ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY of HAWAIʻI at MĀNOA

ECE 491D/693D Introduction to quantum information science

Syllabus

Time and location: MW 12:00 PM – 1:15 PM in Holmes 248

Prerequisites: MATH 307 (Linear algebra) and ECE 342 (Probability)
* PHYS 481 and 480 (Quantum mechanics) are helpful but not necessary

Instructor: Bo-Han Wu, bohanwu@hawaii.edu

Office hour: Scheduling appointment by email for in-person and here for zoom meetings.

Text book: Quantum Computation and Quantum Information (Michael A. Nielsen and Isaac L. Chuang), Quantum Information and Computation (John Preskill's note)

Course description: This multidisciplinary course integrates mathematics (60%), physics (20%), and electrical engineering (20%) to address three central questions: What is quantum information science?, Why is it important?, and What are the state-of-the-art developments in quantum technology?

Students will develop a foundational understanding of quantum technologies such as quantum computing, focusing on the conceptual foundations of quantum states and operations, the transformative potential of quantum algorithms, and an overview of cutting-edge quantum platforms. The course emphasizes mathematical rigor through selected proofs presented in class, complemented by problem sets for independent practice. By the end of the course, students will be able to follow and interpret current advancements across major quantum platforms, including photonics, atomic systems, and superconducting circuits, and understand how quantum information science connects with modern technology and research.

Course objectives: By the end of this course, students will be able to:

- *Explain fundamental concepts* in quantum information science, including qubits, pure and mixed states, quantum coherence, entanglement, quantum gates, and quantum channels.
- *Use rigorous mathematical proofs* related to quantum information theory.
- *Describe and evaluate the principles* of quantum error correction and continuous-variable quantum information for preserving quantum information.
- *Compare and contrast major quantum technology platforms*, including photonics, atomic systems, and superconducting circuits, with respect to their operating principles and technical challenges.
- *Interpret and explain recent research developments* in quantum computing, communication, and sensing.
- *Communicate technical concepts* clearly through written problem sets, oral presentations, and collaborative discussions.

Major deliverables and assessments:

Undergraduate: 5 × problem sets (35%), midterm exam (30%), final exam (35%)

Graduate: 5 × problem sets (35%), midterm exam (20%), final exam (25%), and final oral presentation (20%)

Grading Standard

Scores: A:>80, B:70-79, C:60-69, D:50-59, F: <49

Problem sets and examinations: Problem sets and exams are graded on correctness and clear reasoning: a fully correct, well-explained solution earns full points; a thorough but not entirely correct solution earns partial points (depending on correctness); submissions that show minimal original work will receive zero point.

* AI tools warning: AI tools, such as ChatGPT, are double-edged swords. While they can generate answers quickly and efficiently, their outputs are not guaranteed to be correct and may contain inaccuracies ("hallucinations"). You are expected to learn the material yourself and can use AI tools only to aid your understanding of the context.

For problem sets, all solutions must show clear, logical, and step-by-step derivations. If the work appears to rely on AI-generated content or copied material rather than your own reasoning, grading will be significantly penalized.

Oral presentation (for graduate students): Each presenter choose a paper related to quantum information. A list of suggested readings will be provided, but other papers may be approved by the instructor. Each presenter will give a 10-minute oral presentation (followed by 1 minutes for questions).

Presentation should at least cover the following three categories:

Background introduction: The presenter should address the following questions in the presentation to make sure audience has clear background knowledge for the work to be presented.

1. What is the problem that people are trying to solve?
2. Why are people interested in solving this problem?
3. What are the difficulties of this problem?
4. What effort has been made, trying to solve this problem, before this research?

Content: The presenter should clearly presents the results and methods of the study.

Take-home message: Use one page to summarize the key strengths of this work

Presentations will be evaluated according to the following criteria:

- Time management – 10%
- Ask questions – 10%
- Clarity of introduction – 45%
- Clarity of results and methods – 25%
- Correctness of the examination questions – 10%

Make sure you fully understand the paper's main ideas and technical details, which may require reading several of its references.

Course Policies

Lamaku: All slides, problems sets and reference papers will be uploaded to Lamaku.

Late Work: Problem sets must be submitted on time. If you have a valid reason for a late submission, you must inform the instructor in and wait for the permission.

NO-CHEATING: Zero tolerance on problem sets and examinations cheating. The students, who violate the rule, will fail the course WITHOUT ANY EXCEPTION.

Email: I will use email to communicate with you. You can contact me by email or using the website to book my time in zoom. Please be sure to state your question or concerns clearly and respectfully. I check my email regularly and do my best to respond within 24 hours.

Tentative Course Schedule

	Topics and contents	Deliverables	References
Week 1 (8/25, 27)	Brief introduction to quantum mechanics **Key points:** Stern Gerlach experiment, Bell's inequality, quantum mechanics postulations		Introduction to Quantum Mechanics (D. Griffith) Ch. 12 John Preskill's note Ch. 2
9/1 Labor Day Week 2 (9/3)	Basics of quantum information 1 **Key points:** Qubit, Bloch sphere, Landuer's principle		Quantum Computation and Quantum Information, Ch. 2, 3
Week 3 (9/8, 10)	Basics of quantum information 2 **Key points:** Schmidt decomposition, Bell states, partial trace, density operator, no-cloning theorem, LOCC	HW1 released (9/8)	Quantum Computation and Quantum Information, Ch. 1 John Preskill's note Ch. 4
Week 4 (9/15, 17)	Basics of quantum information 3 **Key points:** Noiseless compression theorem, Shannon entropy, mutual information, POVM, quantum gates, Solovay-Kitaev, Gottesman-Knill theorems		Quantum Computation and Quantum Information, Ch. 4, 10 John Preskill's note Ch. 5
Week 5 (9/22, 24)	Quantum channels **Key points:** Classical capacity, quantum capacity (Holevo information), superdense coding, teleportation, Kraus operator, quantum channels (e.g., depolarizing channel)	HW1 due (9/22) HW2 released (9/24)	Quantum Computation and Quantum Information, Ch. 8 John Preskill's note Ch. 4
Week 6 (9/29, 10/1)	Quantum computing - algorithm **Key points:** HSW theorem, super-additivity ($1 + 1 \geq 2$), deferred measurement theorem, quantum Fourier transform, phase estimation	HW1 return (9/29)	Quantum Computation and Quantum Information, Ch. 6 John Preskill's note Ch. 6

	Topics and contents	Deliverables	References
Week 7 (10/6, 8)	Quantum computing — applications **Key points:** Deutsch-Josa problem, Grover search problem, Computational complexity introduction, RSA cryptography, number factoring, order finding, Shor's algorithm	HW2 due (10/6) HW3 released (10/8)	John Preskill's note Ch. 6
Week 8 (10/13, 15)	Quantum communication and quantum state measure **Key points:** One-time pad, prepare-and-measurement QKD protocol (BB84), entanglement assisted QKD protocol (E91), EA communication, trace distance, hypothesis testing	HW2 return (10/13)	Quantum Computation and Quantum Information, Ch. 12 Quantum Optics An Introduction (M. Fox), Ch. 12
Week 9 (10/20, 22)	Quantum sensing **Key points:** Quantum fidelity, Classical and quantum Fisher information	HW3 due (10/20) HW3 return (10/22)	Quantum Computation and Quantum Information, Ch. 9
Week 10 (10/27, 29)	Quantum error correction 1 **Key points:** Classical repetition code and quantum repetition code	**Midterm exam** (10/27) Midterm exam return (10/29)	Quantum Computation and Quantum Information, Ch. 10 Daniel Gottesman - Quantum Error Correction and Fault Tolerance (Part 1) - CSSQI 2012
Week 11 (11/3, 5)	Quantum error correction 2 **Key points:** Shor's nine-qubit code, conditions of QEC, Hamming bound and GV bound, CSS code	HW4 released (11/3)	Quantum Computation and Quantum Information, Ch. 10
Week 12 (11/10, 12)	Quantum error correction 3 **Key points:** Steane code, stablizer code	Presentation references released (11/10)	Quantum Computation and Quantum Information, Ch. 10
Week 13 (11/17, 19)	Quantum error correction 4 **Key points:** Fault tolerance quantum computing, magic-state injection, threshold theorem	HW4 due (11/17) HW5 released (11/17)	Quantum Computation and Quantum Information, Ch. 10

	Topics and contents	Deliverables	References
Week 14 (11/24, 26)	Continuous-variable quantum information **Key points:** Qudit system, Qumode system, field operators, Wigner function , Gaussian states (e.g., coherent state, squeezed state), Gaussian unitary	HW4 return (11/24)	
Week 15 (12/1, 3)	State-of-the-art quantum platforms 1 **Key points:** Photonics, neutral atoms	HW5 due (12/1)	
Week 16 (12/8, 10)	State-of-the-art quantum platforms 2 **Key points:** Superconducting circuits	HW5 return (12/8) **Oral presentation** (12/10)	
Week 17 (12/19)		**Final exam** (12/19)	

Campus Resources & Services

Statement on Disability: KOKUA Program:If you have a disability and related access needs, please contact the KOKUA Program (Office for Students with Disabilities) at 956-7511, KOKUA@hawaii.edu, or go to Room 013 in the Queen Lili‘uokalani Center for Student Services. Please know that I will work with you and KOKUA to meet your access needs based on disability documentation. Kokua’s services are confidential and offered free of charge.

Academic Integrity and Ethical Behavior: Office of Student Conduct: Cheating, plagiarism, or other forms of academic dishonesty are not permitted within this course and are prohibited within the System-wide Student Conduct Code (EP 7.208). Examples include: fabrication, falsification, cheating, plagiarism, and use of improper materials. Any incident of suspected academic dishonesty will be reported to the Office of Student Conduct for review and possible adjudication. Additionally, the instructor may take action in regards to the grade for the deliverable or course as they see fit.

Department of Public Safety: (808)956-6911 (Emergency) / (808)956-8211 (Non-Emergency) http://manoa.hawaii.edu/dps/

UH System Basic Needs (text to be used) include food and housing, childcare, mental health, financial resources and transportation, among others. Student basic needs security is critical for ensuring strong academic performance, persistence and graduation and overall student well being. If you or someone you know are experiencing basic needs insecurity, please see the following resources: UH System Basic Needs

Student Success Resources: The Division of Student Success (DSS) houses student support services to build success inside and outside the classroom. If you want learning assistance, academic advising, career resources and guidance, counseling, family and relationship support, identity-based support, services for underrepresented groups, health and wellness services, opportunities for leadership growth, and community engagement, you will find this and more in DSS, (808) 956-3290, https://manoa.hawaii.edu/studentsuccess/departments/

University of Hawai‘i at Mānoa (UHM) TITLE IX SYLLABUS INFORMATION:As a member of the University faculty, I am required to immediately report any incident of sex discrimination or gender-based violence to the campus Title IX Coordinator. Although the Title IX Coordinator and I cannot guarantee confidentiality, you will still have options about how your case will be handled. My goal is to make sure you are aware of the range of options available to you and have access to the resources and support you need. For more information regarding sex discrimination and gender-based violence, the University’s Title IX resources and the University’s Policy, EP 1.204, go to: http://www.manoa.hawaii.edu/titleix/

UHM is committed to providing a learning, working and living environment that promotes personal integrity, civility, and mutual respect and is free of all forms of sex discrimination and gender-based violence, including sexual assault, sexual harassment, gender-based harassment, domestic violence, dating violence, and stalking. If you or someone you know experiences any of these, UHM has staff and resources on campus to support and assist you. Staff also can direct you to resources in the community. Here are some: If you wish to remain ANONYMOUS, speak with someone CONFIDENTIALLY, or would like to receive information and support in a CONFIDENTIAL setting, contact: (* Confidential Resource).