CHMENG 187/287 Electrochemical Device Engineering
Summer Session D 2025 (6 weeks)
Transcript Title: Electrochem Eng

I. Course Identity, Teaching Staff, and Logistics

Instructor: Prof. Shannon Boettcher, email: boettcher@berkeley.edu, Office: 212 Gilman

This is a new lecture course that would be taught/co-taught by Prof. Boettcher, Prof. Bryan McCloskey, Prof. Niel Razdan, Prof. Nitash Balsara, PhD level Lawrence Berkeley scientists, or a new electrochemistry instructor / program director (PhD level, TBD).

Graduate Student Instructor (GSI): Student Name will serve as a GSI for this course. They are available at GSIemail@berkeley.edu and will schedule weekly tutorial office hour sessions to assist in learning the material.

Office hour: There will be three office hours per week, held in Gilman 212. The times will be determined on the first day of lecture based on student availability.

Format: The course will be offered in person. The course will make use of pre-recorded lecture content a blend of lecture and active learning in particular through think-pair-share activities during the in person in class period.

Students in CHMENG 287 will have required projects that are not required for CHMENG 187 students.

Credits: 3

Location: Lectures will be held in Building, Room# four days per week (M, Tu, W, Th). Each class will be 1.5 h in duration and generally held in the mid morning.

Required course materials:

Fuller and Harb*. Electrochemical Engineering,* Wiley 2018. ISBN-13: 978-1119004257

Supplementary Text: Newman and Balsara, *Electrochemical Systems*, 4th Edition, ISBN: 978-1-119-51460-2

Course website: Lecture notes, videos, homework solutions, and grades will be posted on the course site website. Daily discussion will generally not be recorded.

Prerequisites: CHMENG 186/286 Advanced Electrochemistry Fundamentals.

II. Course Catalog Description

Electrochemical engineering combines the study of charge transfer at electrode/electrolyte interfaces with the development of practical materials and processes. Electrochemical devices/reactors, their voltage and current distribution, mass-transport, hydrodynamics, geometry, and overall performance in terms of reaction yield, conversion efficiency, and energy efficiency are examined. Electrochemical energy storage (batteries and capacitors), energy conversion (low- and high-temperature fuel cells and electrolyzers), and metal plating and electrosynthesis devices are covered. Fundamental chemistry, physics, and engineering principles that govern device response are emphasized.

III. Expected Learning Outcomes

- Critically apply foundational concepts in chemical thermodynamics to electrochemical devices. Specifically, students will be able calculate the ideal thermodynamic voltage input/output voltage for electrolysis process, battery charging/discharging, and fuel cells.
- Critically apply foundational concepts in kinetics to electrochemical devices. Specifically, students will be apply quantum mechanical and classical models of electron transfer to predict and analyze the rates at which charging and discharging processes occur in batteries, reduction/oxidation processes occur in fuel cells, and corrosion occurs in engineered metal systems.
- Critically apply foundational concepts in transport to electrochemical devices. Specifically, students will apply transport physics (drift, diffusion, hydrodynamic flow) to key engineered electrochemical systems including batteries, electrolyzers, fuel cells, and for electrodeposition processes.
- Be able to describe how electrochemical catalyst surfaces mediate electron transfer through different electrochemical mechanisms.
- Understand and evaluate device-specific performance metrics including specific power, specific energy, energy efficiency, coulombic efficiency, volumetric energy, volumetric power, and faradaic efficiency for different electrochemical technologies with a focus on batteries, fuel cells, and electrolyzers
- Understand how to optimize electrochemical devices for specific applications, particularly batteries, fuel cells, and electrolyzers, using modelling and considering effects of mass transport and kinetics losses
- Understand how corrosion processes work, how to predict which corrosion processes will occur and their mechanism, and how to prevent corrosion processes in practically relevant materials
- Be able to apply the foundational concepts of electrochemical kinetics and transport to understand, design, and interpret data from metal electrodeposition processes used broadly in semiconductor and plating industries

IV. Estimated Student Workload

Course participants will attend lecture, perform assigned reading and watch/study assigned pre-class lectures, work assigned problem sets, and demonstrate the knowledge learned on exams. The table below shows the estimated workload.

Activity	Estimated hours per term	Comments
Lectures	36	6 h / wk * 6 weeks
Assigned Reading and Video Content	36	From Fuller and Harb
Problem Sets	54	Assigned Weekly
Projects (CHEMENG 287 students only)	(16)	8 h /project
Exam Preparation	10	4 h for midterm, 6h for final
Total hours:	136 (or 152)	Consistent with 3 credit workload

V. How Grades Will Be Determined

The grades will be determined based on the following percentage breakdown of the final total score:

<u>**Graduate Students**</u>

Problem Sets and in-class work - 20% **Projects - 20%** **Midterm Exam - 20%** **Final Exam - 40%**

<u>**Undergraduate Students**</u>

Problem Sets and in-class work - 35% **Midterm Exam - 25%** **Final Exam - 40%**

Problem sets will be graded for completion, students who complete each problem set and turn them in by the deadline will receive full credit. Each problem must be fully worked, with clear logical explanation of the approach to receive credit.

Projects will be graded based on the quality of the project report. Reports are expected to be concise formal documents with professional quality graphs and analysis and insightful discussion (5 pages of concise, single spaced, scientific writing for each). Each project assignment is accompanied by a document outlining project expectations (see attached rubric). These projects will include work-up of provided real-word data, simulation, and analysis of large data sets.

A = Clearly written, concise document, with high-quality figures. All required pieces of data are shown and discussed without major errors in the interpretation.

B = One or more issues with the items above.

C = Multiple issues with quality of the written document and interpretation/discussion.

D = Multiple issues and incomplete.

The midterm and final exams will be based largely on the content in the assigned problem sets, content emphasized in class discussion, and that emphasized in the projects. Letter grades will not be assigned on these exams, students will receive a percentage score for the exam.

Students earning >90% in the course will earn at least and A, > 80% at least a B, >70% at least a C, and >60% at least a D. The instructor may curve the course to increase the letter grades for a given percentage score to account for variations in difficulty of the exam questions from year-to-year. Students with a given percentage score will not, however, earn a grade lower than that indicated above.

VI. Course Schedule and Assignments

Assigned reading and pre-class lecture videos: Weekly reading from Fuller and Harb given after each topic. Reading should be started prior to the start of the weekly lectures and completed before the start of the following weeks lectures. Pre-recorded lecture videos will also be assigned prior to each class meeting.

<u>**Week 1**</u>
Lecture 1: Porous Electrode Structures
Lecture 2: Electrochemical System Analysis
Reading: Chapter 5: Electrode Structures and Configurations (pg. 93-108)
Problem set 1: Selected problems from Fuller and Harb, Chapter 5 and 6.
Lecture 3: Battery Fundamentals: Cells, Classification, Theoretical Capacity and SOC
Lecture 4: Cell Characteristics and Performance Metrics
Reading: Chapter 7: Battery Fundamentals (pg. 151-169)
Project 1: Li ion battery model and analysis.
Problem set 2: Selected problems from Fuller and Harb, Chapter 7.

<u>**Week 2**</u>
Lecture 1: Battery Cell Design, Layout, Capacity, Rate, Construction
Lecture 2: Battery Pack Design: Thermal, Mechanical, Performance Optimization
Problem set 3: Selected problems from Fuller and Harb, Chapter 8.
Reading: Chapter 8: Fuel Cell Stack and System Design (pg. 223-241)
Lecture 3: Fuel Cell Fundamentals: Types, J-V characteristics, Operation
Lecture 4: Electrode Structures, Proton Exchange Membrane Fuel Cells, Solid Oxide Fuel Cells

Reading: Chapter 9: Fuel Cell Fundamentals (pg. 195-216)
Problem set 4: Selected problems from Fuller and Harb, Chapter 9.

Week 3
Lecture 1: Fuel Cell System Overview, Stack Design Concepts, and Configurations
Lecture 2: Fuel Cell System construction and components, oxidant and fuel utilization, flow field design, water and thermal management
Reading: Chapter 10: Fuel Cell Stack and System Design (pg. 223-247)
Lecture 3: Catch-up and review for Midterm.
Lecture 4: Midterm exam covering all materials covered in week 1-3.
Project 1 Due at end of week.

Week 4
Lecture 1: Electrochemical Double Layer Capacitors
Lecture 2: Energy Storage and Conversion for Electric Vehicles
Reading: Chapter 11 and Chapter 12 (pg. 251-277)
Problem Set 5: Selected problems from Fuller and Harb, Chapter 11-12.
Project 2: Fuel cell system model and analysis OR Industrial electrolysis/electrosynthesis model and analysis.
Lecture 3: Industrial Electrolysis: Performance, polarization curves, electrochemical reactor design
Lecture 4: Example processes, sustainable electrochemical reactors, thermal design
Reading: Chapter 14: Industrial Electrolysis, Electrochemical Reactors (pg. 323-350)
Problem Set 6: Selected problems from Fuller and Harb, Chapter 14.

Week 5
Lecture 1: Electrodeposition: Faraday's law, fundamentals, nucleation rates and growth
Lecture 2: Morphology, Additives, Current Distribution, Side reactions, substrates
Reading: Chapter 13: Electrodeposition (pg. 299-319)
Problem Set 7: Selected problems from Fuller and Harb, Chapter 13.
Lecture 3: Corrosion: Thermodynamics, Kinetics, Evan's Diagrams
Lecture 4: Corrosion: Localized Corrosion, Corrosion Protection, Materials considerations

Week 6
Lecture 1: in class project presentations, questions, structured feedback
Lecture 2: in class project presentations, questions, structured feedback
Lecture 3: Review for final exam
Lecture 4: Final Exam or take home

VII. Course Policies

- Late or missed work will not generally be accepted without prior approval.

- For students in the graduate level course: Project reports must be your own work. You may share data across the class if it strengthens the quality of the report but the analysis and discussion of the data in the report must be your own work.
- There will be a zero-tolerance policy for plagiarism and or cheating on exams.
- Homework solutions must be your own work. You must clearly show your own work and the reasoning used to obtain the answer to get credit.

Academic Misconduct: The University Student Conduct Code (available at https://conduct.berkeley.edu/code-of-conduct/) defines academic misconduct. Students are prohibited from committing or attempting to commit any act that constitutes academic misconduct. By way of example, students should not give or receive (or attempt to give or receive) unauthorized help on assignments or examinations without express permission from the instructor. Students should properly acknowledge and document all sources of information (e.g. quotations, paraphrases, ideas) and use only the sources and resources authorized by the instructor. If there is any question about whether an act constitutes academic misconduct, it is the students' obligation to clarify the question with the instructor before committing or attempting to commit the act.

Use of Artificial Intelligence, ChatGPT, and other related technologies:
AI is a powerful tool to help you learn and improve your communication. You are welcome to make use of AI tools in this class. However, directly copying from AI sources is considered plagiarism. AI written text is also poor and use of AI without applying your own critical thinking and editing skills will likely result in a poor grade. AI may also be helpful in performing calculations. However, each student is responsible for understanding the calculations and analysis as well as the language used in their writing. Any student may be asked to explain concepts and repeat calculations in person if there is suspected plagiarism from AI work or from other humans.

Statement on Classroom Climate:
We are all responsible for creating a learning environment that is welcoming, inclusive, equitable, and respectful. The expectation in this class is that we all live up to this responsibility, even during vigorous debate or disagreement, and that we will intervene if exclusionary or harassing behavior occurs. If you feel that these expectations are not being met, you can consult your instructors or seek assistance from campus resources.

Academic Accommodations and Accessibility:
The purpose of academic accommodations is to ensure that all students have a fair chance at academic success. If you have Letters of Accommodations from the Disabled Students' Program or another authorized office, please share them with me as soon as possible, and we will work out the necessary arrangements. While individual circumstances can vary, requests for accommodations often fall into the categories listed on the Academic Calendar and Accommodations website. The campus has well-developed processes in place for students to request accommodations, and you are encouraged to contact the relevant campus offices listed on the Academic Accommodations Hub. These offices, some of which

are confidential, can offer support, answer questions about your eligibility and rights, and request accommodations on your behalf, while maintaining your privacy.

Electrochemistry Science, Engineering, and Technology Course Sequence Project and Laboratory Report Grading Rubric

	4 - Good	3 – Barely/nearly acceptable	2 - Needs improvement	1 - Not acceptable	0 – Bad	SCORE
Introduction	A cohesive, but concise, well-written summary (including all relevant chemistry, physics, and engineering concepts) of the background material pertinent to the experiment with appropriate references. Places the purpose of the experiment in context.	Is nearly complete but does not provide context for minor points. Contains relevant information but fails to provide background for one aspect of the project or certain information is not cohesive. Certain major introductory points are missing (ex: background, theory, context, etc.) or explanations are unclear and confusing. References are used properly.	Certain major introductory points are missing (ex: background, theory, chemistry, context, etc.) or explanations are unclear and confusing. References are used properly but are not complete.	Very little background information is provided and/or information is incorrect. Poor use of references.	None or unrelated	_____
Experimental	Contains details on how the experiment/simulation was performed and the procedures followed. The experimental setup must be described, detailing the instrumentation/software used and what purpose each piece of equipment serves in the overall experiment. This information should be presented in a brief and concise manner. Written grammatically correctly and omits information that can be assumed by peers (electrochemists)	Narrative includes most important experimental detail but is missing one or more relevant pieces of information.	Missing several experimental details or some incorrect statements.	Several important experimental details are missing. Narrative is incorrect, illogical, or copied directly from other sources. Written in the incorrect tense.	None or unrelated	_____
Results Including experimental data, provided project data, or data from numerical simulation	All figures, graphs, and tables are numbered with appropriate captions and of professional quality. All units are provided for data. All tables, figures, etc. are explicitly mentioned in the text. Relevant experimental data are presented which are used in the discussion.	All figures, graphs, and tables are correctly drawn, but some have minor problems that could be still be improved. Units are used consistently. Figures quality is good, but could be improved. All data and associated figures, etc. are mentioned in the text. Most relevant data present.	Most figures, graphs, and tables are included, but some important or required features are missing. Certain data reported are not mentioned in the text or are missing. Captions are not descriptive or incomplete.	Figures, graphs, and tables are poorly constructed; have missing titles, captions or numbers. Certain data reported are not mentioned in the text. Important data missing.	None or unrelated	____ **× 2**

Discussion/ Conclusions	Demonstrates a logical, coherent working knowledge and understanding of important concepts, forms appropriate conclusions based on interpretations of results, includes references, data and analysis, refers to the literature when appropriate, and demonstrates accountability by providing justification for any errors. Key equations are justified and their application appropriately discussed. All equations are appropriately typeset. Address all specific points or questions posed in the project/laboratory guidelines/manual.	Demonstrates an understanding of the majority of important concepts, forms conclusions based on results and/or analysis but either lacks complete interpretation, refers to the literature insufficiently, or lacks complete justification of error and or use of models and theoretical equations. Address most of the specific points or questions posed in the project/laboratory guidelines/manual.	While some of the results have been correctly interpreted and discussed, partial but incomplete understanding of results is evident. Student fails to make one or two connections to underlying theory. Address only some of the specific points or questions posed in the project/laboratory guidelines/manual.	Does not demonstrate an understanding of the important experimental concepts, forms inaccurate conclusions, suggests refers to the literature insufficiently, and lacks overall justification of error and/or use of models and theoretical equations. Address none of the specific points or questions posed in the project/laboratory guidelines/manual.	None or unrelated	____ **× 2**
References	All sources (information and graphics) are accurately documented in ACS or AIP format.	All sources are accurately documented, but formatting is not consistent or always correct.	Some sources are not accurately documented. Formatting is not consistent or correct.	Sources are not accurately documented. Formatting is not consistent or correct.	None or unrelated	___ **× 0.5**
Overall Style, Organization, and Writing Quality	Appropriate as a piece of scientific or engineering writing, words were chosen carefully and appropriately. Figures of professional quality. Sentence structure was clear and as concise. Includes no excess or unnecessary text. Evidence the report was edited by the author to improve clarity and readability. From a technical standpoint, the paper is free of spelling, punctuation, and grammatical errors	Minimal awkward phrasing or word choices. Report is easy to read and constructed properly. Some excess unneeded text. Evidence of editing. Acceptable quality figures. Few grammar and spelling errors.	Many passages are phrased poorly, contained awkward word choices, or many long sentences. Narrative is disorganized in many places. Substantial excess text that should be eliminated by editing .Tense not appropriate or not in agreement in several places. Multiple grammatical and/or spelling errors.	Poorly organized narrative with frequent awkward phrases and poor word choices. Setences are too long or short. Lacks cohesion, style and fluidity. Many instances of verb tenses not agreeing. No evidence of editing. Frequent spelling and grammar errors. Focus on technical writing improvement critical	Poor style, format, and organization. Extreme writing errors. Report very difficult to read. Focus on technical writing improvement critical	___
					SUM	**/30**

Grading: A-range = 26 to 30 D-range = 13 to 17
B-range = 21 to 26 below 17 = F
C-range = 17 to 21