A3 Lemon batteries and other batteries – Electricity from chemical energy

Note: This answer sheet will go into the analyses for the individual subexperiments only if experience shows that there could be particular difficulties.

1 How well does the "fruit and vegetable battery" work?

1.6 Questions

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

Answer: A reasonable answer would be: I can decide that only if I test different fruits and vegetables. If the effect is the same for different fruits and vegetables, the electricity must come from the metals that are inserted into the fruit or vegetable as electrodes, or perhaps also from a common property of the fruits or vegetables.

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

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?

Note: It depends on the different (!) metals that are used.

2.6 Questions

a) What does the experiment have to do with the electrochemical voltage series of metals?

Answer: The greater the difference between the two electrode metals in the electrochemical voltage series, that is, the less noble the metal of the one electrode is compared to the other electrode, the better the corresponding battery will work.

b) What else could close the circuit instead of the fruit or vegetables?

Answer: Instead of the fruit or vegetables, you can select any electrically conductive aqueous salt solution ("electrolyte"). You can use normal table salt for the salt solution, but any other water-soluble salts will also work. (It is often assumed that the acid is the important factor. However, the acid too only functions as an electrolyte in this case. We will explain this in the next subexperiment.)

c) What does every fruit and vegetable have in common? How could you replace this "common characteristic"?

Answer: Fruit and vegetables contain the sodium, potassium, calcium, and magnesium salts of the fruit acids. This salt solution (ion solution) in the fruit or vegetable serves as the electrolyte, establishing the necessary link between the metal nails (electrodes): The internal circuit is thus closed. (Note: Salt is not the same as table salt (NaCl).)
You could therefore leave out the fruit or vegetable and instead place the two nails in any aqueous salt solution.

3 The "lemon battery" without the lemon

3.5 Analysis

a) Can you detect a voltage between the metal nails in the tap water?

Note: Distilled water with a pH value of 7.00 should not produce a voltage between the nails. Tap water, however, normally contains Ca^{2+}, Mg^{2+}, and Na^{+} ions and does not have a neutral pH (depending on the water's source, e.g., in Germany, it ranges between pH 6.5 and 7.5). For this reason, you should be able to detect some voltage.

b) What happened when you replaced the tap water with a solution of salt or citric acid? What voltages were you able to read?

Note: Electrolytes such as acids and salt solutions produce a clearly measurable voltage.

c) Explain what effect a load has on the voltage in the electrical circuit.

Note: When a load is connected, the voltage should drop sharply. (As we will see in the next subexperiments, this drop is due primarily to a lack of dissolved copper ions.)

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.

Answer: The successful use of table salt will make it clear that the medium must be an aqueous solution in which ions are dissolved. This will make the essential function of the electrolyte clear, specifically, closing the internal circuit through (ionic) conduction. While it's true for every acid that ions (H^{+}) are dissolved in water, there are also other aqueous solutions that contain ions such as Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, and SO_4^{2-}.

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.

Answer: Ions must be present so that the charge is carried and electricity can flow.

4 Boosting battery performance

4.6 Questions

a) Do you have an idea of how you could prevent this deposition on the less noble metal?

Answer: You can install a semipermeable separator, which is impermeable for metal ions yet permeable for the anions of the salt or the acid (Cl^{-}, SO_4^{2-}). In this way, the charge required for the internal circuit can be carried without the metal ions depositing on the counter-electrode (e.g., Cu on the Zn electrode). This direct deposition on the counter-electrode is equivalent to an internal short circuit of the battery and will discharge it very quickly.

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?

Answer: With this effect, you can coat a less noble metal with a thin layer of a more noble metal. To do so, you need only to place the less noble metal in a salt solution with ions of the more noble metal (see next subexperiment). If you apply an external voltage to metal salt solutions, you can also coat more noble metals with less noble metals, e.g. coat iron with zinc. The latter process is called zinc electroplating and is used for rust protection.

5 Spontaneous copper plating?

5.5 Analysis

a) Explain why copper apparently deposited on the coin.

Note: See next item

b) Explain what role the aluminum played in the process.

Note: It is best to explain the two items together: The relatively noble coin (for example, a euro coin consists of brass and nickel) is placed on the far less noble aluminum, which dissolves as Al^{3+} and gives off electrons to the coin. Cu^{2+} ions touch the coin's surface, absorb the electrons there, and deposit on the coin as Cu^0.

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?)

Answer: Citric acid and copper ions form a complex that is extremely soluble in water (clear blue solution). In this subexperiment, the citric acid thus plays a part in the copper being deposited particularly quickly and evenly.

b) If you have Internet access, find out where metal plating plays a role in technology.

Answer: Electroplated coatings are applied using metals such as copper, gold, nickel, chromium, zinc, and tin. The purpose is to provide ornamentation or to increase corrosion protection. A keyword for searching online is “electroplating.”

6 A professional zinc-copper battery

6.5 Analysis

a) Explain what function the paper towel performs in this experiment.

Note: The paper towel performs the function of the separator, although imperfectly.

b) Explain why the battery performance is therefore usually higher than in subexperiments 1, 3, and 4.

Note: Due to this separator, the gap between the two electrodes is narrower, and the entire surface of the electrodes can be used. The internal resistance drops as a result, and the battery can produce a higher current. In addition, a relatively large number of copper ions are formed when charging the battery, which also boosts the battery’s performance.

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.

Answer: Different membranes are used for different types of batteries and accumulators. A keyword for searching online is “separator (battery).” Today’s technology usually uses a plastic sheet with a predefined pore size such that the ions (e.g., chloride or sulfate) required for the internal electric circuit pass through the separator and the metal ions do not.

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.

Answer: At the anode, zinc atoms give up two electrons and are dispersed into the solution as zinc ions. At the cathode, the dissolved copper ions combine with two electrons to form copper and are thus removed from the solution. To balance out the charge difference, sulfate ions pass through the membrane. The formulas for the entire process are written as $Cu^{2+} + 2e^{-} \rightarrow Cu$ at the cathode and $Zn \rightarrow Zn^{2+} + 2e^{-}$ at the anode.