ECE/BIOM 527A Cells as Circuits

Fall 2023

Meets first 5 weeks of semester

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Important note: You must include "ECE527A" or "BIOM527A" as part of the subject line for all emails regarding this class, or else my email filters will not highlight them.

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Office Hours: See Canvas

This course is a module in the GAUSSI series, developed in part to support the NSF-sponsored GAUSSI program. Courses in this series include:
Cells as Circuits - ECE 527A
Signal and Noise in Biosensors - ECE 527BSensor Circuit Fundamentals - ECE 5??
Affinity Sensors - ECE 5??
Electrochemical Sensors - ECE 5??
Biophotonic Sensors Using Refractive Index - ECE 5??
Some of these modules are not offered every year

COURSE DESCRIPTION: Treatment of biological cells as circuits and their electrical time-dependent function and frequency dependent impedance. Topics include the Hodgkin–Huxley circuit model, diffusion equation, and modeling action potential propagation.

COURSE OBJECTIVES: Upon successful completion of this class, students will be able to:

- Draw an equivalent circuit model for biological cells and calculate the frequency dependent impedance of cells from the equivalent circuit
- Interpret Nyquist plots of bioimpedance to determine properties of biological tissue
- Describe the temporal evolution of action potentials and corresponding states of ion distributions and ion channel permeability in terms of circuit variables
- Write solutions to the diffusion equation satisfying varying flux and concentration boundary conditions, choose appropriate boundary conditions and parameters for realistic physical configurations, calculate fluxes from solutions, and interpret time and length scale parameters of problems
- Discuss the utility and limitations of different circuit models in approximating the propagation of action potentials in neurons

PREREQUISITES: BIOM101 or LIFE102; CHEM111; PH142; MATH255 or MATH261; MATH340 or MATH345, may be taken concurrently

Moderate computer programming (such as Matlab) skills or advanced spreadsheet skills are needed for completion of homework assignments involving finite difference equations.

REQUIRED MATERIALS: There is no required textbook for this class. Readings and notes will be provided as needed.

Canvas: canvas.colostate.edu will have the syllabus, links, homework, course grades and other postings. It is your responsibility to check the course website each week for new postings and to watch for announcements.

COURSE TOPICS: The planned topics for this course are:

Week 1	• Introduction / motivation • Basic cell structure and circuit equivalence of cellular membrane and cytosol • Frequency dependent electrical impedance and application to impedance of cells and tissue. (Supplemental resources will be made available to students who have not recently studied resistor-capacitor circuits.) • Bioimpedance and Nyquist plot
Week 2	• Bioimpedance (continued); multi-frequency Coulter Counter • [Optional introduction to electroimpedance tomography] • Circuit equivalence of ion channels and pumps; membrane and reversal potentials; Nernst equation; Goldman equation • Cellular electrical measurement techniques • [Optional: introduction to electrodiffusion and electrochemical potential] • Membrane intensive parameters (specific R and C), time constant
Week 3	• Overview of the anatomy and function of a neuron; axial resistivity • Cable equation and transformation to diffusion equation; length and time scales • Diffusion equation and its solutions for various boundary conditions • Integrate and fire model • [Optional: Use of non-linear circuit elements to model bistability and hysteresis]
Week 4	• Hodgkin–Huxley model including dynamical equations, action potential, voltage-gating, refractory periods, and temporal dynamics. • Comparison of measured and modeled action potential propagation.
Week 5	• Current topics in modeling electrical properties of cells. • Final exam or project

(Continued on next page.)

GRADING:

Quizzes / participation in discussions 10%
Homework assignments 45%
Final exam or project 45%

Homework will be due at the start of class one week after it is assigned, typically each Tuesday, but check the website for updates. Links to the homework can be found on Canvas. I request that you record the time spent on each question on your paper.

Some homework assignments for this course will require computer programming or advanced spreadsheet skills.

The final exam for this course will occur in class on Thursday, October 25th in class.

Final grades will be determined by the following scale:

≥ 90% A	80-83.99% B	70-73.99% C
87-89.99% A-	77-79.99% B-	60-69.99% D
84-86.99% B+	74-76.99% C+	≤ 59.99% F

ACADEMIC INTERGRITY: Students are expected to adhere to the Academic Integrity Policy of Colorado State University, outlined in the CSU General Catalogat http://catalog.colostate.edu/general-catalog/policies/students-responsibilities/#academic-integrity. Academic dishonesty is not accepted in this course, and any form of cheating (including plagiarism) will be reported. Penalties may include a lowered course grade, loss of course credit, and expulsion from the university. See https://tilt.colostate.edu/integrity/knowTheCode/ for more details and definitions.

STUDENTS MUST CITE SOURCES, INCLUDING DISCUSSIONS WITH OTHER STUDENTS OR PRIOR HOMEWORK ASSIGNMENTS OR SOLUTIONS, THEY USE FOR ANY ASSIGNMENTS OR ASSESSMENTS DONE OUT-OF-CLASS. Students do not need to cite 527A course slides, lectures, or discussions with the instructor on their assignments. COPYING FROM OTHER STUDENTS IS NOT PERMITTED, AND DUPLICATE WORK RESULTING FROM COLLABORATIONS WITH OTHER CURRENT STUDENTS WILL BE SUBJECT TO ACADEMIC PENALTIES. Discussions with other students are strongly encouraged, but do not share work you will submit with other students.