Electrical Energy Module: Labs
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Laboratory 1
Insulators and Conductors
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Materials
(For both electric energy module laboratories)

1. SAFETY GLASSES: wear at all times
2. 4 1.5V batteries ("AA" cells)
3. 4 "AA" battery holder (Radio Shack #270-383)
4. 2 "AA" battery holder (Radio Shack #270-382A)
5. 1 "AA" battery holder (Radio Shack #270-401A)
6. 9V battery snap connector (Radio Shack #270-325)
7. alligator clip to alligator clip leads (Radio Shack #278-1156C)
8. 6.3V 150mA bayonet-base light bulb (Radio Shack #272-1110A)
9. miniature bayonet lamp base with solder tabs (Radio Shack #272-355)
10. 1/4W resistors:
    100 ohm (Radio Shack #271-1311)
    1000 (1k) ohm (Radio Shack #271-1321)
    10,000 (10k) ohm (Radio Shack #271-1335)
    100,000 (100k) ohm (Radio Shack #271-1347)
11. multimeter (Radio Shack #22-810) and battery (Radio Shack #23-144)
12. quad ruled 5 squares per inch graph paper
13. at least 3 fresh lemons
14. old newspapers to protect working surface from lemon juice
15. stripped length of 2.5" copper wire, > 12 gauge (needs to be stiff), one per lemon
16. #8 1.5" long zinc plated wood screw, one per lemon
17. 1.8V 20mA 120mcd red LED (Radio Shack #276-330)(BEND ANODE LEAD)
18. 10V 47 uF electrolytic capacitor
19. DPST switch with soldered leads for ease of connection
20. 2 solar cells (Radio Shack #276-124A) connected in series (see Figure 6 of Lab 2) with soldered leads for ease of connection.

Learning Objectives

1. Safe electrical engineering laboratory operating procedures.
2. Constructing simple electric circuits from a schematic and/or wiring diagram.
3. Identifying energy sources and sinks.
4. Measuring voltage and current.
5. Qualitatively and quantitatively understanding electrical power.
6. Designing a simple test instrument.
7. Understanding conductors and insulators.
8. Understanding and measuring resistance.
10. Organizing experimental data.
11. Developing and testing mathematical models developed from experimental data.
12. Using a best-fit line (linear regression).
13. Predicting experimental results using a mathematical model.
14. Developing, researching, and testing a hypothesis.
15. Presenting technical information.

Prelab

1. Read and study the "Safety in an Electrical Engineering Laboratory" (at end of this lab).
2. For the circuit of Figure 1, assume that the battery voltage is exactly 6V and that the battery current is exactly 250 mA (1 mA = 0.001 A). Compute the power of the battery and light bulb.

Laboratory Procedures

1.0 Simple Electric Circuit

1.1: Sketch the electric circuit schematic of Figure 1 in your notebook. On your sketch, draw arrows indicating the direction of conventional current flow. What is the energy source in your circuit? What is the energy sink?

![Figure 1. A simple electric circuit: schematic and wiring diagram](image-url)
1.2: Construct the electric circuit of Figure 1 as in Figure 2.
1.3: Consulting Figure 2, measure the battery voltage using your multimeter. Note that voltage is measured between two terminals (voltage is an ACROSS quantity).
1.4: CAUTION: an ammeter (current measuring device) is a SHORT CIRCUIT. Ask that the instructor verify your setup BEFORE connecting your battery. Consulting Figure 3, measure the battery current using your multimeter. Note that measuring current requires that the circuit branch of interest be "broken" and the meter inserted into the "break" (current is a THROUGH quantity).
1.5: Compute the battery and light bulb power.
1.6: Repeat procedures 6 to 8 using a voltage of 3V.
1.7: How does the voltage level affect the bulb brightness? Reconnect the 3 or 6V batteries if needed. How do the power levels compare for these two cases?
Figure 2. Measuring the battery voltage (photo and wiring diagram). Note that the meter is ACROSS the voltage of interest.
Figure 3. Measuring the battery current. Note that the meter is IN SERIES with the current of interest.
2.0 Design Problem: Building a Continuity Tester

Using only a 6V battery pack, a 6V light bulb, and one or more alligator clip leads, build a circuit to test whether or not a given item (e.g. a nail) is a good conductor of electric current. Record your design in your lab notebook. How does your continuity tester work? Develop a one paragraph "user's manual" on how to operate your continuity tester.

3.0 Identifying Conductors and Insulators

Using your continuity tester, find at least three conductors and five insulators. List these in a table in your notebook.

4.0 Resistance

Resistors are common electronic components used to "resist" or limit current flow.

4.1: Using the resistor color code (see Appendix), identify the 1k ohm, 10k ohm, and 100k ohm resistors. Measure and record the exact value of each resistance using the multimeter (the ohmmeter is an improved version of your continuity tester which provides a numeric value of resistance rather than a qualitative indication, i.e. the bulb brightness). Using a set of alligator leads to connect the meter to the resistor is convenient. (Figure 4) In any case, be sure not to become part of the circuit by touching the metal probe tips! What is the percent deviation of the resistances from their "advertised" value?
Figure 4. Measuring the value of a resistor

4.2: Using the appropriate battery holder, apply a voltage of 1.5V, 3V, and 6V to the 1k ohm resistor as in the circuit of Figure 5. Measure and record the resistor voltage and resistor current in each case (Figure 6). Use a Table to organize your data.

Figure 5. Resistor test circuit schematic

4.3: Plot the resistor voltage vs. the resistor current on graph paper.
4.4: Repeat 4.2 and 4.3 for a 100k ohm resistor.
4.5: Examine your plots from procedures 4.3 and 4.4. From this data, hypothesize a simple mathematical relationship between the resistance voltage V and current I (hint: what is the slope of the best fit line (see Appendix) for your data?).
4.6: How well does your law of 4.5 predict the currents for the 1k ohm and 100k ohm resistors for each voltage? Give percentages in a tabular form. What is the average error of your law?
4.7: Use the relationship you discovered in procedure 4.5 to predict the current for a 10k ohm resistor for each of the voltages of procedure 4.2. Arrange your data in a Table. What level of error (as a percentage) do you expect?

4.8: Now test your predictions of 4.7 by experimentally measuring the currents for the 10k ohm resistor as in 4.2. Quantify how "good" your predictions were (use percentages).

Figure 6. Measuring the resistor current

Analysis

Continuity Tester

1. Identify one material characteristic that may be used to determine if that material will be a conductor or an insulator. Write your answer as a hypothesis. Now, test your hypothesis using at least five additional items to those already listed in the Table of procedure 3.0. Based on your experimental data, is the hypothesis valid?

2. Using appropriate library references (not the web), research why your hypothesis of the previous question is either valid or invalid.
3. Prepare a poster presenting your hypothesis and supporting experimental data that supports or refutes this hypothesis. Also include supporting evidence from the literature found in the previous question. What conclusions can be drawn? Be prepared to present and defend your poster in class.

**Resistance**

4. Using appropriate library references (not the web), research the relationship between voltage and current for a resistor.
5. Prepare a poster presenting the relationship between the resistor current and voltage. Include supporting experimental data and information on how well your law works. How does this compare to what you discovered in the previous question? Be prepared to present and defend your poster in class.

**Appendices**

1. Safety in an Electrical Engineering Laboratory
2. Resistor Color Code
3. Equations for a Best Fit Line
Safety in the electrical laboratory, as everywhere else, is a matter of the knowledge of potential hazards, following safety precautions, and common sense.

Many hazards are present in any electrical/computer engineering laboratory. Therefore, for your and your partner's personal safety as well as the safety of the equipment you must always observe safety precautions.

Death is usually certain when 0.1 ampere or more flows through the head or upper thorax. Currents of one-quarter to one-half this value have been fatal to persons with coronary conditions. The current depends on body resistance, the resistance between body and ground, and the voltage source. If the skin is wet, the heart is weak, the body contact with ground is large and direct, then 40 volts\(^1\) could be fatal. Therefore, never take a chance on "low" voltage.

When working in a laboratory, injuries such as burns, broken bones, sprains, or damage to eyes are possible and precautions must be taken to avoid these as well as the much less common fatal electrical shock.

Always observe the following safety precautions when working in the laboratory:

1. Do not work alone on energized electrical equipment.

2. Power must be switched off whenever an experiment or project is being assembled, disassembled, or modified. Discharge any high voltage points to grounds with a well insulated jumper. Remember that capacitors can store dangerous quantities of energy.

3. Make measurements on live circuits with well insulated probes keeping one hand behind your back. Do not allow any part of your body to contact any part of the circuit or equipment connected to the circuit.

4. Never touch electrical equipment while standing on a damp or metal floor.

5. Never handle wet, damp, or ungrounded electrical equipment.

6. Wearing a ring or watch can be hazardous in an electrical lab since such items make good electrodes for the human body.

7. Never lunge for a falling part of a live circuit such as leads or measuring equipment.

8. Never touch two pieces of equipment simultaneously.

9. Never touch even one wire of a circuit; it may be hot.
10. Avoid heat dissipating surfaces of high wattage resistors and loads because they can cause severe burns.

11. Keep clear of rotating machinery. Do not be fooled by the stroboscopic effect.

12. When using rotating machinery, place neckties or necklaces inside your shirt or, better yet, remove them.

13. Never open field circuits of D-C motors because the resulting dangerously high speeds may cause a "mechanical explosion".

14. Keep your eyes away from arcing points. High intensity arcs may seriously impair your vision or a shower of molten copper may cause permanent eye injury.

15. Be careful when two lab groups are working back to back.

16. Never use water on an electrical fire. If possible switch power off, then use CO$_2$ or a dry type fire extinguisher. The CO$_2$ or dry type extinguishers are painted crimson red. Locate extinguishers and read operating instructions before an emergency occurs.

17. Never operate the black circuit breakers on the main and branch circuit panels.

18. In an emergency all power in the laboratory can be switched off by depressing the large red button on the main breaker panel. Locate it. It is to be used for emergencies only.

19. In case of electric shock, quickly remove the victim from the circuit without endangering yourself. If the victim is not breathing, apply CPR immediately continuing until he/she is revived, and have someone dial 911 for assistance.

20. Always wear safety glasses in designated areas or when required for a particular procedure by your instructor.

21. Chairs and stools should be kept under benches when not in use. Sit upright on chairs or stools keeping the feet on the floor. Be alert for wet floors near the stools.

22. Horseplay, running, or practical jokes must not occur in the laboratory.

$^1$Popular Electronics, p. 31, January 1972.
Resistor Color Code

Source: TOKEN PASSIVE COMPONENTS
used with permission.

top example: RED 2
RED 2
BLACK 1 => 22 x 1 = 22 ohms
GOLD: 5% tolerance
Equations for a Best-Fit Line

(source: Numerical Analysis: A Practical Approach,
(your calculator may be able to do this under "linear regression")

The best fit line associated with the n points \((x_1, y_1), (x_2, y_2), \ldots, (x_N, y_N)\) is

\[
y = m x + b\]

where

\[
m = \frac{-\sum_{n=1}^{N} x_n \sum_{n=1}^{N} y_n + N \sum_{n=1}^{N} x_n y_n}{N \left( \sum_{n=1}^{N} x_n \right)^2 - \left( \sum_{n=1}^{N} x_n \right)^2}
\]

\[
b = \frac{\sum_{n=1}^{N} x_n^2 \sum_{n=1}^{N} y_n - \left( \sum_{n=1}^{N} x_n \right) \left( \sum_{n=1}^{N} x_n y_n \right)}{N \left( \sum_{n=1}^{N} x_n \right)^2 - \left( \sum_{n=1}^{N} x_n \right)^2}
\]
Laboratory 2
Energy Storage
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Learning Objectives
(continued from laboratory 1)

16. How to make a lemon battery.
17. Using an LED.
18. Series and possibly parallel battery configurations.
19. Experimentally investigating a physical phenomenon (effect of battery current on battery voltage)(effect of adding more lemon batteries).
20. Using a capacitor to store and provide energy.
21. Planning an experiment to investigate alternative engineering solutions (comparison of three energy sources).
22. Selecting one engineering solution over another given a set of experimental data and different requirements.
23. Comparing engineering alternatives at a societal level, e.g. societal need, environmental impact, cost, feasibility, etc.

Prelab

1. Read this laboratory; prepare a list of at least four questions to ask the instructor at the beginning of lab.

Laboratory Procedures

1.0 Lemon Battery

1.1: Build a lemon battery powered LED circuit consisting of two lemon cells as shown in Figure 1. Insert the screw and the copper into the lemon about one inch apart. Roll the lemon on a hard surface to soften the lemon before use. Figure 2 shows a lemon battery in operation.

1.2: Measure and record the LED voltage and current. Remember that voltage is ACROSS and current is THROUGH.
Figure 1. A lemon battery powered LED (schematic and wiring diagram)
1.3:  Now use a 1.5V battery in series with a 100 ohm resistor to light the LED (Figure 3).

1.4:

Figure 3. Using a battery to drive a LED.

1.5:  Measure and record the LED voltage and current.
1.6:  Qualitatively, how bright is the LED as compared to the lemon battery case? How can you quantitatively compare these two cases?
1.7:  **Investigation:** Can you increase the light emitted by the LED by using additional lemons? Be sure to document your work including measurements of the LED voltage and current to add quantitative evidence to your conclusion.
1.8: **Investigation:** Using your knowledge of resistance, determine the effect of the current drawn from the lemon battery on the battery voltage. Hint: Consider plotting the battery voltage vs. battery current for different resistor values.

### 2.0 Lemon Battery Energy Storage with a Capacitor

A capacitor can be used to store or "build-up" the electric energy provided by your lemon battery.

2.1: **BEING SURE TO OBSERVE THE POLARITY OF THE CAPACITOR** (have the instructor check your circuit before connecting to the lemon battery) construct the circuit of Figures 4 and 5 with the "switch" in the CHARGE position. Allow the capacitor to charge for at least 20 seconds. Measure and record the capacitor voltage.

2.2: Put the "switch" in the DISCHARGE position. Describe what the LED does; compare the LED brightness with the results obtained in procedure 1.1. Repeat operation of your energy storage system several times. What is going on here? Explain.

![Lemon battery charge/discharge circuit](image)

**Figure 4. Lemon battery charge/discharge circuit**
Figure 5. Measuring the capacitor voltage for the charge/discharge circuit

3.0 Comparison of Energy Sources

3.1: Based on your work in procedure 1.5, plan an experiment to compare the energy delivery performance of your lemon battery, 1.5V battery, and solar cell (Figure 6).

3.2: Perform the experiment planned in 3.1. Use your results to rank the energy delivery performance of your lemon battery, 1.5V battery, and solar cell.
Analysis

Lemon Battery Energy Storage with a Capacitor

1. Provide an example of an everyday device that stores energy in a manner similar to that of Figure 4.
2. Prepare a poster describing the results you obtained in procedure 2.2; include your answer to the previous question in your poster.

Comparison of Energy Sources

3. A particular application requires a relatively high amount of current over sustained periods of time. Another requires a relatively high current for a brief amount of time and no current the rest of the time. Prepare a poster that recommends one of the three energy sources you investigated for each of these two cases. Justify with experimental data and other considerations. Be prepared to present and defend your conclusions to your classmates.
4. Using a number of sources, prepare a two page report on the advantages and disadvantages of various energy sources, e.g. fossil fuels, nuclear, solar, etc.