Fuel Cell Science and Technology

Midterm Exam

April 19 2021
14:00~15:15

1. [25 pts] Explain following terms in fuel cells.
   a) Triple phase boundary
   b) Regenerative Fuel Cell
   c) Extrinsic vacancy
   d) Exchange current density
   e) Heat generation from fuel cells

2. [35 pts] A fuel cell has the reactions:

ANODE: $2A_2 \rightarrow 4A^{++} + 8e^-$

CATHODE: $4A^{++} + B_2 + 8e^- \rightarrow 2A_2B$

All data are at RTP. The overall reaction releases free energy of 300 MJ per kilomole of A_2B. The entropies of the different substances are:

A_2: 200kJ/K kmole

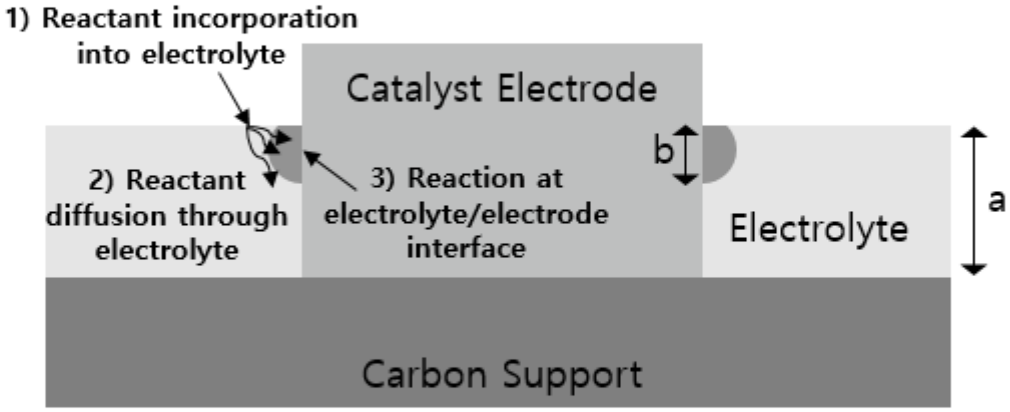
B_2: 400kJ/K kmole

A_2B: 150kJ/K kmole

A_2 and B_2 are gases whereas A_2B is liquid.

(a) What is the voltage of an ideal fuel cell that uses the above reaction at RTP?
(b) Estimate the voltage at standard pressure and 50C.
(c) How much heat does the ideal fuel cell produce per kilomole of A_2B at RTP?
(d) What is the voltage of the cell if the gases are delivered to it at 100 MPa? The operating temperature is 25C
(e) If the internal resistance of the cell (operating at RTP) is 0.001 ohm (which is constant for different fuel cell current), what is the maximum power the cell can deliver to a load?
(f) What is the fuel consumption rate of the cell under these circumstances?
(g) What is the fuel cell efficiency of the cell? (Hint: stoichiometry number is 1)

3. [20 pts] Even though we learned that triple phase boundary is a line, the reaction site has certain area. The following figure describes that hydrogen dissociation reaction happens under a **"cylindrical"** platinum particle in contact with Nafion membrane.



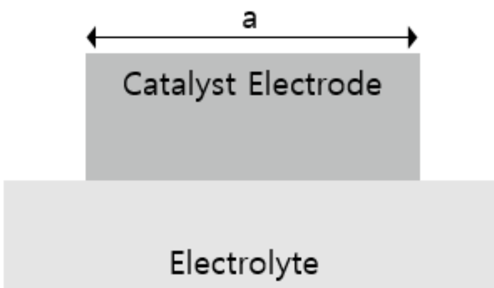
It is conceived that hydrogen diffuses into Nafion membrane and dissociates at the surface of Pt in contact with Nafion (step 1, 2 and 3 in the figure). Shaded area at the side of Pt catalyst electrode in the figure depicts such reaction area. From the picture, you can see that TPB is a "band" not a line. The following figure describes the Faradic resistance (= slope of the Faradaic overvoltage in IV curve) of a "single" Pt catalyst particles at open circuit voltage as the thickness (a in the above figure) of the electrolyte changes.

X axis represents the thickness of the electrolyte in um and Y axis represents the Faradaic resistance in Ohm.

From this, answer the following question.

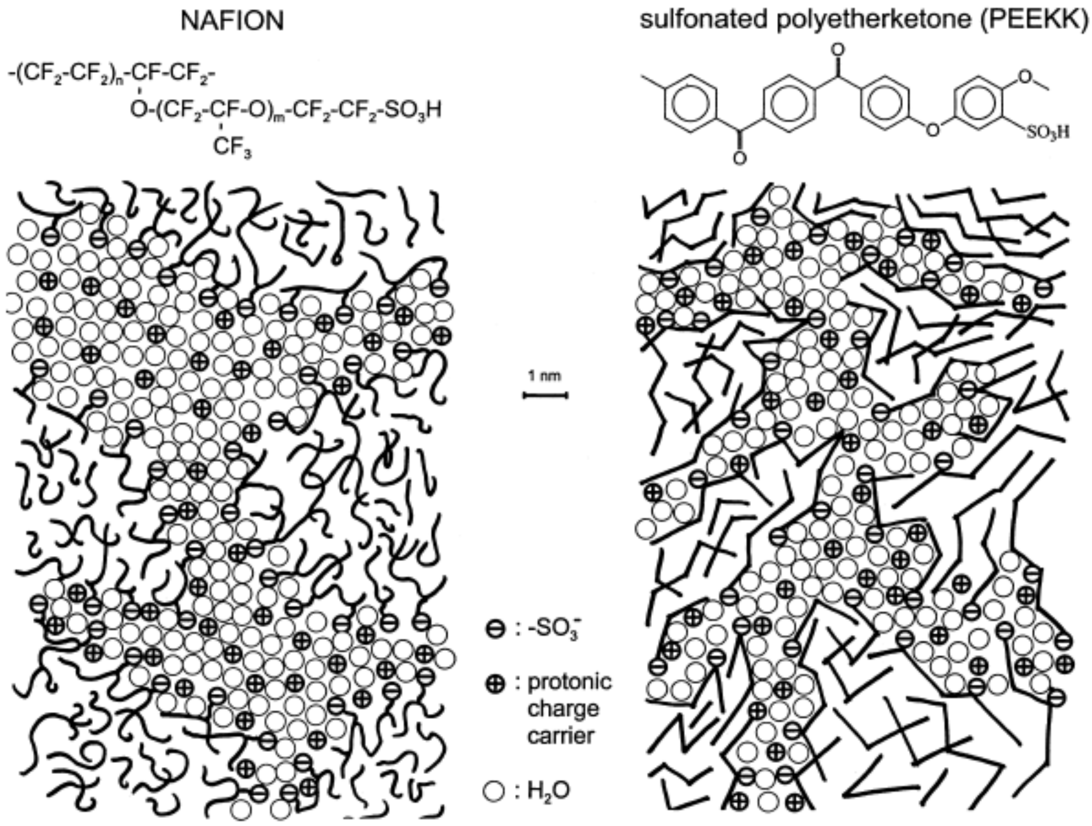
(a) Explain why the slope of the line in the previous figure changes from 1 to 0 as the thickness of Nafion increases.

(b) Consider another geometry in the following figure. Sketch the Faradic resistance curve having X axis as the diameter of catalyst particle (a in the following figure) and explain your answer.



4. [10 pts] Commonly, Bultler-Volmer equation is simplified to "Linearized BV equation" or "Tafel equation". Which equation will you use for a) hydrogen oxidation and b) oxygen reduction? Explain why.

5. Sulfornated PEEKK is a good proton-conducting polymer with hydrocarbon backbone structure. The chemical structure and the proton-conducting mechanism are shown in the following figure.



Based on your observation, answer the following question.

[10 pts] a) How does the level of hydration affect the conductivity of PEEKK? And why?

[10 pts] b) Scientist found out that the size of water channel is smaller in PEEKK compared to NAFION. How does it affect the proton conductivity of PEEKK?

[10 pts] c) The hydrocarbon backbone of PEEKK is “more hydrophilic” than flouroethlylene structure of NAFION. How does it affect the proton conductivity of PEEKK?