

CH EN 5308/6308 Fall 2021

Electrochemical Systems for Energy Storage and Beyond

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Prerequisite	CH EN 2300 Thermodynamics I CH EN 3603 Mass Transfer & Separations CH EN 3853 Chemical Engineering Thermodynamics CH EN 3553 Chemical Reaction Engineering
Class time	TBD
Classroom	TBD
Class Description	<p>In this course, we will first introduce the basics of electrochemical systems, including thermodynamics, mass transport, kinetics and interface. After that, we will cover the principle of electrochemical energy storage technology, including Li-ion batteries, redox flow batteries, etc. Then we will introduce the frontier of these technologies, including the electrode materials, electrolytes, membrane, etc.</p> <p>This is a cross-listed course, in which undergraduate and graduate students can register at the same time. The course contents will be the same, albeit the requirement for undergraduate students will be different from that of graduate students.</p>
Learning Objectives	<ol style="list-style-type: none">1. Apply basic concepts of electrochemical systems to analyze and solve problems in electrochemical engineering.2. Develop preliminary designs of energy storage systems including specification of materials for different storage technologies.3. Critically analyze state-of-the-art energy storage research and identify future challenges and trends.
Reference books	Electrochemical methods: fundamental and applications. Allen J. Bard, Larry R. Faulkner, 2 nd edition, John Wiley & Sons, Inc. 2001

	<p>Fundamentals of Electrochemistry. V.S. Bagotsky, 2nd edition, John Wiley & Sons, Inc. 2006</p> <p>Electrochemical Systems, John Newman, Karen E. Thomas-Alyea, 3rd edition, John Wiley & Sons, Inc. 2004</p>
Course Structure	<p>Lectures: In the first half of the course, students and instructor will meet twice per week in the specific classroom, where lectures will be given by the instructor.</p> <p>Presentations: In the second half of the course, each student needs to choose the topic of interest, study the papers given by the professor, and give a presentation to summarize the background, the status, the challenges, and the future trend of the chosen research topic. The student will be evaluated based on how well his/her presentation is delivered and how active he/she participate in the discussion.</p> <p>Projects: Following the presentation, each graduate student needs to finish a project, which is a 3-page research proposal. For undergraduate student, the project is optional. Bonus points will be given to undergraduate students who finishes the project.</p> <p>Homework: There will be several homework assignments. Homework will be assigned after the corresponding lectures are done. At least two weeks are given for finishing the homework.</p> <p>Quiz: There will be 10 in-class quizzes to examine students' understanding of the basic concepts. Each quiz typically consists of 5 True/False questions and 5 multiple-choice questions. Close book.</p> <p>Exams: There will be an exam after all the lectures are done to examine how students understand the course materials. The exam is closed book.</p> <p>Seminars: Students will be required to listen to several graduate seminars related to our class. Bonus points will be given to students who attend these seminars and write 1-page summary of the seminar.</p>
Grading	<p>For graduate student: Homework: 15%, Quiz: 25%, Presentation:15%, Project: 15%, exam: 30%</p> <p>For undergraduate students: Homework: 15%, Quiz: 30%, Presentation:20%, exam: 35%.</p>

	Bonus: Undergrad students who finish the project can get a maximum of 10% bonus. Any student can get a maximum of 2% bonus for each seminar summary. The template for the seminar summary is given in the course materials. The seminars valid for this bonus point include:
Homework late policy	Assignments handed in late will receive a 10% penalty for the first day late (or fraction thereof), and an additional 2% penalty for each additional day (or fraction thereof) late. No late work will be accepted past the last day of classes for the semester (Note that this is not the same day as the last day of finals).
Exam Policy	If you are unable to take an exam on the assigned date because of a medically verifiable illness or a school-sponsored activity, you must provide Prof. Gao with appropriate documentation as soon as possible, and no later than ONE WEEK in advance of the exam, so that appropriate accommodations can be made. Prof. Bai will consider last-minute medical emergencies on a case-by-case basis.
Letter Grades	Score ≥ 90 A(A-, A, A+); ≥ 80 B (B-, B, B+); ≥ 70 C(C-, C, C+); ≥ 60 D.
Regrades	Regrades must be submitted within one week of the day the assignment or exam was returned.
Academic Integrity	All students must adhere to high standards of academic integrity. You are encouraged to discuss course material with other students, as this can be a key part of learning. However, everything you turn in should be your own independent work. Copying answers or parts of answers from other students or other resources (the Internet, etc.) is not permitted in any way. This activity will be considered as willful cheating and will be dealt with accordingly. We will be actively searching for academic dishonesty on all assignments, exams, etc. If you are found guilty of cheating, all students involved will receive a zero on the assessment in question, and in severe cases, an F in the course.
COVID information	<p>University leadership has urged all faculty, students, and staff to model the vaccination, testing, and masking behaviors we want to see in our campus community.</p> <p>These include: • Vaccination • Masking indoors • If unvaccinated, getting weekly asymptomatic coronavirus testing.</p> <p>Vaccination: Get a COVID-19 vaccination if you have not already done so. Vaccination is proving highly effective in preventing severe COVID-19 symptoms, hospitalization and death from coronavirus. Vaccination is the single best way to stop this COVID resurgence in its tracks.</p> <p>• Many in the campus community already have gotten vaccinated:</p>

	<ul style="list-style-type: none"> • More than 80% of U. employees • Over 70% of U. students • Visit http://mychart.med.utah.edu/, http://alert.utah.edu/covid/vaccine, or http://vaccines.gov/ to schedule your vaccination. <p>Masking: While masks are no longer required outside of Health Sciences facilities, UTA buses and campus shuttles, CDC guidelines now call for everyone to wear face masks indoors.</p> <p>o Check the CDC website periodically for masking updates— https://www.cdc.gov/coronavirus/2019-ncov/vaccines/fully-vaccinatedguidance.html</p> <p>o Treat masks like seasonal clothing (i.e. during community surges in COVID transmission, masks are strongly encouraged indoors and in close groups outside).</p> <p>Testing: If you are not yet vaccinated, get weekly asymptomatic coronavirus tests. This is a helpful way to protect yourself and those around you because asymptomatic individuals can unknowingly spread the coronavirus to others.</p> <ul style="list-style-type: none"> • Asymptomatic testing centers are open and convenient: <p>Online scheduling Saliva test (no nasal swabs) Free to all students returning to campus (required for students in University housing) Results often within 24 hours Visit alert.utah.edu/covid/testing</p> <ul style="list-style-type: none"> • Remember: Students must self-report if they test positive for COVID-19 via this website: https://coronavirus.utah.edu/.
Non-attendance Policy	Given the nature of this course, attendance is required and adjustments cannot be granted to allow non-attendance. However, if you need to seek an ADA accommodation to request an exception to this attendance policy due to a disability, please contact the Center for Disability and Access (CDA). CDA will work with us to determine what, if any, ADA accommodations are reasonable and appropriate
Nondiscrimination and Disability Access Statement	I expect our class to be a place where you will be treated with respect. For any professional engineer, it is a vital career skill to be able to work harmoniously with a diversity of individuals and draw on their unique strengths. We welcome individuals of all ages, backgrounds, beliefs, veteran status, ethnicities, genders, gender identities, gender expressions, national origins, religious

	<p>affiliations, sexual orientations, ability – and other visible and nonvisible differences. All members of this class should work to contribute to a respectful, welcoming and inclusive environment for every other member of the class.</p> <p><i>The University of Utah is fully committed to affirmative action and to its policies of nondiscrimination and equal opportunity in all programs, activities, and employment with regard to race, color, national origin, sex, age, status as a person with a disability, religion, sexual orientation, and status as a veteran or disabled veteran. The University seeks to provide equal access to its programs, services and activities for people with disabilities. Reasonable prior notice is needed to arrange accommodations. Evidence of practices not consistent with these policies should be reported to the Office of Equal Opportunity and Affirmative Action, 801-581-8365 (V/TDD).</i></p> <p><i>Upon request, this information is available in alternative formats, such as cassette, Braille, or large print.</i></p>
Addressing Sexual Misconduct	<p><i>Title IX makes it clear that violence and harassment based on sex and gender (which includes sexual orientation and gender identity/expression) is a Civil Rights offense subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories such as race, national origin, color, religion, age, status as a person with a disability, veteran's status or genetic information. If you or someone you know has been harassed or assaulted, you are encouraged to report it to the Title IX Coordinator in the Office of Equal Opportunity and Affirmative Action, 135 Park Building, 801-581-8365, or the Office of the Dean of Students, 270 Union Building, 801-581-7066. For support and confidential consultation, contact the Center for Student Wellness, 426 SSB, 801-581-7776. To report to the police, contact the Department of Public Safety, 801-585-2677 (COPS).</i></p>
Safety Information	<p><i>The University of Utah values the safety of all campus community members. To report suspicious activity or to request a courtesy escort, call campus police at 801-581-COPS (801-585-2677). You will receive important emergency alerts and safety messages regarding campus safety via text message. For more information regarding safety and to view available training resources, including helpful videos, visit https://safeu.utah.edu</i></p>

Tentative Schedule

Week	Date	Format	Content	Quiz*	HW, presentation Project	Reading
1	Aug 23	Lecture	Introduction			Bard Ch1 Bagotsky Ch1
	Aug 25				Presentation topics	
2	Aug 30		Thermodynamics	Quiz 1		Bard Ch2
	Sep 1				HW1	
3	Sept 6	Labor day	No class			
	Sep 8	Lecture	Mass transport	Quiz 2		Bard Ch4 Newman Ch11,12
4	Sep 13					
	Sep 15		Kinetics	Quiz 3	HW1 due	Bard Ch3
	Sep 20					
5	Sep 22		Interface	Quiz 4	HW2	Bard Ch1.2, Ch13
	Sep 29					
6	Sep 17		Li-ion batteries	Quiz 5	HW3	provided review papers
	Sep 29					
7	Oct 4				HW2 due	
	Oct 6				HW4	
8		No class	Fall Break. October 10-17			
9	Oct 18	Lectures	Li metal batteries	Quiz 6		provided review papers
	Oct 20				Presentation topic choice due	
10	Oct 25		Flow batteries	Quiz 7	HW3 due	provided review papers
	Oct 27					
11	Nov 1		Electrochemical methods	Quiz 8	HW4 due	Bard Ch5,6,8,10
	Nov 3					
12	Nov 8		Theory of batteries	Quiz 9		provided review papers
	Nov 10					
13	Nov 15	Mid-term	Review	Quiz 10		
	Nov 17		Mid-term exam			
14	Nov 22	Presentation	Presentation 1-2			
	Nov 24		Presentation 3-4			

15	Nov 29	Presentation	Presentation 5-6			
	Dec 1		Presentation 7-8			
16	Dec 6		TBD			
	Dec 8		Dr.Gao's research		Project due	

*If the corresponding lecture is not finished before the scheduled Quiz date, the quiz will be postponed until the lecture is finished.

Presentation

The purpose of this part of this course is: 1) to familiarize the class with the background and frontier of different fields of electrochemical energy storage technologies; 2) to train the students to master the skills for surveying and presenting a given topic; 3) to train the students to engage in a scientific discussion; and 4) to provide students the experience of peer-reviewing.

The presentation topics will be given out in the first half of the semester. The student will pick one topic of his/her interest before the due, and start to read the given papers to learn the topic. The topic is assigned by a first-come-first-serve method. The student is encouraged to read more relevant papers (> 10 papers recommended). The papers can be found by tracing the cited papers of the given paper, or searching keywords using Google Scholar or other search engine.

Topics for literature review:

1. Cathode materials for LiB: high voltage polyanion cathode
2. Cathode materials for LiB: Ni-rich oxide
3. Cathode materials for LiB: Li-rich oxide
4. Anode materials for LiB: graphite, carbon and C/Li
5. Anode materials for LiB: Si, Si/C and Si/Li
6. Fast charging of LiB
7. liquid electrolyte for LiB and SEI
8. solid electrolyte for LiB: ceramic electrolyte
9. solid electrolyte for LiB: polymer electrolyte
10. Lithium metal anode
11. Li/S battery
12. Li/air and Li/O₂ battery
13. Aqueous Redox flow battery based on inorganic materials
14. Aqueous Redox flow battery based on organic materials
15. Non-aqueous redox flow battery
16. Zn hybrid flow battery
17. Zn-ion battery
18. Na-ion battery
19. Mg-ion battery
20. Safety of LiB and dendrite formation
21. supercapacitor
22. CO₂ electrochemical reduction
23. CO₂ electrochemical capture
24. Proton exchange membrane fuel cell
25. Proton exchange membrane electrolyzer
26. Manufacturing of LiB
27. Recycling of LiB

The student needs to read the given papers, and preferentially search more papers, to understand the background, principle, challenges, state-of-the-art, and future direction of the chosen topic. The student needs to prepare a 30-40 minutes PowerPoint presentation and present this topic to

the class. Other students are encouraged to ask questions during and after the presentation. The content of the presentation should include:

- Background: why the chosen topic is important? And what's its history?
- Principle: how does the chosen topic work?
- Challenges: what challenges need to be overcome to make the chosen topic successful?
- State-of-the-art: what has been done to tackle these challenges? Have these challenges been addressed? To what extent? Are there any remaining challenges?
- Future direction: what's the direction that future research should focus on to further advance the chosen topic?
- References: the references for this presentation.

The length of the presentation should be 30-40 minutes. Recommended time for each section:

- background: 2-4 minutes
- principle: 2-4 minutes
- challenges: 2-4 minutes
- state-of-the-art: 24-32 minutes
- future directions: 2-4 minutes

During and after the presentation, the presenter needs to answer the questions from the instructor or other students taking this class. Other students are expected to actively participate in the discussion of the topic, by asking questions related to the presentation or the topic. Each student will be evaluated both by how well he/she comprehend the topic, summarize the topic and presents this understanding to the class (2/3), and how active he/she participate into the class discussion of others' presentation (1/3).

Four weeks before the presentation, the student needs to schedule a meeting with the instructor to go over the structure and content of the presentation. The student is expected to show the outline of the presentation to the instructor. Two weeks before the presentation, the student needs to schedule another meeting with the instructor to go over the slides. In both meetings, the instructor will provide feedback to the student. The presentation will be evaluated by other students and the instructor in the below aspects. This peer-review accounts for 2/3 of the total grade of the presentation. An evaluation form will be handed out to every student before the presentation, and each of these aspects will be evaluated by a 10-point rating, i.e., Outstanding (10), excellent (8), very good (6), good (4), fair (2), and poor (0).

- The presentation is well prepared.
- The presentation is clearly presented.
- The presenter shows a good understanding of the topic.
- The presenter does a good job in teaching the class this topic.
- The presenter does a good job in answering the questions.

The class participation will be evaluated by the instructor based on the below criteria, and it counts toward 1/3 of the total grade of the project. The instructor will give credits to students who meet the below criteria in each presentation. The credits will be summed and used to determine each student's grade for the presentation.

- The student is actively engaging in the discussion.
- The student is asking well-thought question that helps the class to understand the topic better.
- The student is providing valuable comments that benefit the class.

Project

The purpose of the project is to 1) test the student's understanding of the choose topic; 2) to train the student for creative and hypothesis-driven thinking; 3) to train the student to write grant proposal.

Writing grant proposal is a very important step for a scholar to obtain funding from government agency, industry, or private foundation to support the implementation of a research idea. In this project, the student needs to write a 3-page proposal (including references) for a one-year research project. In this proposal, the student needs to propose a new idea to address a critical challenge the student discussed in his/her presentation. The proposal needs to consist of the following parts:

- Abstract: a high-level summary of the proposal
- Introduction: what's the scientific or technological problem the proposal aims to address? Why it is important? What has been done? What challenge remains?
- Hypothesis, objective and novelty: what's the hypothesis of the proposal? What's the rational of the hypothesis? What's the objective of the proposal? What the expected outcome of the research? Why the proposed idea is novel?
 - E.g., we hypothesize that by ..., we can realize... and then address the challenge.
- Research plan: what research tasks do you plan to perform to test the hypothesis and address the challenge. List three tasks.
- Reference:
- 2 figures: one figure to illustrate the hypothesis, another figure to illustrate the research plan

Length for each section:

- Abstract: < 250 words (Mandatory)
- Introduction: 600-1000 words, roughly 1 page (Recommended)
- Hypothesis, Objective, and novelty: 400-600 words (Recommended)
- Research plan: 600-1000 words, roughly 1 page (Recommended)
- Reference: <10 references (Mandatory)

Format requirement: Arial 12, single-spaced. The references should be added with Mendeley. The font size of the reference should be Arial 10.

The proposal will be evaluated by the below criteria.

- Abstract

- (10/100 points) The proposal has a well-written abstract.
- Introduction
 - (10/100 points) The proposal well describes the importance of the research.
 - (10/100 points) The proposal shows a good understanding of the problem it aims to address.
- Hypothesis, Objective and novelty
 - (15/100 points) The proposal has a clear and testable hypothesis.
 - (5/100 points) The objective and expected outcome of the proposal are clear.
 - (10/100 points) The proposed idea is novel.
- Research Plan
 - (10/100 points) The proposal has a well-thought actionable and feasible research plan.
 - (10/100 points) All the tasks have clear goals.
- References
 - (10/100 points) Proper references are cited to support the discussion.
- Format
 - (10/100 points) The format meets the requirement.