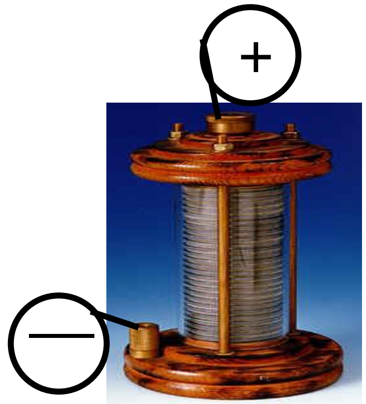
CHBE 477/577:
Fuel Cells and Electrochemical Engineering



Syllabus

Prof. Elődd Gyenge
Dept. of Chemical and Biological Engineering

January 10, 2023

THE UNIVERSITY OF BRITISH COLUMBIA

• Course Highlights

- The course assumes no previous knowledge of electrochemistry but presumes familiarity with fundamental chemical engineering knowledge (e.g., thermodynamics, reaction kinetics, mass and energy balances, momentum, mass and heat transfer, some unit operations).

- It starts with the fundamentals of electrochemical science and engineering and gradually builds up the toolbox necessary to understand and analyze state-of-the-art technologies and applications in the areas of fuel cells, batteries and electrochemical synthesis. These technologies are crucial for the transition to clean and renewable energy sources and decarbonization of the chemical and energy industries.

- The theory is connected to practical applications and examples such that students can develop problem solving and critical thinking skills enabling them to analyze and design electrochemical systems. Furthermore, students will have the opportunity to select and work on group class projects that will give them insights into the modern literature in the field and develop and incite their curiosity regarding the fascinating world of electrochemistry.

• Learning Objectives:

- Understanding the scientific and engineering principles of electrochemical science and engineering
- Development of problem solving skills and critical thinking for quantitative analysis of electrochemical processes.
- Gain familiarity with modern applications and literature in fuel cells, batteries, capacitors and electrochemical synthesis.

General Course Information

- Professor: Dr. Előd Gyenge: preferred method of contact: message on Canvas
- TAs: *Joseph English, **joseph.english@ubc.ca***
  *Alec Jameson, **alecjame@mail.ubc.ca***
- Course Website: **Canvas, Lectures In-Person**
- Assignments will be posted on Canvas.
- Assignment submissions online.
- *Late assignments: -5% per day. No assignment submission is allowed after 1 week past deadline.*
- *Assignment Grades will be posted on Canvas.*
- No textbook purchase is required. I developed my own course notes that are posted on the website. Useful reference books are listed at the end of Syllabus.

Course Organization and Assessments

- **Lectures:** approx. 23 lectures, 1.5 hrs. each; January 10 to April 13, 2023
- **Assignments:** 4 or 5 individual numerical assignments
  - CHBE 577 assignments will contain additional and/or different questions/problems
- **Exams – In Person, Written Exam, similar in style to the Assignments**
  - **Midterm (60 minutes): Thursday, February 28, 11 AM PST**
  - **Final Exam (120 minutes.): during the April exam session (TBA)**
  - CHBE 577 Exam will contain additional and/or different questions/problems
- **Group Project :**
  - Groups of 3 students: 2 undergrad and 1 grad student per group
  - The Project is compulsory to all students
  - More information on the next slides

Grading

- **Assignments: 20%**
- **Midterm Exam: 20%**
- **Project: 20%**
- **Final Exam: 40%**

- Note the Midterm Exam weight cannot be transferred to the Final Exam.
- The Midterm covers only the 1st approx. 25 to 30% of the material, whereas the Final covers the entire course.
- 3 Winning projects will be selected and will present their projects on the last day of classes.
- Assuming that the Project grade is higher than the Final Exam, the winning project weight will be increased to 30%, while the Final Exam weight will be reduced to 30%.

Project Objectives and Guidelines

- **Learning Objectives:**
  - To familiarize students with modern topics and the combination of theory and practical applications of electrochemical processes.
  - To gain proficiency with scientific literature search and analysis
  - Gain experience with team work.
- **Project Group Organization:**
  - Groups of 3 students: 1 graduate and 2 undergrad students per group (preferred)
  - Sign-up on Canvas with the groups.
- **Project theme:**

  Electrochemical engineering for clean energy and sustainable chemical industries

  Choose from one of these topics. All topics must be selected:

  - Magnesium-based batteries: Opportunities and Challenges
  - Na-ion and K-ion batteries: Opportunities and Challenges
  - New developments in Lithium Iron Phosphate ($LiFePO_4$) batteries
  - Paired Electrosynthesis: producing useful chemicals at both electrodes
  - Novel electrochemical processes for water treatment technologies
  - Semiconductor electrodes and photo-electrochemistry: from fundamentals to application

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Project Writing Instructions

- Maximum 15 pages total (including cover page, figures, tables, references), spacing 1.5, font size 12.
- It should be based on at least 10 different research papers (and patents if applicable) from reputable Journals.
- Use your own words, write your own thoughts and apply critical analysis to the literature. This is NOT a copy – paste exercise!
- Try to connect as much as possible what you read in the literature with the course material and explain things based on concepts learned in the course. Maybe not always 100% possible depending on the topic BUT a good effort should be made to connect the project with what you learn in the course.
- When using Figures/Tables from literature, while copyright is not required, you must indicate the reference source for each Figure/Table.

Project Instructions

- **Project Headings/Sections:**
  - *Cover page*: Title, Name, Date, Course etc.
  - *Table of Contents*
  - *Abstract*: max. 250 words
  - *Introduction and Background* (*max. 3 pages*): What are the problems that your selected project tries to address? Describe the background: both theoretical and practical as it applies.
  - *Discussion and Presentation of a Specific System(s) you selected (max 3 pages):* Description of experimental set-up and/or associated mathematical model (if applicable), Is there any novelty in the proposed set-up? Comparison between systems, etc.
  - *Results and Discussion (max. 4 pages):* Discuss critically the performance of the selected system. Focus on a critical analysis emphasizing advantages and disadvantages and indicate options for improvement.
  - *Scale-up Considerations (max 1 page):* Are there large-scale deployment of the system you studied? In your opinion what would be the necessary figures of merit that should be achieved for scale-up? What are the factors that are limiting scale-up at present and how to overcome those?
  - *Knowledge Gap and Conclusion (max 1 page):* What are the areas that still need improvement (i.e., knowledge gap)? How do you see the future of the proposed system? What are the most important new things you learned in this project?
  - *Group member contributions:* Include a Table summarizing each member's contribution to the project. <u>Example</u>: John wrote the Introduction and Background and researched the Na-ion battery component of the project etc. All group members need to sign the contribution page.
  - *References (max. 1 page):* minimum of 10 references are needed. Use the Vancouver referencing style.

Project Grading Template

Item	Weight (%)
Originality and quality of writing, critical analysis, connection to course material	30
Scientific / engineering accuracy and understanding	30
Quality of the selected references and referencing	20
General report presentation: format, style, quality of Figures/Tables and equations	10
Individual contribution to the group project and iPeer score	10

Project Deadlines

- **by Jan 27:** form the groups, sign up on Canvas with your proposed project topic. You are welcome to discuss the proposed project topic beforehand with me.
- **by March 31**: submit your project on Canvas.
- **April 13:** winning group presentations

COURSE OUTLINE

1. Introduction and Basic Concepts

Electrochemical power sources vs. power sinks (electrolysis)
Volta's pile: Lessons from the past
The concept of electrochemical equilibrium
The rate of electrochemical processes: Faraday's law
Extent of reaction and Faraday's law: material balance equations
Specific power and energy: Ragone plot
Examples of different electrochemical systems

2. Electrochemical thermodynamics

Measurement of electrode potentials: two and three-electrode set-up
Reference electrodes
Equilibrium electrode and cell potentials
Nernst equation
Activities and activity coefficients
Thermodynamic heat generation / consumption by electrochemical cells
The open circuit cell voltage, power source vs. power sink
Cell voltage balance equation
Junction potentials

3. Electrode kinetics and electrocatalysis

A closer look at the electrode (electronic/ionic conductor) interface: electric double layer models
Electrode kinetic models
Surface-activation overpotential and its relationship to the current density
Electrocatalysis
Experimental techniques for studying electrode kinetics: linear and cyclic voltammetry at static and rotating electrodes (i.e., rotating disk and rotating ring disk electrodes).

4. Transport phenomena in electrochemical systems

Mass transfer boundary layer theory and the limiting current density
Concentration overpotential
Engineering of electrochemical processes
Gas diffusion electrodes: solid/liquid/gas interface, porous electrodes
Migration, diffusion and convection: the general flux equation for dilute electrolytes
Conductivity of electrolyte solutions: effect of concentration, inert phases and temperature
Transport in solid electrolytes: ion exchange membranes, ion-conducting ceramics

Examples and Applications are presented throughout the course selected from a wide range of processes

Polymer electrolyte-membrane (PEM) fuel cells
Diverse battery technologies
Diverse electrosynthesis processes: inorganic and organic

References

- **COURSE NOTES** posted on a timely manner on Connect. No textbook required.

- J.N. Harb and T. Fuller, *‘Electrochemical Engineering*’, (2018)
- G. Kreysa and H. Wendt, ‘*Electrochemical Engineering: Science and Technology in Chemical and Other Industries’,* Springer (1999)
- F.C. Walsh, *‘A First Course in Electrochemical Engineering’,* The Electrochemical Consultancy (1993)
- G. Prentice, *‘ Electrochemical Engineering Principles’*, McGraw Hill (1991)
- J. Newman, ‘*Electrochemical Systems*’, 3rd ed., Wiley-Interscience (2004).
- D. Pletcher and F.C. Walsh, *‘Industrial Electrochemistry’*, 2nd ed., Blackie Academic (1993)
- F. Barbir, *‘PEM Fuel Cells: Theory and Practice’*, Elsevier, (2005)
- O’Hayre, S-K. Cha, F. Prinz, *‘Fuel Cell Fundamentals’* 2nd ed., John Wiley & Sons (2018).
- D.A.J Rand, R. Woods and R.M. Dell, *‘Batteries for Electric Vehicles*’, Society for Automotive Engineers, Warrendale, Pa, (1998).