Sustainable Hydrogen and Electrical Energy Storage
SET3031

Question 1.

a. Which factors need to be realized if an energy economy based on hydrogen as an energy carrier is to become a reality? Name 4.
b. Which of the above factors would you consider to be mature enough to be implemented and which do still require research & development efforts?

Question 2.

a. Storage of hydrogen in liquid form can be realized. Which two fundamental properties of hydrogen play a role for liquid storage?
b. Explain in a hand-waving manner why it cost more energy to compress 1 mol of H_2 than 1 mol of methane.

Question 3.

a. Describe H_2 production from fossil fuels.
b. Where is a catalyst needed, and where play possible unwanted side-reactions a role?

Question 4.

Consider the Daniel element, where the equilibrium potential follows the Nernst law $E_{eq}=E_0 -(RT/2F)\ln(c_{Zn2+}/c_{Cu2+})$, and $E_0=1.097$ V, $RT/2F=0.013$ V, c_{Zn2+} is the Zn^{2+} concentration (mol/l) near the Zinc electrode and Cu^{2+} near the Copper electrode. During discharge the following reactions occur: Zn(s) -> Zn^{2+} + 2e at the Zinc electrode and Cu^{2+} + 2e -> Cu(s) at the copper electrode.

a. What is the driving force for such electrochemical reactions?
b. Assume the starting concentrations are $c_{Zn2+}=1$ and $c_{Cu2+}=1$. What potential would you measure between the two electrodes?
c. When does the reaction stop?
d. How could you increase the capacity of the Daniel element?

Question 5

a. Give five required properties for rechargeable batteries.
b. Which of those properties makes Li-ion batteries interesting?
c. Explain how a Li-ion battery works, what are the components, and what is their function?
d. What is the advantage of making electrode particles very small (nano-structured)

Question 6

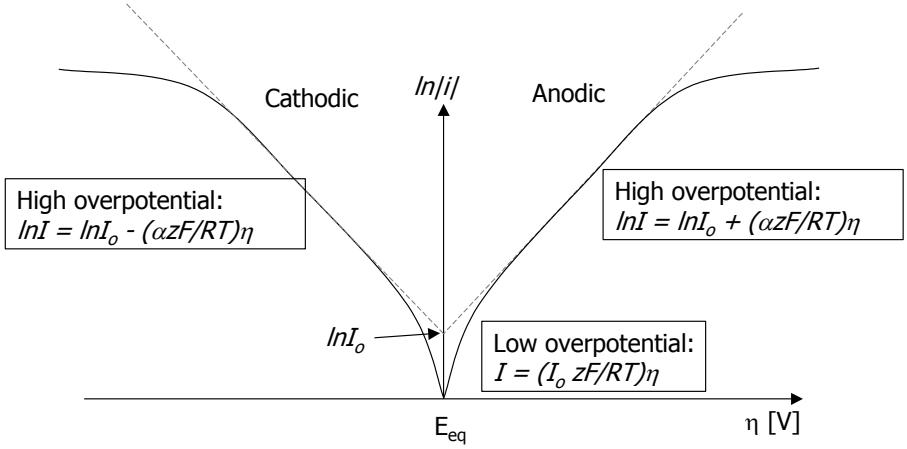
With electrolysis hydrogen can be produced using electricity

a. What limits the overall energy efficiency for electrolysis (name 2 factors)? What is the reason for this if you look on a molecular scale?
b. How can one realize electrolysis of seawater to produce hydrogen? Give two methods.

Question 7
Photoelectrolysis would provide a direct means to produce hydrogen from water.

a. Describe a basic photoelectrochemical cell with a sketch.
b. What are six requirements for the semiconductors used?
c. Give a rough indication of photoelectrochemical cell efficiencies and compare that to a solar cell + electrolyser.

Question 8
A "Tafel" plot describes how an electrochemical reaction responds if a specific overpotential (η) is applied, resulting in a current (i). A schematic "Tafel" plot is shown below.



a. Which process normally dominates at low overpotentials?
b. Which process limits the current at high overpotentials?
c. What is the meaning of I_0 the exchange current density?
d. Draw a schematic line in the "Tafel" plot, that would represent a battery that can be (dis)charged faster than that shown in the plot.

Question 9

a. Name three losses in the conversion of H_2 + O_2 towards H_2O in a fuel cell.
b. What is the role of the catalyst in fuel-cells?
c. What does poisoning of the fuel-cell catalyst mean?
d. Give two advantages of fuel-cell technologies working at high temperatures.
e. Why are these high temperature technologies considered to be not suitable for application in cars?

Question 10
Hydrogen storage using surface adsorption attracts worldwide interest. In addition surface adsorption is used in purification steps in the hydrogen production process. The Langmuir isotherm describes the adsorption of as molecules on a surface.

a. What are basic assumptions behind the Langmuir isotherm?

b. Derive the Langmuir isotherm where you can use that the flux of incoming molecules n equals $n = \frac{N_M P}{\sqrt{2\pi mRT}}$
c. Describe how you use the isotherms at different temperatures to determine the adsorption interaction energy.

Question 11.
Hydrogen storage other than in high pressure gas cylinders requires interactions between hydrogen and materials or itself.

a. Describe what types of interaction may be used and indicate the relative strength
b. Is hydrogen adsorption possible at room temperature and 1 Bar?

Question 12.
Metal hydrides can store hydrogen chemically.

a. What steps are required for the hydrogen to be stored in the material, coming from the gas phase? Which factors can be rate limiting for the storage speed?
b. How can one modify the materials in order to improve the hydrogen absorption speeds and operating conditions? (use an example)
c. What properties would an optimal metal hydride have for hydrogen storage purposes (name 5)?
d. How can one modify the enthalpy of formation of (light)metal hydrides (name two ways)?

Question 13.
What impact could a hydrogen based energy economy have on the climate, discuss 2 potential positive and a potential negative effect.