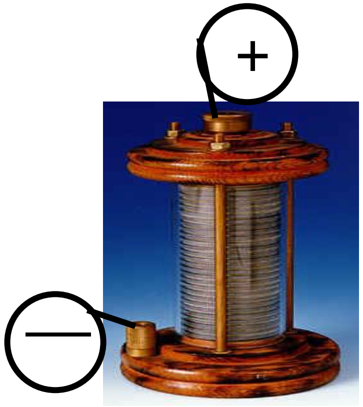
CHBE 477/577:
Fuel Cells and Electrochemical Engineering



Syllabus

Prof. Elődd Gyenge
Dept. of Chemical and Biological Engineering

January 11, 2022

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
- TA: Joseph English, joseph.english@ubc.ca
- Course Website: **Canvas, Lectures on Zoom / 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

- **Lectures: 23 lectures, 1.5 hrs. each; Jan 11 to April 08, 2022**

- **Assignments:** 5 individual numerical assignments
  - CHBE 577 assignments will contain additional and/or different questions/problems

- **Exams – Online Quizzes with Multiple Choice Answers**
  - **Midterm Quiz (60 minutes): Thursday, March 3, 11 AM PST**
  - **Final Exam/Quiz (120 minutes.): during the April exam session (TBA)**
  - CHBE 577 Exam Quizzes will contain additional and/or different questions/problems
  - More about the Quiz on the next slides

- **Individual Project :**
  - Further details on next slides

Grading

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

Online Quiz Exams

- Canvas Quiz – Multiple Choice Answers
- Open book
- Midterm Exam: 1 hr: expect 6 to 10 questions
- Final Exam: 2 hrs: expect 12 to 20 questions
- Questions can be:
  - Theoretical
  - Conceptual
  - Numerical
- For the <u>numerical questions</u>: have paper, pen and calculator ready to solve the numerical questions
- At the end of the exam scan or take a picture of your Exam work papers and upload it as a single file in the designated Exam dropbox
- Grading is done automatically by Canvas based on the nr. of correct answers. However, the submitted Exam work papers will be considered by the TA in determining your final exam grade.

Project Objectives and Guidelines

- **General Principle:**
  - 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 retrieval.

- **Project theme:**
  - Electrochemical engineering for a greener environment and more sustainable energy and chemical industries

    - Choose a topic as part of the above broad and general theme that fascinates you and develop your project based on that.

    - The project should <u>not be too general and vague</u>. It is expected you go in some specific details regarding your selected topic.

    - Use the ‘helicopter approach to writing: you survey the general landscape in the field but than – similar to helicopter spot landing – you discuss some specific details about a technology.

Project Instructions

- Maximum10 pages total (including figures, tables, references), spacing 1.5, font size 12.
- It should be based on at least 5 different research papers (and patents if applicable) from reputable Journals.

- Project Headings:
  - *Cover page*: Title, Name, Date, Course etc.
  - *Abstract*: max. 250 words
  - *Introduction and Background* (*max. 1-2 pages*): What is the problem that your selected project tries to address? Describe the background: both theoretical and practical as it applies.
  - *Experimental Aspects (max. 2-3 pages)*: What are some of the interesting the experimental details utilized in building and testing the system you study?
  - *Results and Discussion (max. 4 pages):* you can use figures and tables to illustrate the performance under various operating conditions. Make sure you reference the figures/tables that you take from literature. Discuss critically the performance indicators. Focus on a critical analysis emphasizing advantages and disadvantages and indicate options for improvement.
  - *Knowledge Gap* / what are the areas that still need improvement
  - *Conclusion and Outlook for the Future (max. 1 page).* What is your conclusion about the system and how do you see its future?
  - *References (max. 1 page):* minimum of 5 refs. are needed. Style:

  A. Zxy, B. YYU, **J. of Power Sources,** *volume, pages, year.*

Project Deadlines

- **by Jan 28:** email me on Canvas your proposed project topic.
- **by April 8**: submit your project on Canvas as a *pdf.*

GENERAL COURSE OUTLINE (Note some specific topics very year-to-year)

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
Specific power and energy: Ragone plot
Fuel cell types
Membrane electrode assembly

Electrochemical thermodynamics

Measurement of electrode potentials
Three-electrode setup
Reference electrodes
Equilibrium electrode and cell potentials
Nernst equation
Activities and activity coefficients
Thermodynamic heat generation and consumption by electrochemical cells
Liquid junction potential differences
Measurement of the electrode potential: reference electrodes
The open circuit cell voltage, power source vs. power sink
Cell voltage balance equation

Electrode kinetics, electrocatalysis and gas diffusion electrodes
A closer look at the electrode (electronic/ionic conductor) interface: electric double layer models
Electrode kinetic models: the Erdey-Gruz_Butler_Volmer equation; low and high-field approximations
Electrocatalysis
Experimental techniques for electrode kinetics
Gas diffusion electrodes: solid/liquid/gas interface, porous electrodes

Transport phenomena and Electrochemical engineering
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
Mass transfer boundary layer theory and the limiting current density
Concentration overpotential
Engineering of electrochemical processes: current and potential distribution

Polymer electrolyte-membrane (PEM) fuel cell engineering and technology
Bipolar plate designs and stack assembly
Heat balance
Water management and humidification
Direct alcohol PEM fuel cells

High temperature (> 600 ^{o}C) fuel cells
Solid oxide fuel cell (SOFC)
Molten carbonate fuel cell (MCFC)

Hydrogen generation by electrochemical methods and hydrogen storage
Rechargeable batteries (time permitting): Lead-acid; Ni-metal hydride and Li-ion

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).