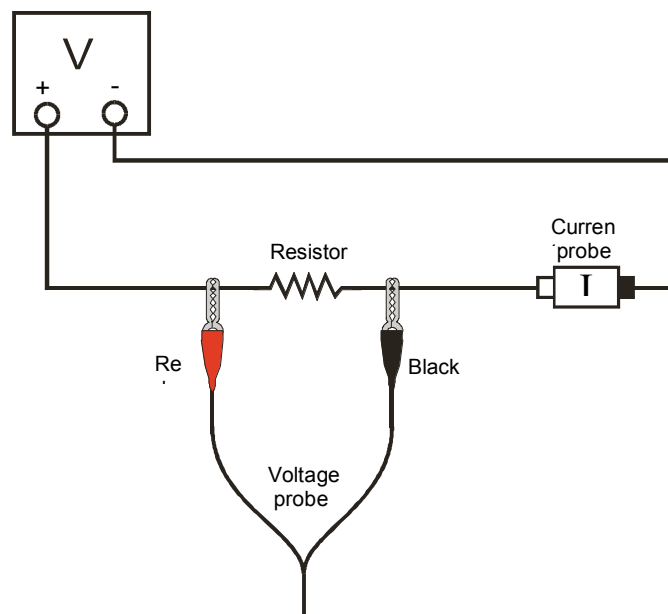
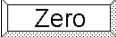
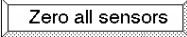





Figure 2

- Click . A dialog box will appear. Click . This sets the zero for both probes with no current flowing and with no voltage applied.
- Have your TA check the arrangement of the wires before proceeding. Turn the control on the DC power supply to 0 V and then turn on the power supply.
- Slowly increase the voltage to 5 V. Monitor the Meter window in *Logger Pro* and describe what happens to the current through the resistor as the potential difference across the resistor changes. If the voltage doubles, what happens to the current? What type of relationship do you think exists between voltage and current?

C2. Record Data

- Make sure the power supply is set to 0 V. Click  to begin data collection. Monitor the voltage and current. When the readings are stable click “keep”. **Note:** Clicking “Keep” adds data to the data table window on the right side of your screen.
- Increase the voltage on the power supply to approximately 0.5 V. When the readings are stable click “keep”.
- Increase the voltage by about 0.5 V. When the readings are stable click “keep”. Repeat this process until you reach a voltage of 5.0 V.
- Click  and set the power supply back to 0 V.
- Record the data table and sketch the graph in your lab notebook. Are the voltage and current proportional?
- Click the Linear Regression button, . Record the slope and y-intercept of the regression line in your lab notebook, along with their units.

C3. Measure voltage and current for the light bulb

- Replace the resistor in the circuit with the small light bulb. Repeat the data recording steps from C2. Do not exceed 4 V as this will burn out the bulb.
- Record the data table and sketch the graph in your lab notebook. Compare the voltage vs current graph to the graph for the resistor. What differences do you see?

C4. Analysis for the resistor

- Add another column to the data table for the resistor. In this column enter the value of the voltage across the resistor divided by the current through it. This quantity is defined to be the “resistance” of the resistor and has units of volts/amps which is called “ohms”. For the component that you used, is the value of the resistance constant or does it depend on current or voltage? Materials that have a constant resistance over a wide range of voltages are said to be “ohmic” (implying they obey Ohm’s law). Is the resistor “ohmic”?
- Give a mathematical relationship for the current through the circuit as a function of the voltage of the power supply.
- If the voltage across the resistor is 3 V how much power would be delivered to the resistor by the power supply?

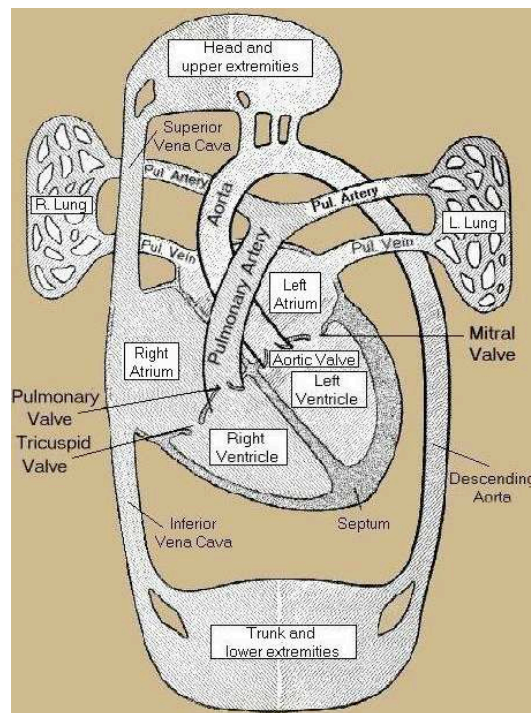
C5. Analysis for the light bulb

- Add another column to the data table for the light bulb. In this column enter the value of the voltage across the bulb divided by the current through it. For the light bulb, is the value of the resistance constant or does it depend on current or voltage?
- Describe what happened to the brightness of the light bulb as the potential across it increased. What would you infer happened to the temperature of the filament in the bulb?
- How does the bulb’s resistance vary with your estimate of temperature?
- Does the light bulb filament change resistance consistently with the temperature variation of resistance described in your text book in section 17.6?
- If the voltage across the light bulb is 3 V, how much power would be delivered to the resistor by the power supply?

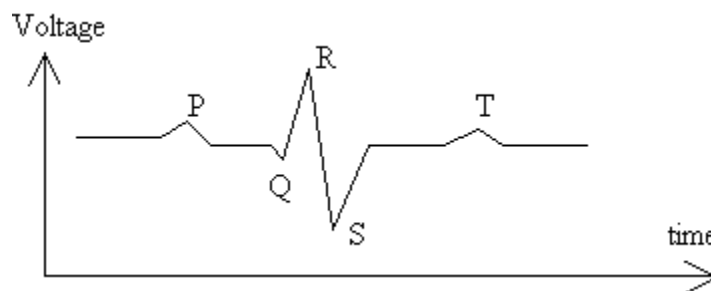
D. Electrocardiogram

There is a single electrocardiogram (ECG or EKG) sensor for the lab. This sensor will be used in turn by each group, and this activity can be done at any time during the lab period. You should complete your work with the sensor in about 10 minutes and pass it to the next lab table.

Your heart circulates blood through two separate systems. The two chambers on top (atria) are receiving stations for blood. The two lower chambers (ventricles) are pumping stations. The left ventricle chamber receives blood from the left atrium through the mitral valve and pumps it through the aortic valve into the aorta and throughout your body. The blood then returns to the right atrium, which passes it through the tricuspid valve into the right ventricle chamber. The right ventricle pumps this blood through the pulmonary valve to the pulmonary artery and then to the lungs, where it picks up oxygen. Oxygen-rich blood then returns to the left atrium of the heart, then into the left ventricle, and the cycle repeats.



Your heart is a complicated electrochemical machine which produces time-varying voltages as it beats (some details are in your textbook, please review section 17-9). For each heart beat a wave of electrical potential spreads through the heart. This causes the heart to have net positive charge on one part and net negative charge on another part. The sizes, positions and orientations of these charges change in a regular way during each heart beat cycle. These electric fields produce small voltage differences between points on the skin which can be measured and used to diagnose the condition of the heart. Voltage differences on the skin are about 1 mV (1 millivolt = 10^{-3} V). During a professional EKG typically 9 to 15 electrodes, positioned at various points on the patient's body, record a full electrocardiogram. In this lab we will use three electrodes to measure the voltage between, for example, your right and left arms and a reference voltage. (On our unit, the black wire provides the reference or baseline voltage and enables small differences in voltage between the red and green wires to be recorded).



A typical plot of voltage difference between two points on the arms of a human body vs. time is shown in the figure. The P deflection corresponds to the contraction of the atria at the start of the heart beat. The QRS group corresponds to the contraction of the ventricles. The T deflections correspond to a repolarization, or recovery of the heart cells in preparation for the next beat.

Typical values for portions of the EKG are:

P-R interval 0.12 to 0.20 seconds

QRS interval less than 0.1 seconds

Q-T interval less than 0.38 seconds

If your EKG does not correspond to the numbers above do not be alarmed! These numbers represent typical averages and many healthy hearts have data that fall outside of these parameters. To read an EKG effectively takes considerable training and skill. This sensor is NOT intended for medical diagnosis.

E1. Measuring and Recording an EKG:

- Open the file “ekgsensor.xml”. You will find this here:
LoggerPro\experiments\probes and sensors\EKG sensor\ekgsensor.xml
Set the sample rate to 200 samples per second and the time to collect data to 5 seconds.
- Your team should choose a volunteer for the measurement as there will not be time to measure the EKG for each person. Attach three electrode patches, one on each of the upper arms and one on the inside of the right wrist. Attach the black probe to the right wrist, the green probe to the right upper arm and the red probe to the left upper arm.
- With the subject standing still, measure the EKG and record the data.
- Now ask the volunteer to lie flat on the ground and repeat data acquisition and save this data. Note in your lab book which data set corresponds to which position.
- Lastly, if you have time, have the volunteer jog in place for 2 minutes, then repeat the standing EKG measurement. Store this file also.
- When you have finished taking data pass the sensor to the next table.

E2. Analysis of the EKGs

- For each EKG measure a typical time between beats (use the R peak which is easy to identify for this). Calculate the number of beats per minute for each data set. Comment on any changes.
- For each EKG measure typical PR, QRS and QT intervals. Do these values change from one data set to the next?

Post Lab:

- 1(a)** A 100 W light bulb is plugged into a standard 120 V outlet. How much does it cost per 31-day month to leave the light turned on continuously? Assume electrical energy costs \$0.06/kW-hr.
 - (b)** What is the resistance of the bulb?
 - (c)** What is the current in the bulb?
- 2.** An interesting application of electric fields and potentials is in the transport of charged ions and neutral molecules through cell walls surrounding biological cells. The most straightforward example of capacitance in nature is the cell walls of bacteria or plant mesophyll cells. The cell wall has certain openings with *proton pumps*, which use energy from ATP to raise the V of each and every *proton* (*i.e.*, an H^+ ion) by a set amount as it

pumps it outside the cell. This means that there is a surplus of H^+ ions in the extracellular fluid outside, making it positive; and a deficit of H^+ ions inside the cytoplasm, making it negative. The cell wall itself is neutrally charged, so in effect it becomes the spacing between two parallel regions of opposite charge, like a capacitor. Thus there are equal and opposite charges, a voltage difference ΔV , and an electric field between either side of the cell wall.

It requires energy from ATP to pump each H^+ ion from inside the cell to the outside, as each H^+ is being taken from the negatively charged region inside the cell, where it would prefer to be, to the positively charged region outside the cell, where it would not prefer to be. The ΔV between the inside and outside regions is usually about 50-75 mV.

Consider the model of H^+ -sucrose symport through a bacterial cell wall that is maintained at a constant potential difference of 50 mV.

- If the thickness of the bacterial cell wall is 10 nm, what is the magnitude and direction of the electric field in a proton pump?
- What is the magnitude and direction of the force on a H^+ ion while in a proton pump?
- How much energy does it take for a proton pump to expel a H^+ ion?

3. As usual, write a conclusion on the section of this lab assigned by your TA.

