SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

Renewable Energy: Batteries Exercise

In this exercise, you will review core electrochemistry concepts, analyse battery types, and apply your knowledge to design electrochemical cells. You will also compare lead-acid, Li-ion batteries and thermal engines for real-world applications, considering cost, efficiency, and practical constraints.

Exercise 1: Definitions

(a) In electrochemistry, an electrode playing a specific role is the SHE.

- What is this specific role?
- What do the letters stand for?
- What is the redox- couple involved?

(b) An electrolyte is:

	true	false
• an ionically conducting medium	☐	☐
• a vessel used for performing electrolysis	☐	☐
• a compound that dissolves in a solvent giving rise to ions	☐	☐
• a man performing electrolysis	☐	☐

(c) In electrochemistry, the cathode:

	true	false
• is always the negative electrode of the system	☐	☐
• always has a negative potential vs SHE	☐	☐
• is always a reduction site	☐	☐

(d) In an electrochemical system:

	true	false
• at thermodynamic equilibrium, the current is always zero	☐	☐
• if the current is zero, the system is always in thermodynamic equilibrium	☐	☐

(e) Primary batteries:

	true	false
• are a simple version of secondary batteries	☐	☐
• can be used to store chemical energy	☐	☐
• cannot be recharged	☐	☐
• are not used any more	☐	☐
• are often used for large scale stationary energy storage	☐	☐

(f) Li-ion batteries:

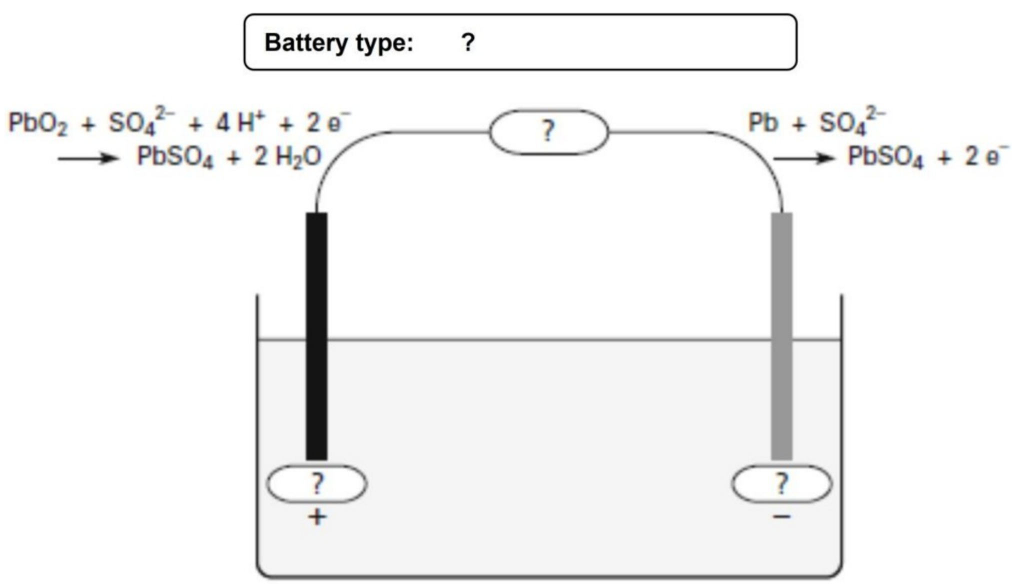
	true	false
• have always an open circuit voltage of 4.2V	☐	☐
• contain always anodes made of Li-foil	☐	☐
• use water as electrolyte	☐	☐
• use organic compounds as electrolyte	☐	☐
• are a good choice for mobile applications	☐	☐

Exercise 2: Electrochemical cells

(a) Considering the electrode reactions given below, complete the following diagram, by specifying:

- the battery type
- the positions of the anode and the cathode
- the direction of the current
- the type of the external circuit component

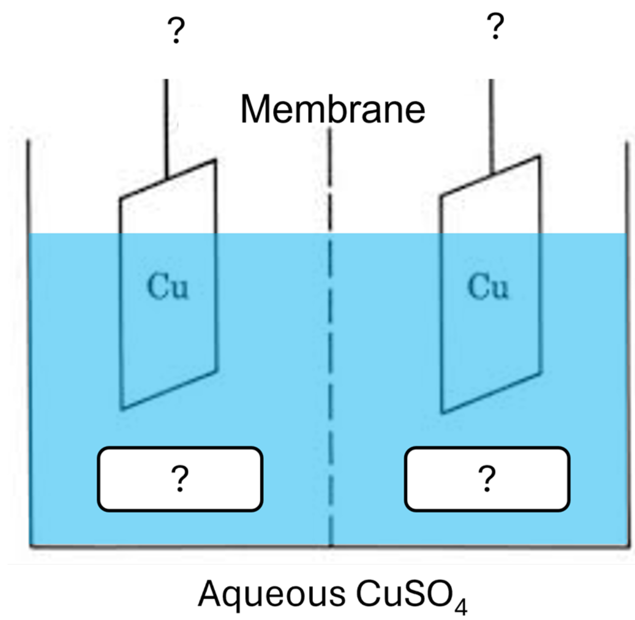
Indicate your answers by replacing the question marks on the diagram!



(b) Concentration dependence of electrochemical potentials

Two copper electrodes are immersed in $CuSO_4$ solutions separated by a membrane, thus forming two half-cells. Since the membrane is permeable to water but impermeable to $CuSO_4$, the concentrations in the half-cells differ.

- Specify two concentrations that result in a potential difference of 0.118 V. Consider that a concentration difference of one decade is expected to result in a potential difference of 0.059 V/2z (z = charge). Show how this formula is derived!
- Label the electrodes accordingly as cathode and anode.



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Exercise 3: Battery applications - stationary energy storage

A good friend of yours wants to live "off grid" in a mountain valley, i.e., without being connected to the public power grid. They can easily generate energy using a small hydroelectric power plant on a creek. However, the creek occasionally freezes over in winter, typically for no longer than a week. Your friend wants to be sure that they have enough energy stored in appropriate storage media to be able to survive self-sufficiently for a week in winter. They ask you to help them decide whether they should buy lead-acid batteries or Li-ion batteries for their stationary energy storage.

What type of batteries do you recommend? Justify your recommendation with a cost calculation and two arguments related, for example, to mass or maintenance requirements of your proposed solution.

Household profile: The electricity consumption of a single-person household with hot water is estimated at 2500-2900 kWh/year. The winter months account for a particularly large share of this, with an upward deviation of around 10%. Your friend assumes that they will not have more than 20 devices with a power rating of 500W in operation at the same time.
Battery specifications: Typical car batteries (sealed lead-acid type) have the following specifications: 12 V, 100 Ah, peak current: 700 A, price: CHF 150, weight: 21 kg/unit Typical Li-ion batteries (used as storage for caravans) have the following specifications: 12.8 V, 100 Ah, peak current: 200 A, price CHF 790, weight: 11 kg/unit

Exercise 4: Battery applications – mobile energy storage

Disadvantages and advantages of batteries as an energy source for powering automobiles

(a) Compare the specific energies of Li-ion batteries and gasoline in an average passenger car: How heavy is the car battery with an energy of 57.5 kWh (specific energy 200 Wh/kg)? How heavy is a tank of gasoline if the tank holds 60 L and the density of gasoline is 0.75 kg/L (calorific value: 46.7 MJ/kg) and how much energy does it hold?

(b) Calculate the range of the electric car compared to the gasoline car at an efficiency of 90% for an electric motor and 20% for a gasoline engine!
The energy required by an average electric car to travel 100 km is approximately 15.1 kWh. The weight of the combustion engine car is about 300 kg less than the average electric car weight of 1.8 t. Use this information to estimate the gasoline consumption of the combustion engine car per 100 km before calculating the range.