EXAM

Prof. Franco's "Fuel Cells and Beyond" Lecture Series
Jan. 13, 2015 (Amiens, France)

<u>Duration:</u> strictly 2 hours

No need of long answers. Concise answers are preferred.

CONTEXT (read carefully… !)

Hi guys! This is Arnold…I am happy to see you again! How are you? I hope you had great vacations.

The "Fuel Cells and Beyond" exam is finally arrived…Fortunately for Prof. Franco…Actually he is happy with the presents you gave him in last December, in particular the boat ("ship modeling"). But he has a problem: he cannot navigate with it because an object is missing!

Please help him on finding the missing object: 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 the missing object.

Final hint to solve this quiz from my friend Pablo Picasso:

"Learn the rules like a pro, so you can break them like an artist…"

So, just relax, play and enjoy…

Good luck!

1. The 2015 Dakar Rally.

The **Dakar Rally** is an annual rally raid or off-road endurance race of 2 weeks of duration. The terrain that the competitors traverse is very tough and the vehicles used are off-road vehicles. Most of the competitive sections are off-road, crossing dunes, mud, rocks, among others. The race involves cars, motorbikes, trucks and quads. The distances of each stage can cover up to 800–900 kilometers per day. Since 2009 the Dakar Rally is organized in South America. The 2015 Dakar Rally started on last January 4 in Buenos Aires, and is running through Argentina, Chile and Bolivia (9000 km loop).

Besides the specific problems of cost and durability, based on state-of-the-art fuel cell technology, and by considering the very severe conditions of the race:

1.1 List **two** possible technical challenges that should be overcome in order to power a Dakar Rally **truck** with a **SOFC**.

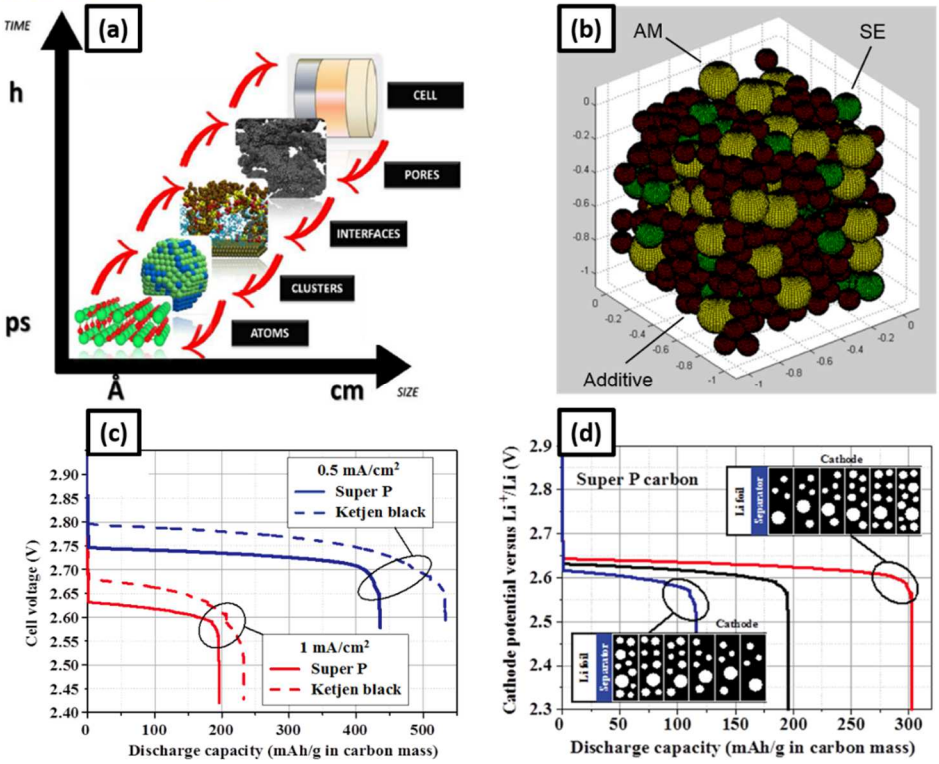
1.2 List **two** possible technical challenges that should be overcome in order to power a Dakar Rally **motorbike** with a **DMFC**.

1.3 List **three** possible technical challenges that should be overcome in order to power a Dakar Rally **car** with a **hydrogen-feed PEMFC**.

1.4 A state-of-the-art PEM Water Electrolyzer anode, used to produce H_2 in the Atacama desert (stage #6 of the 2015 Dakar Rally) can be made of **A)** platinum nanoparticles supported on carbon; **B)** platinum nanoparticles supported on IrO_2 particles; **C)** a mixture of IrO_2 and RuO_2 particles; **D)** IrO_2-decorated carbon nanotubes.

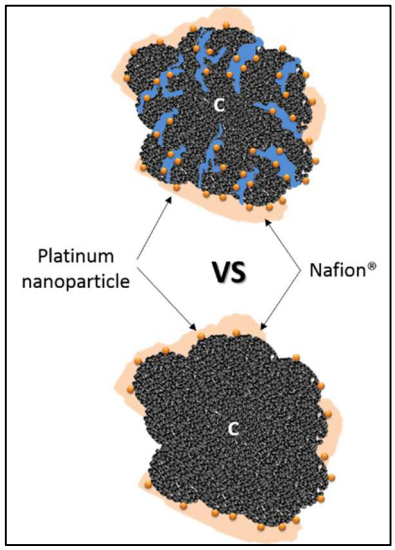
2. Collage of Prof. Franco's figures.

Let's consider the following four figures from Prof. Franco's lectures with **(a)** referring to the topic of multiscale modeling of fuel cells, **(b)** referring to an all solid state lithium ion battery electrode (AM: active material particle; SE: solid electrolyte particle) and **(c)** and **(d)** referring to the modeling-calculated performance of lithium air batteries with different carbon-based cathodes.



2.1 Briefly explain some[1] meaning for each of these figures.
2.2 During the discharge of a Lithium Ion Battery, the driven force of Li^+ transport in the electrolyte is **A)** electromigration; **E)** diffusion; **I)** convection; **O)** diffusion and electromigration; **U)** Praveen and Aman are good dancers ☺.

3. Antagonistic PEMFC cathodes.



Let's consider the two Pt/C systems on the right constituting two different PEMFC cathodes.

3.1 Discuss the electrochemical performance differences towards the Oxygen Reduction Reaction (ORR) that can be observed between the two types of Pt/C systems.
3.2 How an externally applied magnetic field (applied in the radial direction of the carbon particle) may affect the ORR activity of the two Pt/C systems?
3.3 Is the carbon hydrophobicity impacting the Pt ORR activity? Briefly justify your answer.
3.4 Briefly discuss the tolerance differences towards NO_x contamination of the two systems.
3.5 A $Pt_3Ni(111)$ catalyst provides the highest H_2O_2 production rate if it presents **B)** a bulk truncated structure; **M)** a skin structure; **N)** a skeleton structure.

[1] For each figure: no need to be exhaustive and scope is free.

4. Keywords soup to warm you up.

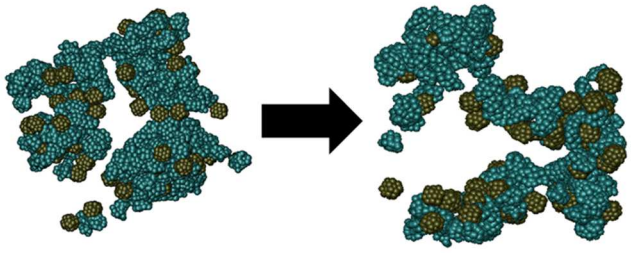
4.1 See the intriguing "soup" herebelow. Find **5 keywords** related to Prof. Franco's lectures (write the words in your copy).

E	C	O	R	R	O	S	I	O	N
P	H	A	S	E	T	I	E	R	U
A	E	R	T	E	A	R	T	Y	Y
E	M	B	S	A	L	G	H	I	C
J	I	X	C	O	L	K	P	L	A
N	C	O	N	G	I	Y	O	I	M
L	A	P	O	R	O	U	S	N	A
M	L	I	U	P	N	Z	A	T	Z

4.2 In a PEMFC cathode, Pt catalyst degradation leads to **A)** Pt ions oxidation in the ionomer; **E)** carbon support corrosion; **P)** Pt ions reduction with H_2 and precipitation in the membrane; **R)** Pt ions reduction with N_2 and precipitation in the membrane.

5. Carbon corrosion in a "catastrophic" PEMFC cathode.

Let's consider the corroding PEMFC cathode carbon in the figure with the associated elementary mechanisms.



$$C + H_2O \Rightarrow C(H_2O)_{(ads)}$$
$$C + H_2O \Rightarrow C(OH)_{(ads)} + H^+ + e^-$$
$$C(H_2O)_{(ads)} + C(OH)_{(ads)} \Rightarrow C(OOH)_{(ads)} + 2H^+ + 2e^-$$
$$C(OOH)_{(ads)} \Rightarrow CO_2 + H^+ + e^-$$

5.1 Are these reactions **electro**chemical?

5.2 Write the corresponding kinetic rate expressions.

5.3 Write the balance equation allowing calculating the surface concentration on C of $(OH)_{(ads)}$.

5.4 Propose a technical solution to mitigate the cathode C corrosion.

5.5 Pt dissolution may **A)** slow down the carbon corrosion kinetics **B)** accelerate carbon corrosion, **C)** slow down the cathode ionomer degradation, **D)** may maintain the PEMFC potential constant; **Z)** I am already tired…

6. Voynich manuscript and porous electrode theory.

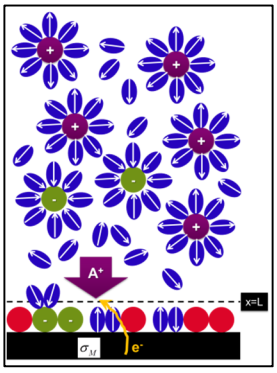
The Voynich manuscript is an illustrated codex written in an unknown writing system probably in the early 15th century. The mystery of the meaning and origin of the manuscript has excited the popular imagination, making the manuscript the subject of many speculations. None of the hypotheses proposed has yet been independently verified. Many illustrations seem ahead "the manuscript time" as they look like representations of galaxies and objects which can be observed only my microscope. For example, in the manuscript illustration of the figure, Prof. Franco see 9 interconnected pores of a PEMFC cathode.

6.1 Briefly explain the basics[2] of the Pore Network Modeling technique applied to such a system of interconnected pores: what it can be simulated with this technique?

6.2 Is the diffusion coefficient of O_2 dependent on the liquid water saturation? Why?

6.3 Accumulation of liquid water in a cathode carbon pore may accelerate **S)** the carbon corrosion kinetics; **T)** the SO_{3-} poisoning of the catalyst; **O)** the liquid water formation.

7. Electrochemical double layers...yeah!



Consider the electrochemical double layer formed at the interface between a catalyst and a liquid electrolyte (see the figure) in a PEMFC cathode environment.

7.1 Under the hypothesis of diluted solutions, provide the partial differential equation (PDE) describing the transport of the proton (A^+ in the figure) in the electrolyte.

7.2 Which properties of the solvent may impact the proton transport at this interface?

7.3 The song "attached" to this topic: **S)** Don't worry be happy; **T)** Don't cry for me Argentina; **E)** El Mariachi Loco.

8. The missing object.

So…did you discover the missing object? If so, please write it!

[2] No need to provide equations, just focus on the concepts.