

# ECE4710/5710

## MODELING, SIMULATION, AND IDENTIFICATION OF BATTERY DYNAMICS

Fall 2016

*Derives mathematical models of the electrochemical dynamics of battery cells, including thermodynamic and kinematic properties, at multiple scales. Modern, lithium-ion chemistries are emphasized. Students will use simulation software and will use lab-test data to create and validate parameterized models. Prer., ECE2205, MATH2350, MATH3400 or equiv.*

**Instructor:** Dr. Gregory Plett    **Office:** EN-290    **Phone:** 255-3468    **email:** gplett@uccs.edu  
**Course web-page:** <http://mocha-java.uccs.edu/>

**Office Hours:** TBD

**Text:** There is no required textbook. I plan to have background journal articles, etc, for each section of notes on the course web site. This is a pretty “modern” class in the sense that the literature, and especially the textbooks, have not yet caught up with everything I hope to teach.

**Optional Software:** The Matlab<sup>®</sup> Student Version (full windows version is running in the computer lab). Comsol<sup>®</sup> will also be used, and is available in the Multimedia lab.

**Evaluation:**                    Eight graded homework assignments/mini-projects;  
   Unequal weighting (based on individual requirements), 100% total.

**Grading:**                      90–100=A<sup>-</sup> to A;    80–89=B<sup>-</sup> to B<sup>+</sup>;    70–79=C<sup>-</sup> to C<sup>+</sup>;  
   60–69=D<sup>-</sup> to D<sup>+</sup>;    0–59=F.

Topics	Evaluation	Est. Weeks
1. Battery boot camp.		2.0
2. Equivalent-circuit cell models.	Project	1.0
3. Microscale cell models.	Project	3.5
4. Continuum (porous electrode) cell models.	Project	2.0
5. State-space models and the dynamic realization algorithm.	Project	3.0
6. Reduced-order models of cell dynamics.	Project	2.0
7. Thermal models.		1.5

**Work Load:** This is an aggressive course requiring weekly homework assignments. Expect to spend six to nine hours per week outside of class reading the textbook and completing homework assignments. This is in accord with UCCS policy relating credit hours for a lecture course to student workload. Some students will find that more time is required, while others will find that less time is required.

**Homework Policy #1:** Homework will be collected at the beginning of class on the assigned date. Homework turned in after the class period will be penalized 10%. Homework turned in after the due date will be penalized an additional 25% per day unless previous arrangements have been made with the instructor. Examinations will be based on the homework problems and the material covered in class. It is to your advantage to understand the fundamental concepts that are demonstrated in the homework problems. It will be difficult to earn higher than a "C" without performing well on the homework assignments.

**Homework Policy #2:** Your coursework (homework/project/exams) is expected to be a bona-fide individual effort. Copying homework, project or exam solutions from another student or other source is CHEATING and will not be tolerated. You may (and are encouraged to) discuss homework/project problems with other students, but only to the extent that you would discuss them with the instructor. Don't ask another student a question that you would not expect the instructor to answer. Most of us know when we are compromising our integrity. If you are in doubt, ask first.

**Homework Policy #3:** Part of your engineering education involves learning how to communicate technical information to others. Basic standards of neatness and clarity are essential to this process of communication. Your process of solving a problem must be presented in a logical sequence. Consider your assignments to represent your performance as an engineer. Do not submit scrap paper, and do not submit paper containing scratched out notes. Graphs are to be titled and axes are to be labeled (with correct units). The above standards of clarity and neatness also apply to your work on exams.

**Attendance:** Attendance is your responsibility. Class lectures will cover a significant amount of material. Some will not be in the text or may be explained differently. It is to your advantage to take notes, ask questions, and to fully participate in the classroom experience.

**Missed Exams:** Missed exams will count as ZERO without a physician's documentation of an illness, or other appropriate documentation of an emergency beyond your control and requiring your absence.

**Drop Date:** This course complies with the UCCS campus rules for drop date.

**Disability Accomodation:** If you have a disability for which you are requesting an accommodation, you are encouraged to contact Disability Services within the first week of classes.

**Military Students:** If you are a military student with the potential of being called to military service and /or training during the course of the semester, you are encouraged to contact me no later than the first week of class to discuss the class attendance policy.

**Homework Format Rules:** Points will be deducted for failure to comply with the following rules:

1. Use 8 1/2 by 11 paper (engineering paper is good).
2. Write on one side of the paper only.
3. Enclose your final answer to each problem in a box so that it may be clearly identified.
4. Write name and date and homework set number in the right corner.
5. Staple in the upper left corner. Use only one staple!
6. Be sure to write in pencil. Do not use ink to complete your homework assignments.

**The Course Reader:** These notes have been entered using LyX, and typeset with L<sup>A</sup>T<sub>E</sub>X<sub>2 $\epsilon$</sub>  on a Macintosh Core i7 computer running the OS X operating system. Special thanks to Drs. Jim Lee and Kanhao Xue for their very hard work to develop some of the materials for this course.

## Course Outcomes

The following are expected outcomes for each course unit. By the end of the noted unit, the student should be able to:

### **Unit 1:** Battery boot camp.

- Work comfortably with definitions such as “cell,” “battery,” “primary,” “secondary,” “capacity,” “C-rate,” and others given in the chapter
- State the difference between energy and power, and an application example that needs to know each
- Explain how a lithium-ion cell operates electrochemically (at a high level)

### **Unit 2:** Equivalent-circuit cell models.

- Predict how a battery cell will respond to an input-current stimulus given an equivalent circuit of the cell
- Find ballpark parameter values for a circuit model given the results of a pulse test
- Implement an equivalent-circuit cell model in MATLAB
- Run MATLAB toolbox optimization programs that determine model parameter values from lab-test data

### **Unit 3:** Microscale cell models.

- Explain the meaning of each of the terms of the five coupled microscale cell-model equations
- Implement code that approximates linear diffusion using a finite-difference method
- Simulate a single-particle model of a cell using a finite-volume method

### **Unit 4:** Continuum (porous electrode) cell models.

- Articulate clearly the difference between microscale and continuum-scale models, and what some of the tradeoffs between the models might be
- Use volume-averaging theorems to convert microscale-model equations to continuum-scale
- Execute a simulation of a lithium-ion cell in COMSOL

### **Unit 5:** State-space models and the dynamic realization algorithm.

- Convert a linear time-invariant ordinary-differential and ordinary-difference equations into state-space models
- Find the discrete-time Markov parameters from a state-space model
- Implement the discrete-time realization algorithm (DRA) for a given transfer function
- Simulate a state-space model that is created by the DRA

### **Unit 6:** Reduced-order models of cell dynamics.

- Explain the derivation steps of the reduced-order-model transfer functions
- Implement a reduced-order model of a cell using the transfer functions, the DRA, and nonlinear corrections

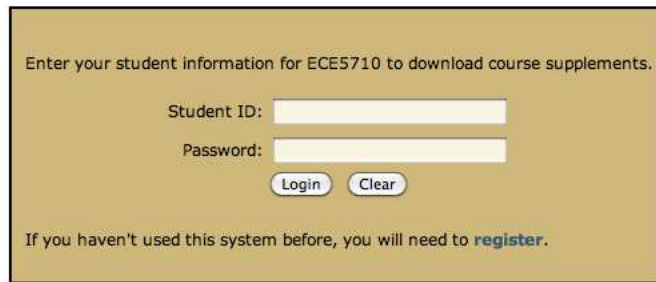
### **Unit 7:** Thermal models.

- Implement a full-order thermal model in COMSOL
- Implement a reduced-order thermal model using a DRA ROM

# The EduFile Course Supplement Management System (*EduFile*):

The class homepage is accessed via <http://mocha-java.uccs.edu/>. Click on the [+] sign next to the course name, and then click on the link to access course supplements.

Follow this link, and you will be directed to the log-on screen:



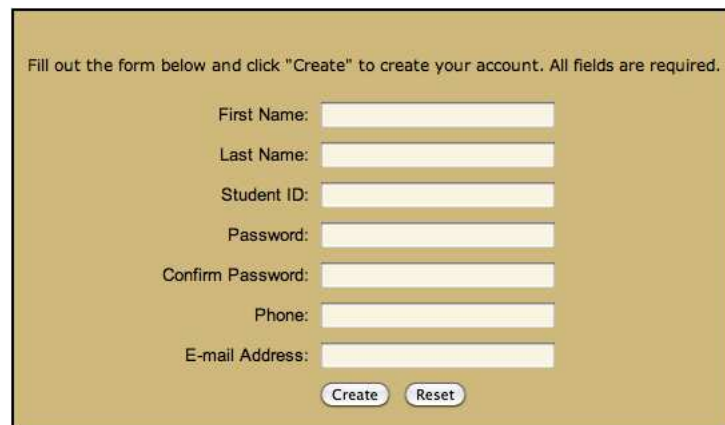
Enter your student information for ECE5710 to download course supplements.

Student ID:

Password:

If you haven't used this system before, you will need to [register](#).

The first time you use the system, click on the word "register". You will be directed to the screen:



Fill out the form below and click "Create" to create your account. All fields are required.

First Name:

Last Name:

Student ID:

Password:

Confirm Password:

Phone:

E-mail Address:

Enter the requested information and press "Create". You should see the screen:

## **User Added To Course**

The user 111223333 has been added to course ECE5710. You are currently registered in another course with this system. Your student ID has been added to the course you have requested. However, you will not be able to use the system until your account has been enabled by your instructor.

Note that passwords are case-sensitive!

You will not immediately gain access to course supplements. You will receive email notification when your account is enabled for this course. Only then may you log on using your student ID and password. You will see a screen like this (tailored to ECE4710/ECE5710, of course):

## Welcome to EduFile

Course Info	
<b>Instructor Name:</b>	Dr. Gregory Plett ( <a href="mailto:glp@eas.uccs.edu">glp@eas.uccs.edu</a> )
<b>Course Name:</b>	Modeling, Simulation, and Identification of Battery Dynamics
<b>Course Description:</b>	Derives mathematical models of the electrochemical dynamics of battery cells, including thermodynamic and kinematic properties, at multiple scales. Modern, lithium-ion chemistries are emphasized. Students will use simulation software and will use lab-test data to create and validate parameterized models. Prer., ECE2205, MATH2350, MATH3400 or equiv.

Click on the Filename to download the file you need.

Update Since Last Download?	Downloaded	Filename	File Description
<b>LECTURE NOTES</b>			
No	Yes	<a href="#">CH01-BootCamp.pdf</a>	Lecture notes chapter 1

[Edit Personal Info](#)

At the top of the page, the course name, course description and instructor are listed. By clicking on the instructor email address, you may send an email message directly from your web browser to the instructor. Below the course description is a listing of supplements that you may download. These are divided into categories (*e.g.*, ANNOUNCEMENTS, CHAPTER 1...) as assigned by the instructor.

In the figure, we see that this student has downloaded the syllabus and the first chapter of the lecture notes. Furthermore, she is assured that she has the most recent copy of the lecture notes since the flag "Update Since Last Download" says "No". However, the syllabus has been updated since the last time she downloaded it, so she should retrieve the newer version. This student has not downloaded the tutoring schedule or the example Matlab simulation files, which she might want for extra help and understanding of the material. Not shown, because it falls at the bottom of the page, is a button allowing the student to modify her personal information (name, password, and so forth).