Advanced Quantum Engineering
MENG 31400
MW 1:30-2:50pm, in-person room TBA
Discussion F 1:30-2:20pm, Zoom
Tian Zhong
Fall 2022

Course goals and expectations: To obtain an introductory knowledge of the techniques and phenomena central to quantum engineering.

Synopsis: Quantum mechanics underlies many areas of modern engineering, including materials science, photonics, electronics, metrology and information processing. This course explores both the fundamental physics of quantum systems as well as the tools utilized to engineer and control them. Topics to be discussed may include eigenvalues and eigenstates, operators, symmetries, spin, angular momentum, perturbation theory, and time evolution. We will also explore examples of engineered quantum systems. Live demos of real-world quantum systems will be included in this course.

Why is this not the same course as quantum mechanics in physics department? Our focus is on the dynamics of systems that are often not in a single quantum state, and so we must consider techniques designed for this, especially the density-matrix formulation of quantum mechanics. Density matrices are well suited for problems of decoherence, noise, imperfect control, and associated phenomena essential to quantum engineering.

Prerequisites: An intermediate undergraduate course in quantum mechanics or permission of instructor.

Text: There is no appropriate textbook for such a course, and so we will be working with my own notes, which will be provided as the course progresses. Some books that may be helpful for various components of the course are:

- *Principles of Quantum Mechanics, 2nd edition*, R. Shankar (Springer)
  [for traditionally-focused quantum mechanics]
- *Density Matrix Theory and Applications*, K. Blum (Springer: free in PDF format on SpringerLink through U. Chicago libraries).
  [density matrix introduction (Ch. 1-3) and other applications]
- *Quantum Computation and Quantum Information*, M. A. Nielsen and I. L. Chuang, Cambridge University Press.
- *Quantum Engineering: Theory and Design of Quantum Coherent Structures*, A. M. Zagoskin, Cambridge University Press.

Makeup classes: These will be arranged throughout the semester to make up class dates when the instructor is out of town (10/8(Th)).

Instructor's Office hour: Office Hours Wednesday 11am-12pm or by appointment. Email: tzh@uchicago.edu

TA: Yat Wong (yatwong@uchicago.edu) Office Hours Friday 1:30-3:30pm or by appointment.

Discussion section: Structure: 1/3 discussion of the problem set just turned in, 1/3 worked examples related to the problem set just assigned, 1/3 open discussion.

Grading: Approximately a problem set per week due Fridays (40%), midterm (30%), final (30%).

Collaboration: You are permitted to collaborate on the problem sets. Discussion of the problems with other students is encouraged. Each student must independently write up their own solutions to the problems. See the University of Chicago policies for the definition of plagiarism. Ask the instructor if you have questions about interpretation.

Final: Open notes are allowed for the midterm and final (class notes, homework, homework solutions). Only notes from this class may be used. It is not permitted to use electronic devices of any kind during the exams, so please keep this in mind as the exam date approaches if you have electronic notes.

Sequence of Topics:

- Review of eigenstate-focused quantum mechanics, time-independent/dependent perturbation theory, Fermi's Golden rule, and their applications in light-matter interactions (atomic dipole coupling and extended systems in solids)
- Introduction to density matrices, spin 1/2, spin 1, two interacting spin 1/2 systems
- Treatment of decoherence, relaxations, and Bloch equation
- Magnetic resonances and hybridization, spin echoes, free-induction decays, connections to quantum memory
- Noise. Classical and quantum origin of noise. Coherent and Fock states.
- Measurement theory, e.g. single-photon measurements: dark counts and quantum efficiency
- Entanglement. Creation and manipulation.
- Connections to quantum information: quantum key distribution, teleportation and quantum computation