A3 Lemon batteries and other batteries – Electricity from chemical energy

1 How well does the “fruit and vegetable battery” work?

You have probably already seen someone push two metal electrodes into a lemon and power a light bulb with it. Try it for yourself and see how a fruit or vegetable battery works and what is necessary for it to function.

1.1 Apparatus and materials

- 6 connecting cables, alligator clip to alligator clip
- 1 LED, red (clear case), 1.7 V
- 2 copper nails (as electrodes)
- 1 lemon or other fruit
- 1 cucumber or other vegetable
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black for each
- 1 digital multimeter
- 1 solar motor, small, bell-type armature, 0.1 V/2 mA
- 1 dual propeller for small solar motor
- 2 zinc nails (as electrodes)

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

1.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

1.3 Conducting the experiment

- Push a copper and a zinc nail into the fruit or vegetable, such as into the cucumber.
- Attach the propeller to the motor and connect the motor to the circuit. Does the motor run?
- Test the circuit using the LED (try both polarities).

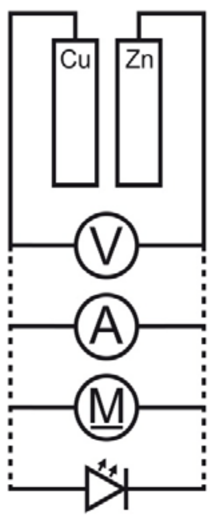

Fig. 1: Circuit diagram for measurements of an electrochemical cell (“battery”).

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- Measure the electrical voltage between the two metal nails using the multimeter. Select a reasonable measurement range. (Where is the resolution better, at 2,000 mV or 20 volts?)
- Measure the current between the two metal nails using the multimeter. Select a reasonable measurement range. (Where is the resolution better, at 2,000 µA or 20 mA?)
- Determine which electrode (zinc or copper) is the positive pole and which is the negative pole of the fruit battery.

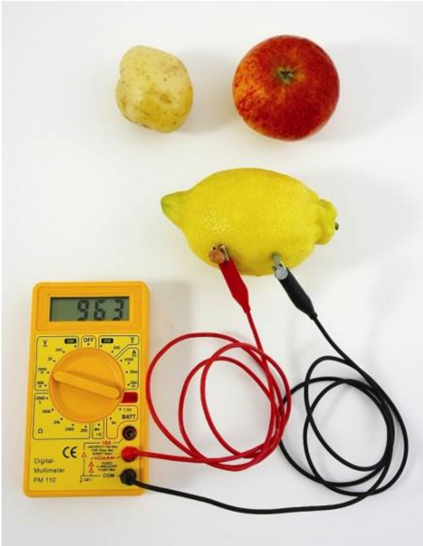

Fig. 2: Measuring the voltage of a fruit battery.

- Now take two pieces of fruit or vegetable, push a copper and a zinc nail into each, and connect the two “batteries” in series (connecting cable from copper to zinc).

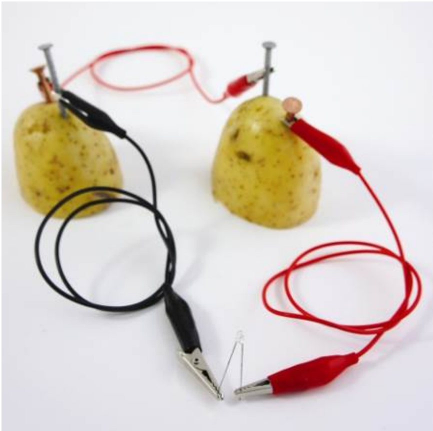

Fig. 3: LED connected in series with two vegetable batteries.

- Test the motor and LED and measure the voltage.

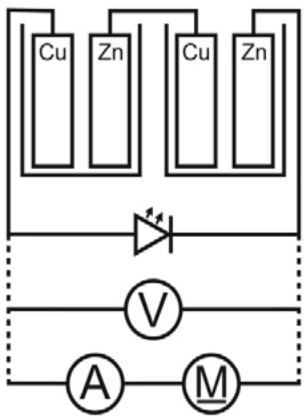

Fig. 4: Circuit diagram for measurements of two electrochemical cells connected in series.

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1.4 Observation

Note your observations for the individual phases of the experiment.

1.5 Analysis

Summarize your results in the following form:

a) The motor with propeller runs when …
b) The LED lights up when …
c) The multimeter indicates …

1.6 Questions

What do you think: Does the electricity really come from the lemon, or what is the real source?

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2 The “lemon battery”: What role does each element play?

With the help of the following tests, you can figure out which parts of the “lemon battery” are absolutely necessary and what role they play.

2.1 Apparatus and materials

- 2 copper nails (as electrodes)
- 1 cucumber, potato, or other vegetable
- 1 digital multimeter
- 1 lemon or other fruit
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black for each
- 1 nail (steel, “iron”)
- 2 zinc nails (as electrodes)

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

2.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

2.3 Conducting the experiment

- Systematically vary the electrodes of the “fruit or vegetable battery” by combining nails of different metals (copper with copper, zinc and iron; zinc with zinc).
- Attach a measuring cable to each nail, with the alligator clip on each nail and the other end of the cable inserted into the multimeter. Observe and note down the indicated voltage values.
- What happens if you remove a nail from the fruit or vegetable?
- What happens if you combine two nails of the same metal?
- Consider: What could you use to replace the first fruit or vegetable you used? Try it.

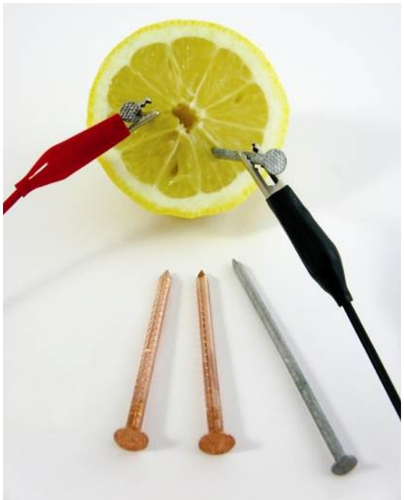

Fig. 5: Measuring different combinations of metal.

2.4 Observation

Write down a summary of your observations. Does the voltage change depending on the fruit or vegetable you push the nails into?

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2.5 Analysis

Check your results.
List the three metals used in the experiment in a logical order according to the measured voltages. Start with copper at the left as the noble metal.
What does the voltage value of a battery basically seem to depend on?

2.6 Questions

a) What does the experiment have to do with the electrochemical voltage series of metals?
b) What else could close the circuit instead of the fruit or vegetables?
c) What does every fruit and vegetable have in common? How could you replace this "common characteristic"?

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3 The "lemon battery" without the lemon

As you know by now, a lemon, cucumber, potato, orange, etc. closes the electrical circuit between nails of different metals. Now you will test what objects can establish the connection in place of fruit or vegetables. You have surely suspected that water plays a key role, because the juicier the fruit or vegetable is, the better your "battery" worked.

3.1 Apparatus and materials

- Citric acid
- 6 connecting cables, alligator clip to alligator clip
- 1 copper nail (as an electrode)
- 1 digital multimeter
- 1 dual propeller for small solar motor
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black
- 1 pair of safety goggles for each student
- 1 plant clip (as a stand for the motor)
- 2 plastic cups, 100 ml
- 1 solar motor, small, bell-type armature, 0.1 V/2 mA (pass around the groups)
- Table salt
- Water
- 1 zinc nail (as an electrode)

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

3.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

- Remove all water-sensitive materials from your workspace.
- Wear safety goggles during the entire experiment! If citric acid splashes into your eye or onto your skin, immediately rinse your eye or skin thoroughly with clear water.

3.3 Conducting the experiment

- Put on your safety goggles.
- Modify the "lemon battery" systematically by replacing the fruit or vegetable with a cup containing one of the following liquids:
  - Tap water only (rinse cup first).
  - Tap water with a bit of citric acid dissolved in it.
  - Tap water with a small spoon of table salt dissolved in it.
- Fill the cup three-fourths of the way with one of these liquids.

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- Place the copper and zinc nails inside the cup (make sure the nails do not touch each other).
- Record the voltage values for the various electrolytes (water only, water with acid, saltwater) in a small table.

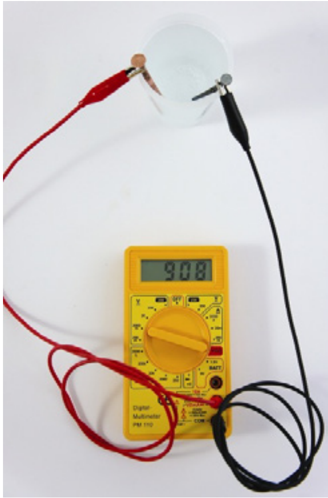

Fig. 6: Measurement setup.

- Test what happens if you connect the motor to the electrical circuit in parallel with the voltmeter.
  Note: If you are working alone, you can use the plant clip to hold the motor (see photo).

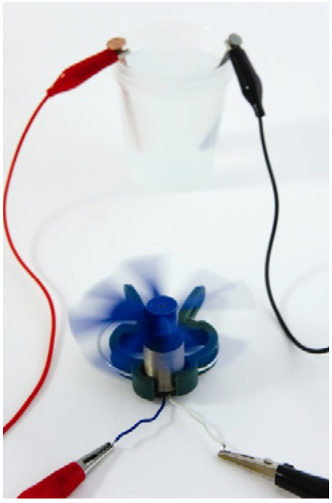

Fig. 7: Experiment with motor.

3.4 Observation

Write down a summary of your observations.

3.5 Analysis

a) Can you detect a voltage between the metal nails in the tap water?
b) What happened when you replaced the tap water with a solution of salt or citric acid? What voltages were you able to read?
c) Explain what effect a load has on the voltage in the electrical circuit.

3.6 Questions

a) Many people believe that acid is needed to generate electricity with an electrochemical cell. Explain why it also works with a salt like table salt.
b) The usually aqueous solution inside every battery or accumulator is called an electrolyte. Explain what must be present in every electrolyte so that it works.

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4 Boosting battery performance

In a battery built with electrodes made from two different metals, the less noble metal will gradually dissolve by forming a salt. At the same time, however, the more noble metal must be able to separate out from the solution of its salt. The following experiments will show you that you can extract more "performance" in this case:

4.1 Apparatus and materials

- 6 connecting cables, alligator clip to alligator clip
- 1 copper nail (as an electrode)
- Copper sulfate
- 1 digital multimeter
- 1 dual propeller for small solar motor
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black for each
- 1 nail (steel, "iron")
- 1 pair of safety goggles for each student
- 1 plant clip (as a stand for the motor)
- 1 plastic cup, 100 ml
- 1 solar motor, small, bell-type armature, 0.1 V/2 mA (pass around the groups)
- Table salt
- 1 teaspoon
- Water
- 1 zinc nail (as an electrode)

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

4.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

- Remove all water-sensitive materials from your workspace.
- Wear safety goggles during the entire experiment! Avoid skin contact with the copper sulfate. If copper sulfate splashes into your eye or onto your skin, immediately rinse your eye or skin thoroughly with clear water.

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4.3 Conducting the experiment

- Put on your safety goggles.
- Fill a cup half way with water and dissolve a small amount of copper sulfate (as much as fits on the tip of the teaspoon handle) in the water by gently swirling the cup.
- Place a copper nail and a nail of another metal in the solution and determine the voltage using the multimeter.
- Connect the motor to the circuit. You may need to move the nails a bit for the motor to start.
- Connect the multimeter and the motor in series with the two nails and measure the current.

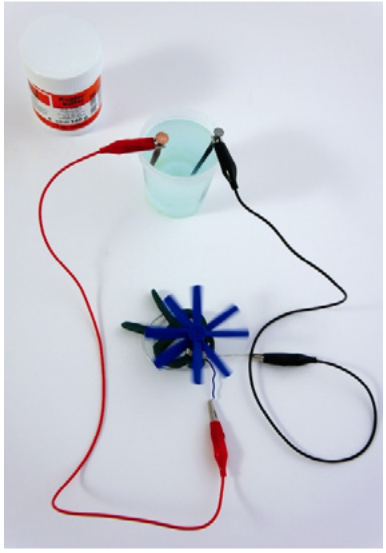

Fig. 8: Test setup with motor.

4.4 Observation

Write down a summary of your observations.

4.5 Analysis

a) What voltages and current are you able to measure?
b) How high is the battery's performance, which you determined from the measured voltage and current?
c) Is the performance higher now than in subexperiments 1 and 3?
d) What changes can you recognize on the nail of the less noble metal? Evidently something is being deposited. Explain what the deposition might consist of.
e) Consider whether this deposition is good or bad for the battery's performance, and write down your assessment.

4.6 Questions

a) Do you have an idea of how you could prevent this deposition on the less noble metal?
b) In principle, the less noble metal should dissolve in a battery, meaning that nothing should be deposited on the less noble electrode. Can you imagine how the deposition on the less noble metal might be put to practical use?

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5 Spontaneous copper plating?

Noble metals are separated out from their salt solutions when less noble metals are immersed in the solution. This experiment shows you what this looks like. The more noble metal is always copper in the following experiments (or copper sulfate as the copper salt).

5.1 Apparatus and materials

- Aluminum foil
- 1 brass or nickel coin
- Citric acid
- Copper sulfate
- 1 nail (steel, "iron")
- 1 pair of safety goggles for each student
- 1 plastic cup, 100 ml
- 1 teaspoon
- Water

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

5.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

- Remove all water-sensitive materials from your workspace.
- Wear safety goggles during the entire experiment! Avoid skin contact with the copper sulfate. If copper sulfate or citric acid splashes into your eye or onto your skin, immediately rinse your eye or skin thoroughly with clear water.

5.3 Conducting the experiment

- Put on your safety goggles.
- Fill a cup half way with water and dissolve a small amount of copper sulfate (as much as fits on the tip of the teaspoon handle) in the water. Add enough citric acid until the solution becomes clear.
- Place a small piece of aluminum foil on the bottom of the cup and place a brass or nickel coin on the foil. **Attention:** The coin must make good contact with the foil.
- If you do not observe anything in the next 10 to 45 minutes, let the experiment sit overnight and analyze it the next day.
- After you have completed this experiment, possibly a few days later, you must follow your teacher's instructions for disposing of the copper sulfate solution.

5.4 Observation

Write down a summary of your observations.

5.5 Analysis

a) Explain why copper apparently deposited on the coin.
b) Explain what role the aluminum played in the process.

5.6 Questions

a) What is the significance of the citric acid in this experiment?
(Tip: Why does the copper sulfate solution become clear only after you add citric acid?)
b) If you have Internet access, find out where metal plating plays a role in technology.

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6 A professional zinc-copper battery

To prevent a portion of the copper salt from depositing on the less noble metal in a short circuit, you must separate the two metals and the surrounding solutions. Nevertheless, the two liquids must conduct the current and must also be conductively connected with each other. For this purpose, we will recreate an experiment similar to that developed by a Mr. Daniell over 150 years ago. This is why a battery or accumulator built from copper and zinc is also called a Daniell cell.

6.1 Apparatus and materials

- 1 accumulator, 9 V
- 1 bowl, plastic
- 2 connecting cables, alligator clip to alligator clip
- 1 copper nail (as an electrode)
- 1 digital multimeter
- 1 dual propeller for small solar motor
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black for each
- 1 pair of safety goggles for each student
- 1 paper tissue, paper towel, or some toilet paper
- 1 plastic cup, 100 ml
- 2 rubber bands
- 1 solar motor, small, bell-type armature, 0.1V/2mA
- Table salt, box
- Water
- 1 zinc nail (as an electrode)

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

6.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

- Remove all water-sensitive materials from your workspace.
- Do not ever short-circuit the accumulator! This results in a risk of explosion and fire.

6.3 Conducting the experiment

- Lay out the two nails and tear off a piece of the paper towel that is as wide as the nails are long.

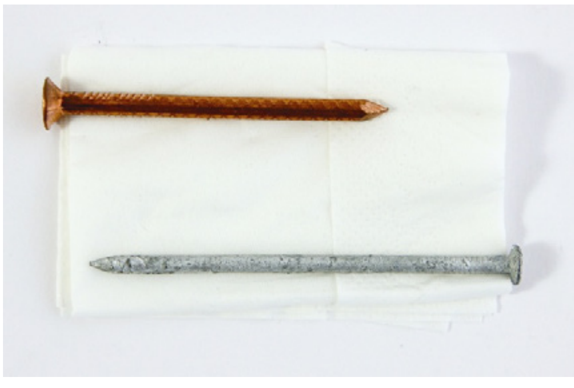

Fig. 9: Wrapping the electrodes in a paper towel.

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- Wrap one of the two nails in part of the paper, place the second nail with its head in the opposite direction, and wrap both nails together with the remaining strip of paper. A nail head should now poke out from each end. (The nails must not touch at all; they must definitely be separated by the paper!)
- Secure the electrode pack with two rubber bands.

Fig. 10: Completed electrode pack soaked in a solution of table salt.

- Fill a cup three-fourths of the way with water and dissolve a small amount of table salt (as much as fits on the tip of a spoon handle) in the water by stirring.
- Place the electrode pack in the plastic bowl and soak it in the table salt solution. Then remove the electrode pack from the bowl.
- Connect the meter and measure the voltage.
- Connect each of the two nail heads to the motor using an alligator clip to alligator clip connecting cable.
- Measure the voltage after connecting the motor.

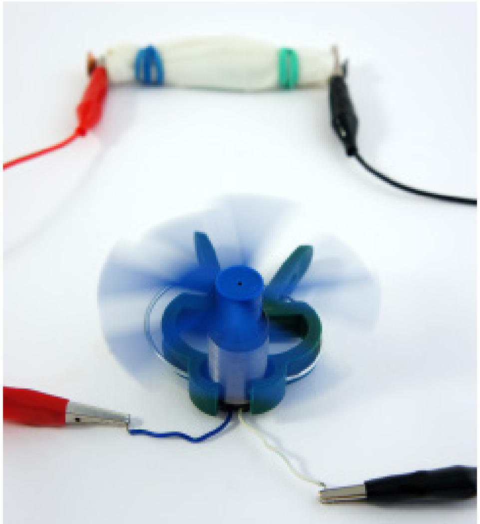

Fig. 11: Operating an electric motor with our Daniell cell.

- Now charge the electrode pack approx. 5 minutes by connecting the 9-volt accumulator (positive pole to the copper nail, negative pole to the zinc nail).
- Do you notice a discoloration around the copper nail?
- Disconnect the 9-volt accumulator and reconnect the charged electrode pack to the motor.
- Measure the voltage again.

Fig. 12: Charging the electrode pack.

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6.4 Observation

Write down a summary of your observations. To what extent did the voltage change when the motor was connected?

6.5 Analysis

a) Explain what function the paper towel performs in this experiment.
b) Explain why the battery performance is therefore usually higher than in subexperiments 1, 3, and 4.

6.6 Questions

a) If you have Internet access, find out what the separator membrane in modern batteries and accumulators is made of. Apply your results to the lemon battery in subexperiment 1.
b) Write the reaction equations for the two electrodes and for the entire process. First write a word equation, and then try to write a precise formula equation.

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