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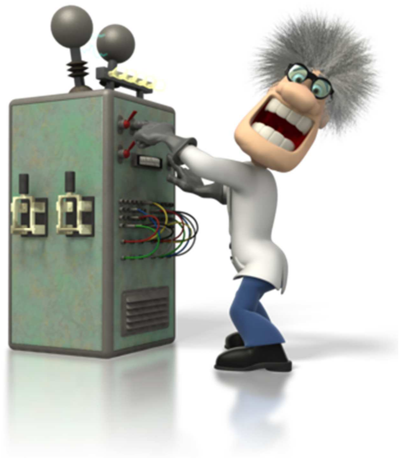
EXAM

Prof. Franco's Fuel Cells Lectures
Jan. 13, 2014 (Amiens, France)

Duration: strictly 3 hours

CONTEXT (read carefully… !)

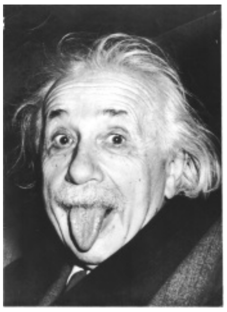


Hi guys! This is Prof. Mad…I hope you had great vacations.

The "Fuel Cells" exam is finally arrived…Fortunately for me, as I need your help!

For instance, I was working the whole vacations trying to unblock my fuel cell-powered computer, because after your fantastic presentations for the Fuel Cell Students' Challenge 2013, I was so enthusiastic that I went for dinner with French wine and I forgot my computer password!

Please help me on finding the password: some of the questions below contain "multiple choice" sub-questions where a unique correct answer exists. By collecting the "item letters" corresponding to the correct answers, and by respecting their order of appearance, you will be able to build a word corresponding to my password.



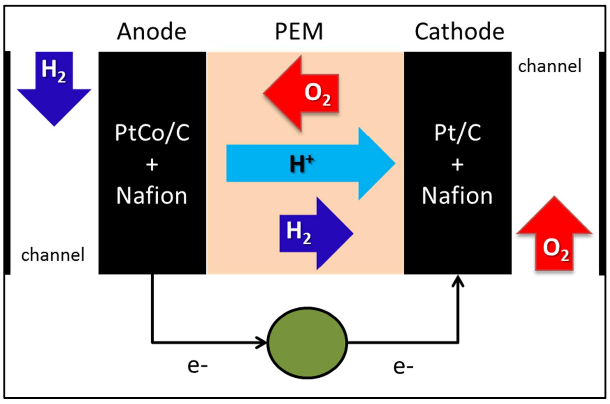
Final hint to solve this password quiz from my friend Albert:

"Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand."

So, just relax, play and enjoy…

Good luck!

1. Consider the operating PEMFC schematized here.



1.1. List the possible materials degradation mechanisms which may happen under current-cycled conditions in the anode, membrane and cathode.

1.2. Is crossover H_2 reacting with crossover O_2 within the membrane? If so, which specie may form?

1.3. Can water content increase in the PEM because of the cathode degradation mechanisms? Explain.

1.4. Generally speaking, continuous injection of 100 ppm of CO in the anode channel may **A)** dissolve Nafion in the cathode, **B)** not affect the PEMFC performance, **C)** corrode the anode carbon support or **D)** dissolve the anode PtCo particles. Justify your answer.

2. Consider the Fenton's reactions within a polymer electrolyte membrane.

(F1) $H_2O_2 + Fe^{2+} + H^+ \rightarrow Fe^{3+} + HO^{\cdot} + H_2O$
(F2) $H_2O_2 + Fe^{3+} \rightarrow Fe^{2+} + HOO^{\cdot} + H^+$
(F3) $HOO^{\cdot} + Fe^{3+} \rightarrow Fe^{2+} + O_2 + H^+$
(F4) $H_2O_2 + HO^{\cdot} \rightarrow H_2O + HOO^{\cdot}$
(F5) $HO^{\cdot} + Fe^{2+} + H^+ \rightarrow Fe^{3+} + H_2O$

2.1. Are these reactions **electro**chemical?

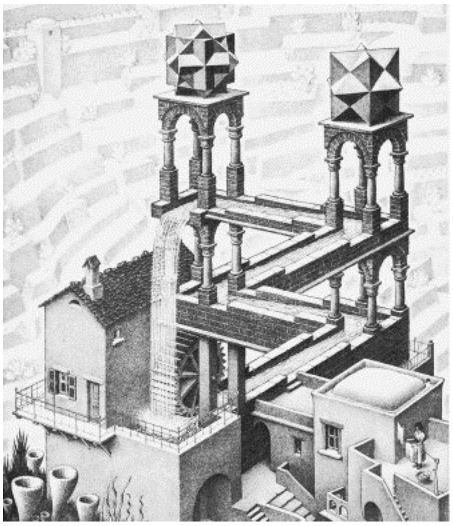
2.2. Write the corresponding kinetic rate expressions.

2.3. Write the balance equations allowing calculating the concentration of H_2O_2, Fe^{2+}, Fe^{3+}, HO° and HOO°.

2.4. Propose a technical solution, integrated in the PEMFC, to avoid the production of OH° and HOO° radicals through the decomposition of H_2O_2.

2.5. The lowest production rate of H_2O_2 may occur for **I)** a bulk-truncated $Pt_3M(111)$ cathode catalyst, **R)** a skeleton $Pt_3M(111)$ cathode catalyst, **L)** a skin $Pt_3M(111)$ cathode catalyst (M being a transition metal element). Justify your answer.

3. Consider the imaginary perpetual machine paint by Escher.



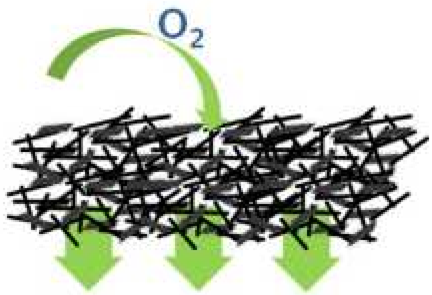
3.1. Explain why this machine cannot work in reality.
3.2. Explain why a fuel cell is not a perpetual machine.

4. "Time traveler" in one of the Charlie Chaplin's movies?

In Charlie Chaplin's movie "Circus" (1928) there is a scene showing a woman holding her left hand to their ear and talking. Few years ago, filmmaker George Clarke saw the scene and deduced the woman was holding a cell phone, and thus was way ahead on her time. He made a YouTube video which generated many debates if the woman was or not a "time traveler" captured by Chaplin's movie. It seems that however the so-called cell phone is really just an old-time Siemens 1924 hearing aid.

4.1. Imagine that the hearing aid is powered by a fuel cell: which type of fuel cell you think may be the most convenient (portable) one?
4.2. Explain the operation principles of such a fuel cell.
4.3. Discuss some technical challenges to overcome to develop fuel cell-powered hearing aids in the status of fuel cell research progress in 1928 vs. nowadays.

5. New catalyst layer supports for PEMFC.



A research group has taken up a recent project to fabricate new cathode catalyst layer support materials for PEMFCs. The new material is Ceramic based with lower conductivity than Carbon but is more resistive to corrosion at high temperature. Pt is used as the catalyst.

5.1. Suggest at least two modeling techniques that are able to predict the interaction of the new support material with Pt? What properties at Pt-support interface should be investigated/predicted using these modeling techniques?
5.2. If both modeling and fabrication studies show sufficient interaction between Pt and new support materials, would you suggest investing in large scale production of these support materials? What are your (other) concerns?
5.3. In PEMFCs, carbon corrosion mainly happens because of **E)** the presence of liquid water at its vicinity, **F)** the presence of Nafion at its vicinity, **O)** the presence of Pt catalyst at its vicinity.

6. Batteries.

6.1. The Peukert number (n) is a measure showing how battery maintains the charge. If n is close to 1, it means that the battery loses very little charge. The higher the n, the less efficient the battery is. This value can be calculated using the formula:

n=[log (C/T)/log (I)]

n (Peukert's number) is equal to the logarithm of C (theoretical capacity) divided by T (discharge time) to the base of I (the current).

Also assume that the cost function of a battery cell is described by:

Cost(Q)=4K+2L+ M

(in which Q is the number of cells manufactured per year, K is the materials in Kg and L is labor used in hour). M is a market factor that determines the application of the battery for automotive and is described by M=2log (C/T). Derive the relationship between Cost and current when K=20, L=50 and n=0.5. Describe how the resulting equation can be used for the material design purposes?

6.2. A phase field modeling approach allows **A)** predicting the solid phases formation and evolution during discharge and charge of lithium ion batteries, **B)** predicting the cost of a battery pack, **C)** predicting how tired you are at this stage of this exam…

7. **General concepts.**

7.1. A multiscale model **L)** is necessary a multiparadigm model, **M)** is necessary a multiphysics model, **N)** is necessarily both, a multiparadigm and a multiphysics model.

7.2. For PEMFCs, as Pt^{2+} is positively charged, and the global electric field is pointing from the anode to the cathode through the membrane, explain how it is possible having the Pt^{2+}, generated during cathode Pt dissolution, moving in the opposite direction to the electric field. What is the main driving force of Pt^{2+} transport from the cathode to the membrane?

8. **My password.**

So…did you discover my password? If so, please provide it!