COURSE: QIC750/ECE676/PHYS768

COURSE TITLE: **Implementations of Quantum Information Processing**

INSTRUCTORS: Prof. Na Young Kim
Office: RAC-2101
Email: nayoung.kim(at)uwaterloo.ca
Office Hours: by appointment (via email)

LECTURE HOURS: Mondays, Fridays 8:30 - 9:50 am (2025/1/6-4/4), Location: E7-4433
When in-person lectures are not allowed, online lectures will be offered through MS Teams (most likely) or Zoom.

TA: TBA
TA OFFICE HOURS: TBD Location: TBD

DESCRIPTION:
This course gives an introduction to physical implementations of quantum computers with an emphasis on common and connecting themes.

PREREQUISITE: Quantum mechanics, linear algebra, differential equations

SYLLABUS:

1. ***Introduction to quantum computing***
   Origin and elements of quantum computers. Quantum circuit models.

2. ***Review of Important Quantum Models***
   Time-evolution and the Hamiltonian. The 2-level system (spin 1/2). Density matrices. The Bloch Sphere. The quantum harmonic oscillator.

3. ***Superconducting Qubits***
   Quantized circuits. Charge and Flux qubits. Circuit Quantum Electrodynamics. Jaynes-Cummings Hamiltonian: Coupling between a harmonic oscillator and two-level system. Noise.

4. ***Trapped-Ion Quantum Computing***
   Trapping ions. Optical and Microwave qubits. Raman transitions. Single- and Two-qubit gates. Noise.

5. ***Photonic Quantum Information***
   Optical elements. Polarization, time-bin, and dual-rail encoding. Quantum key distribution. Noise.

6. ***Nuclear Magnetic Resonance & Spin Quantum Computing***
   Spin qubits. RWA. Single- and Two-qubit gates. Noise.

7. ***Special Topics***
   Students will give presentations on topics of interest to themselves drawn from the literature.

TEXTBOOK: There will be no required textbook.

COURSE MATERIAL: Lecture notes will be provided on **Learn.**

OTHER REFERENCE: Modern Quantum Mechanics, J.J. Sakurai. Addison-Wesley Publishing, (1994).

OTHER RESOURCES:

- We will use the **LEARN** platform for announcements, surveys, submissions, and grading problem sets.

MARKING SCHEME:

- Homework: 30%
- Presentations: 20%
- Final Exam: 50%

Plagiarism detection software (Turnitin) will be used to screen assignments in this course, to verify that the use of all materials and sources is documented. If you object to your work being screened by Turnitin, contact Prof. Kim with your concerns within the first 2 weeks of class.

Week	Date	Topic	Reading	Problem Set
1	Lec. 1: Jan. 11	Introduction to QC	Chap. 1	
	Lec. 2: Jan. 12	Review of QM	Chap. 2.1-2.3	PS1. Out
2	Lec. 3: Jan. 18	Q. Dynamics & Measurement	Chap. 2.4, 2.5	
	Lec. 4: Jan. 19	QHO	Chap. 2.6	
3	Lec. 5: Jan. 25	Superconducting Introduction, Qubit	Chap. 6.1, 6.2	
	Lec. 6: Jan. 26	Superconducting QED	Chap. 6.3	PS1. Due
4	Lec. 7. Feb. 1	Superconducting Initialization	Chap. 6.4	PS2. Out
	Lec. 8. Feb. 2	Superconducting Gates, Measurement	Chap. 6.5, 6.7	
5	Lec. 9: Feb. 8	Superconducting Measurement, Noise	Chap. 6.7, 6.8	
	Lec. 10: Feb. 9	Trapped-Ion Introduction, Single-qubit	Chap. 5.1, 5.2	
6	Lec. 11: Feb. 15	Trapped-Ion Qubit, Interaction Processes	Chap. 5.2, 5.3	
	Lec. 12: Feb. 16	Trapped-Ion Initialization	Chap. 5.4	PS2. Due
7	Study Break			PS3 out
8	Lec. 13: Feb. 29	Trapped-Ion Qubit Control	Chap. 5.5	
	Lec. 14: Mar. 1	Trapped-Ion Measurement, Noise	Chap. 5.6, 5.7	
9	Lec. 15: Mar.7	Photon Introduction, Single Qubit	Chap. 4.1-4,3	
	Lec. 16: Mar. 8	Photon Two-Qubit, measurement	Chap. 4.4, 4.5	PS3. Due
10	Lec. 17: Mar. 14	Photon One-way computation	Chap.4.6	
	Lec. 18: Mar. 15	Photon Continuous Variable QC, Noise	Chap. 4.7, 4.8	PS4. Out
11	Lec. 19: Mar. 21	NMR Introduction, Single & 2 Qubit	Chap. 3.1-3.3	
	Lec. 20: Mar. 22	NMR Measurement, Initialization, Noise	Chap. 3.4-3.7	
12	Lec. 21: Mar. 28	Presentations - I (5 teams)		
	Lec. 22: Mar. 29	Presentations - II (5 teams)		PS4. Due
13	Lec. 23: Apr. 4	Presentations - III (5 teams)		
	Lec. 24: Apr. 5	Presentations - IV (5 teams)		

Scenario 1.1 (2024/1/27)

Week	Date	Topic	Reading	Problem Set
1	Lec. 1: Jan. 11	Introduction to QC	Chap. 1	
	Lec. 2: Jan. 12	Review of QM	Chap. 2.1-2.3	PS1. Out
2	Lec. 3: Jan. 18	Q. Dynamics	Chap. 2.4	
	Lec. 4: Jan. 19	Q. Dynamics & Measurement	Chap. 2.5	
3	Lec. 5: Jan. 25	QHO	Chap. 2.6	
	Lec. 6: Jan. 26	Superconducting Introduction QED	Chap. 6.3	PS1. Due
4	Lec. 7. Feb. 1	Superconducting Initialization	Chap. 6.4	PS2. Out
	Lec. 8. Feb. 2	Superconducting Gates, Measurement	Chap. 6.5, 6.7	
5	Lec. 9: Feb. 8	Superconducting Measurement, Noise	Chap. 6.7, 6.8	
	Lec. 10: Feb. 9	Trapped-Ion Introduction, Single-qubit	Chap. 5.1, 5.2	
6	Lec. 11: Feb. 15	Trapped-Ion Qubit, Interaction Processes	Chap. 5.2, 5.3	
	Lec. 12: Feb. 16	Trapped-Ion Initialization	Chap. 5.4	PS2. Due
7	Study Break			PS3 out
8	Lec. 13: Feb. 29	Trapped-Ion Qubit Control	Chap. 5.5	
	Lec. 14: Mar. 1	Trapped-Ion Measurement, Noise	Chap. 5.6, 5.7	
9	Lec. 15: Mar.7	Photon Introduction, Single Qubit	Chap. 4.1-4,3	
	Lec. 16: Mar. 8	Photon Two-Qubit, measurement	Chap. 4.4, 4.5	PS3. Due
10	Lec. 17: Mar. 14	Photon One-way computation	Chap.4.6	
	Lec. 18: Mar. 15	Photon Continuous Variable QC, Noise	Chap. 4.7, 4.8	PS4. Out
11	Lec. 19: Mar. 21	NMR Introduction, Single & 2 Qubit	Chap. 3.1-3.3	
	Lec. 20: Mar. 22	NMR Measurement, Initialization, Noise	Chap. 3.4-3.7	
12	Lec. 21: Mar. 28	Presentations - I (5 teams)		
	Lec. 22: Mar. 29	Presentations - II (5 teams)		PS4. Due
13	Lec. 23: Apr. 4	Presentations - III (5 teams)		
	Lec. 24: Apr. 5	Presentations - IV (5 teams)		

Scenario 1.2 (2024/2/19)

Week	Date	Topic	Reading	Problem Set
1	Lec. 1: Jan. 11	Introduction to QC	Chap. 1	
	Lec. 2: Jan. 12	Review of QM	Chap. 2.1-2.3	PS1. Out
2	Lec. 3: Jan. 18	Q. Dynamics	Chap. 2.4	
	Lec. 4: Jan. 19	Q. Dynamics & Measurement	Chap. 2.5	
3	Lec. 5: Jan. 25	QHO	Chap. 2.6	
	Lec. 6: Jan. 26	Superconducting Introduction	Chap. 6.1, 6.2	PS1. Due
4	Lec. 7. Feb. 1	Superconducting Cooper-Pair Box	Chap. 6.3, 6.4	PS2. Out
	Lec. 8. Feb. 2	Superconducting Transmon Hamiltonian	Chap. 6.4	
5	Lec. 9: Feb. 8	Superconducting Jaynes-Cummings, Gates	Chap. 6.5	
	Lec. 10: Feb. 9	Superconducting Measurement, Noise	Chap. 6.7, 6.8	
6	Lec. 11: Feb. 15	Trapped-Ion Trapping Potential	Chap. 5.1	
	Lec. 12: Feb. 16	Trapped-Ion Trapping potential	Chap. 5.1	PS2. Due
7	Study Break			PS3 out
8	Lec. 13: Feb. 29	Trapped-Ion Qubit, Interaction Processes	Chap. 5.2, 5.3	
	Lec. 14: Mar. 1	Trapped-Ion Qubit Control, Measurement	Chap. 5.4-5.6	
9	Lec. 15: Mar.7	Trapped-Ion Noise, Summary Photon Introduction	Chap. 5.7, 5.8 Chap. 4.1	
	Lec. 16: Mar. 8	Photon Single Qubit	Chap. 4.2, 4.3	PS3. Due
10	Lec. 17: Mar. 14	Photon Two-Qubit, measurement	Chap. 4.4, 4.5	PS4. Out
	Lec. 18: Mar. 15	Photon One-way computation Continuous Variable QC	Chap. 4.6, 4.7	
11	Lec. 19: Mar. 21	Photon, Noise NMR Introduction, Single & 2 Qubit	Chap 4.8 Chap. 3.1, 3.2	
	Lec. 20: Mar. 22	NMR Overview	Chap. 3.4-3.7	
12	Lec. 21: Mar. 28	Presentations - I (5 teams)		
	Lec. 22: Mar. 29	Presentations - II (5 teams)		PS4. Due
13	Lec. 23: Apr. 4	Presentations - III (5 teams)		
	Lec. 24: Apr. 5	Presentations - IV (5 teams)		

Scenario 2

Week	Date	Topic	Reading	Problem Set
1	Lec. 1: Jan. 11	Introduction to QC	Chap. 1	
	Lec. 2: Jan. 12	Review of QM	Chap. 2.1-2.3	PS1. Out
2	Lec. 3: Jan. 18	Q. Dynamics & Measurement	Chap. 2.4, 2.5	
	Lec. 4: Jan. 19	Quantum Harmonic Oscillator	Chap. 2.6	
3	Lec. 5: Jan. 25	Superconducting Introduction, Qubit	Chap. 6.1, 6.2	
	Lec. 6: Jan. 26	Superconducting QED	Chap. 6.3	PS1. Due
4	Lec. 7. Feb. 1	Superconducting Initialization	Chap. 6.4	PS2. Out
	Lec. 8. Feb. 2	Superconducting Gates, Measurement	Chap. 6.5, 6.7	
5	Lec. 9: Feb. 8	Superconducting Measurement, Noise	Chap. 6.7, 6.8	
	Lec. 10: Feb. 9	Trapped-Ion Introduction, Single-qubit	Chap. 5.1, 5.2	
6	Lec. 11: Feb. 15	Trapped-Ion Qubit, Interaction Processes	Chap. 5.2, 5.3	
	Lec. 12: Feb. 16	Trapped-Ion Initialization	Chap. 5.4	PS2. Due
7	Study Break			PS3 out
8	Lec. 13: Feb. 29	Trapped-Ion Qubit Control	Chap. 5.5	
	Lec. 14: Mar. 1	Trapped-Ion Measurement, Noise	Chap. 5.6, 5.7	
9	Lec. 15: Mar. 7	Photon Introduction Presentations - I (2 teams)	Chap. 4.1, 4.2	
	Lec. 16: Mar. 8	Photon Single-Qubit Presentations - II (2 teams)	Chap. 4.3	PS3. Due
10	Lec. 17: Mar. 14	Photon Two-Qubit, measurement Presentations - III (2 teams)	Chap. 4.4, 4.5	
	Lec. 18: Mar. 15	Photon One-way computation Presentations - V (2 teams)	Chap. 4.6	PS4. Out
11	Lec. 19: Mar. 21	Photon Continuous Variable QC Presentations - VI (2 teams)	Chap. 4.7	
	Lec. 20: Mar. 22	Photon Noise Presentations - VII (2 teams)	Chap. 4.8	
12	Lec. 21: Mar. 28	NMR Introduction Presentations - VII (2 teams)	Chap. 3.1, 3.2	
	Lec. 22: Mar. 29	NMR Single and two-qubit Presentations - VIII (2 teams)	Chap. 3.3, 3.4	PS4. Due
13	Lec. 23: Apr. 4	NMR Measurement, Initialization Presentations - IX (2 teams)	Chap. 3.5, 3.6	
	Lec. 24: Apr. 5	NMR Noise, Summary Presentations - X (2 teams)	Chap. 3.7	

Old-order

Week	Date	Topic	Reading	Problem Set
1	Lec. 1: Jan. 11	Introduction to QC	Chap. 1	
	Lec. 2: Jan. 12	Review of QM	Chap. 2.1-2.3	
2	Lec. 3: Jan. 18	Q. Dynamics	Chap. 2.4, 2.5	PS1. Out
	Lec. 4: Jan. 19	QHO	Chap. 2.5	
3	Lec. 5: Jan. 25	NMR Introduction	Chap. 3.1, 3.2	
	Lec. 6: Jan. 26	NMR Single-qubit	Chap. 3.3	
4	Lec. 7. Feb. 1	NMR Two-qubit, measurement	Chap. 3.4, 3.5	PS1. Due
	Lec. 8. Feb. 2	NMR Initialization, Noise	Chap. 3.6, 3.7	PS2. Out
5	Lec. 9: Feb. 8	Photon Introduction, Single-qubit	Chap. 4.1-4.3	
	Lec. 10: Feb. 9	Photon Two-qubit, measurement	Chap. 4.4, 4.5	
6	Lec. 11: Feb. 15	Photon One-way computation	Chap. 4.6	
	Lec. 12: Feb. 16	Photon CV QC, Noise	Chap. 4.7,4.8	PS2. Due
7	Study Break			
8	Lec. 13: Feb. 29	Trapped-Ion Introduction	Chap. 5.1	PS3. Out
	Lec. 14: Mar. 1	Trapped-Ion Interaction Processes, Initialization	Chap. 5.2-5.4	
9	Lec. 15: Mar. 7	Trapped-Ion Qubit Control, Noise	Chap. 5.5-5.7	
	Lec. 16: Mar. 8	Superconducting Introduction	Chap. 6.1, 6.2	
10	Lec. 17: Mar. 14	Superconducting QED	Chap. 6.3	PS3. Due
	Lec. 18: Mar. 15	Superconducting Gates	Chap. 6.4-6.6	PS4. Out
11	Lec. 19: Mar. 21	Superconducting Measurement, Noise	Chap. 6.7, 6.8	
	Lec. 20: Mar. 22	Summary		
12	Mar. 28	Presentations - I		
	Mar. 29	Presentations - II		PS4. Due
13	Apr. 4	Presentations - III		
	Apr. 5	Presentations - IV		