

Electrochemistry of Fuel Cells and Batteries (ME/MS 545)

Course Description: This course introduces the fundamentals of electrochemistry and electrochemical systems. The course covers the thermodynamics and kinetics of electrode reactions and associated mass transport in electrochemical systems utilizing liquid as well as solid-state electrolytes. It further surveys foundational techniques used in characterizing electrochemical systems such as controlled current and potential measurements, and impedance spectroscopy. Additionally, the course discusses the design and performance metrics of electrochemical storage devices including fuel cells and batteries, electrochemical conversion systems such as electrolyzers, and electrochemical analyzers and sensors.

Instructor: Joerg Werner (Asst. Prof. MechE & MSE & Chem) jgwerner@bu.edu

Office hours: Mondays 4:30-5:30 PM in EMA 220, 730 Commonwealth Avenue

Prerequisites: Advanced thermodynamics and fundamental mass transfer

Course schedule – Tue/Thu: 3:30 – 5:15 PM in CAS 226

Required textbook: “Electrochemical Methods-Fundamentals and Applications”, by Allen J. Bard and Larry R. Faulkner, John Wiley.

Recommended/reference text: “Electrochemical Impedance Spectroscopy”, by Mark E. Orazem and Bernard Tribollet, John Wiley 2017; Relevant primary literature.

Inclusion: I strive to create a learning environment that supports all my students with a diversity of backgrounds, experiences, perspectives, and identities (including race, gender, class, sexuality, religion, ability, etc.). Please talk to me if you feel like your performance in the class is being impacted by your experiences outside of class, or the environment inside class. If something was said in class that made you feel uncomfortable, please let me know, or a trusted person (e.g., academic advisor) who can relay your concerns to me anonymously. My goal is to provide ALL of you with the best learning experience possible.

Blackboard: Used for class announcements, information, assignments, review material, additional notes, discussion forums, and schedule.

Gradescope: Used for submission of problem sets and paper presentation, exam and paper grading.

Course Communication: Questions about problem sets and exam/quiz review topics should be brought up in office hours, during appropriate lecture times, or posted to the Pronto discussion board (access available through Blackboard, app available for cell phones). To ensure fair access to information to all students, questions concerning any course material sent to the instructor via email will be posted to the Pronto discussion board (anonymized).

Course learning objectives:

- Ability to define and write full chemical reactions as electrochemical half reactions.
- Apply thermodynamic principles of (half) reactions to derive and predict cell voltages.
- Identify different designs and setups of electrochemical cells.
- Identify the various types of mass and ion transport and resistances in electrochemical cells based on their design.
- Fundamental understanding of the relation between charge-transfer and mass transfer to determine potential-dependent overall kinetics of electrochemical reactions at electrodes

- Identify the cause and effect in common electrochemical analysis, including chronoamperometry, linear sweep and cyclic voltammetry, chronopotentiometry, AC impedance spectroscopy.
- Ability to design and analyze the performance of applied electrochemical systems such as those represented by fuel cells, batteries, sensors, and electrolytic cells.

Lecture topics

1. Introduction and Overview of electrode Processes
2. Thermodynamics of Electrochemical Cells
3. Kinetics of Electrode Reactions
4. Mass transfer by Migration and Diffusion
5. Ion conduction, junction potentials, sensors
6. Controlled Potential and Controlled Current Techniques, including Microelectrodes
7. Analytical Techniques based on Impedance Spectroscopy
8. Introduction to Solid State Electrochemistry and Ion Transfer
9. Fundamentals of batteries as electrochemical energy storage systems
10. Fundamentals of fuel cells and electrolyzers as electrochemical conversion systems

Grade Distribution:

Class Participation (10% of final grade) – based on pre-lecture quiz recordings and in-class polls.

Homework (20% of final grade) – 5 homework problem sets approximately every other week.

Midterm Exam (35% of the grade) – Exam on fundamentals of electrochemistry ~ week 10

Paper Presentation (35 % of the grade) – Term paper and presentation on student-chosen topic

Pre-lecture recordings: Recordings and accompanying slides of mathematical and conceptual derivations will be posted as a narrated video at least 1 day ahead of some lectures. Pre-lecture recordings for respective lectures will be announced ahead of time. Students are expected to watch the recording BEFORE the lecture and familiarize themselves with the content, which includes the use of the textbook. Recordings contain embedded questions. Watching the pre-lecture recordings and completing the questions is part of the participation grade. Recordings are posted to the respective lecture folders on blackboard.

Lectures: The scheduled lectures will focus on conceptual and analytical aspects of the topics to build an intuitive and quantitative understanding of the subject matter, and apply analytical and semi-analytical solutions to the identification and quantification of common electrochemical phenomena. Lecture will also give an overview of the state-of-the-art in batteries and fuel cells, as well as their analysis, design, and challenges.

Lecture participation: Throughout the lectures, interactive polls will be used to review the topics and concepts and to gain feedback of the students' understanding of the material. The polls are multiple choice/answer-type questions. Participation in the polls is part of the participation grade. A smart phone is sufficient to participate in the polls. If you cannot or prefer not to use your phone, please contact the instructor ahead of time to find an alternative solution.

Homework: Five (5) problem sets will be posted on Gradescope approximately every other week (weeks 3-12) one week before their due dates. Problem sets are due on Fridays by the end of day. Late problem sets are not accepted. Students must upload their *handwritten* solutions to Gradescope: either photos of the handwritten solutions converted to a pdf file, or a pdf file of the solutions handwritten on a tablet/touchpad. For each problem you should clearly show all work

(given, asked for, properties, assumptions, equations, math, answer). Individual homework problems are graded on a 100/80/50/0 scale.

Exam: There is one (1) exam during the semester (approximately week 12). The exam takes place during regularly scheduled class time.

- Missing the exam due to vacation is not excusable. Arrangements will be made on a case-by-case basis for documented emergencies or University conflicts (**7 days prior arrangement**).
- Students requiring additional time or other accommodations for exams must supply proper documentation from the Office of Disability Services **at least 7 days in advance** of an exam.

Topical presentation and paper: Students pick from a list of applied electrochemistry specialty topics, or propose their own, write a term paper (3 pages) and give a presentation to the class (15 minutes). Detailed instructions will be supplied separately. Briefly, the paper and presentation should provide an overview of the topic (half) and an in-depth look at 1-2 relevant publications that use electrochemical analysis (half). Students must pick their topic by the end of February, and submit a brief outline of their paper (bullet points) together with the relevant publications by April 8. The outline and literature papers require approval by the instructor. Full papers are due 3 days before the respective in-class presentation, which will be held over the last 3 weeks of the semester.

Policy on collaboration: Collaboration is encouraged on homework. However, students must turn in their own work in their own words. No collaboration is permitted on quizzes and exams.

Boston University Academic Conduct Code:

Honesty is a core value of Boston University. Any violations of BU academic honesty and integrity standards will be pursued through appropriate University channels. This includes, but is not limited to cheating, plagiarism and misrepresentation. Academic misconduct is conduct by which a student misrepresents his or her academic accomplishments, or impedes other students' opportunities of being judged fairly for their academic work, which includes any help from online tutoring services during quizzes and exams. Knowingly allowing others to represent your work as their own is as serious an offense as submitting another's work as your own. If you have any questions as to what constitutes an honor code violation, please ask. ***Ignorance is not an excuse for cheating.*** BU's Academic Conduct Code:

<http://www.bu.edu/academics/policies/academic-conduct-code/>

Important Semester Dates:

- February 25, 2025: Last Day to Drop Standard Courses (without a "W" grade)
- April 4, 2025: Last Day to Drop Standard Courses (with a "W" grade)