Home Teaching PHY682 Announcement/Update AcademicCalendar

PHY682 Special Topics in Solid-State Physics: Quantum Information Science--an Introduction (Fall 2020)

Website address: http://insti.physics.sunysb.edu/~twei/Courses/Fall2020/PHY682/
Lecture time: 2:40-4:00PM Monday & Wednesday, Lectures will be online (Zoom link will be sent to registered students)
Instructor: **Tzu-Chieh Wei** <tzu-chieh.wei[at]stonybrook[dot]edu> Office Phone: 631-632-7966
Office hour: 11am-12pm Friday (online via Zoom; link will be sent to registered students) [*Time to be confirmed]

Technical and Software Requirement: Zoom meeting will be used. Internet is needed. Microphone needed to participate verbally. Typing questions in Zoom's chat during lectures if no microphone is available. However, for final presentation, microphone is required.

Qualification of the instructor: He has ample research experience in Quantum Information Science since when he was a PhD student, and has supervised a few PhD students and master students on related research projects. See the publication list here.

Course description:
This is a survey of the fast evolving field of quantum information, ranging from Bell inequality, quantum teleportation to quantum algorithms and quantum programming frameworks. It aims to cover the essential knowledge of quantum information science and helps to bridge the gap to the current research activities of the field. Emphasis will be placed on solid-state platforms of quantum computers, topological error correction codes, and applications. Other systems will be introduced when necessary. Some illustration of quantum programming will be done on IBM's transmon-type cloud quantum computers.

Course level: senior undergraduates and beginning graduate students (Master/PhD); students from other departments such as Chemistry, Math, CS and Engineering who have learned linear algebra should find the course accessible. The materials covered in this course are interdisciplinary anyway. The required knowledge of quantum mechanics is also minimal, e.g. superposition, unitary evolution, and measurement described in the first chapter of a standard quantum mechanics textbook. But these will be reviewed as well.

For undergraduates: This course may be taken by upper-level undergraduates with Prerequisite: PHY 251 or Corequisite: PHY 308 (No requirement of any prior solid-state course). It needs the permission and the signature of the instructor in order to register for this course; form can be downloaded here.

Breadth course or not (for Physics PhD students): this can count as a breadth course, provided it is the only 680 or 690 course the student has taken and is the only solid state physics course they have taken.

Learning outcomes:
Students who have completed this course
- Should be able to understand the physical principles of quantum computation and how quantum algorithms work such as Shor's factoring and Grover's searching
- Should be able to understand the basics of information theory and their relation to statistical mechanics and quantum entanglement
- Should be able to understand the working principles of sold-state qubits and be able to perform simple

programming on publicly available quantum computers such as IBM Q

Required Textbooks:
There is no required textbook. Notes or slides will be provided when available.

Recommended Textbooks :
Quantum Computation and Quantum Information, M. Nielsen and I. Chuang (Cambridge University Press)
An Introduction to Quantum Computing, P. Kaye, R. Laflamme and M. Mosca (Oxford)
J. Preskill lecture notes (http://www.theory.caltech.edu/~preskill/ph229/#lecture)
The Feynman Lectures on Physics, Vol. 3 (which can be read online here)
Learn Quantum Computation using Qiskit (free digital textbook)

Math needed in this course:
e.g. The Mathematics of Quantum Mechanics by Dr. Martin Laforest (University of Waterloo)

Grades: (tentative)
(1) Homework 50% [main purpose is to enhance understanding of lecture materials]
(2) Participation 10% [attendance is required; more importantly, this is to encourage active participation and learning; asking questions helps the instructor to clarify and in turn helps you and others to understand; sharing with others how you understand a particular concept is useful; you can ask questions verbally or in Zoom's chat; report technical internet problem to the instructor]
(3) Mid-semester report (2-3 pages) 15% [to gauge how you are doing]
(4) Final presentation (for suggested topics/papers, see below) & end-of-semester report 25% (15%+10%) [to have an in-depth understanding of a subject of your choice and a retrospect of your learning in this course]

Homework policy: no late homework (must be turned in on the due day by submitting it in Blackboard or email); exception must be requested two days or earlier before deadline

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Topics to be covered and tentative syllabus
(This is a tentative syllabus. Exam dates and due dates may change. Check later for update.)

(week 1) [8/24,8/26] **The history of Q:** Overview of this course and review of linear algebra, basics of quantum mechanics, quantum bits and mixed states.

Homework 1 (to be distributed on 8/24, due in one week)

(week 2) [8/31,9/2] **From foundation to science-fiction teleportation**: Bell inequality, teleportation of states and gates, entanglement swapping, remote state preparation, superdense coding, and superdense teleportation.

Homework 2 (to be distributed on 8/31, due in one week)

(week 3) [9/7,9/9] **Information is physical**---Physical systems for quantum information processing: Superconducting qubits, solid-state spin qubits, photons, trapped ions, and topological qubits (p-wave superconductors, frational quantum Hall systems, topological insulators, etc.)

Homework 3 (to be distributed on 9/7, due in one week)

(week 4) [9/14,9/16] **Grinding gates in quantum computers**: Quantum gates and circuit model of quantum computation, introduction to IBM's Qiskit, Grover's quantum search algorithm, amplitude amplification.

Homework 4 (to be distributed on 9/14, due in one week)

(week 5) [9/21,9/23] **Programming through quantum clouds**: Computational complexity, Quantum programming on IBM's superconducting quantum computers, including the use of the variational quantum eigensolver (VQE) on quantum chemistry of molecules, quantum approximate optimization algorithm (QAOA) for optimization, hybrid classical-quantum neural network.

Homework 5 (to be distributed on 9/14, due in one week)

(week 6) [9/28,9/30] **Dealing with errors**: Error models, Quantum error correction, topological stabilizer codes and topological phases (including fractons), error mitigations

(week 7) [10/5,10/7] Mid-semester report due 10/5 **Quantum computing by braiding**: Kitaev's chain, Majorana fermions, anyons and topological quantum computation

Homework 6 (to be distributed on 10/5, due on 10/14)

(week 8) [Fall break on 10/12, class on 10/14] **More topological please**: Topological quantum computation continued, surface code and magic state distillation

(week 9) [10/19,10/21] **Quantum computing by evolution and by measurement**: Other frameworks of quantum computation: adiabatic and measurement-based; D-Wave's quantum annealers

Homework 7 (to be distributed on 10/19, due in one week)

(week 10) [10/26,10/28] **Quantum entangles**: Entanglement of quantum states, entanglement of formation and distillation, entanglement entropy, Schmidt decomposition, majorization, quantum Shannon theory

Homework 8 (to be distributed on 10/26, due in one week)
Choice of a presentation topic

(week 11) [11/2,11/4] **No clones in quantum**: No cloning of quantum states, non-orthogonal state discrimination, quantum tomographic tools, quantum cryptography: quantum key distribution from transmitting qubits and from shared entanglement

Homework 9 (to be distributed on 11/2, due in one week)

(week 12) [11/9,11/11] **Show me your 'phase', Mr. Unitary**: Quantum Fourier Transform, quantum phase estimation, Shor's factoring algorithm, and quantum linear system (such as the HHL algorithm) and programming with IBM Qiskit

Homework 10 (to be distributed on 11/9, due in one week)

(week 13) [11/16,11/18] **The quantum 'Matrix'**: Quantum simulations and quantum sensing and metrology

Presentation preparation

(week 14) [class on 11/23, Thanksgiving break begins on 11/25] **The quantum outlook**: Additional topics time permitting (Quantum Information beyond condensed matter and AMO phsysics, VQE for quantum chemistry, holographic codes, Black hole entropy paradox)

(week 15) [11/30, 12/1] (Student presentation)
(week 16) [12/7 (last day of class)] (Student presentation)

End-of-semester report due on final exam date

(final exam date may also be used for student presentation)

Suggested topics and papers for presentation (click to see the incomplete list, to be updated)

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Announcement, Update and Additional Information

Interesting papers to read:
arXiv:2006.16444 Preparing for the quantum revolution -- what is the role of higher education?
Michael F. J. Fox, Benjamin M. Zwickl, H. J. Lewandowski

Useful resources:
Youtube lectures by Umesh Vazirani

Leonard Susskind's lecture series on Modern Physics: Quantum Mechanics
Lecture 1, Lecture 2, Lecture 3, Lecture 4, Lecture 5, Lecture 6, Lecture 7, Lecture 8, Lecture 9, Lecture 10

More will be posted to Blackboard.stonybrook.edu

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For your information:

Student Accessibility Support Services (SASC):
If you have a physical, psychological, medical or learning disability that may impact your course work, please contact Student Accessibility Support Center, ECC (Educational Communications Center) Building, Room 128, (631)632-6748. They will determine with you what accommodations, if any, are necessary and appropriate. All information and documentation is confidential. https://www.stonybrook.edu/commcms/studentaffairs/sasc/facstaff/syllabus.php

Academic Integrity Statement:
Each student must pursue his or her academic goals honestly and be personally accountable for all submitted work. Representing another person's work as your own is always wrong. Faculty is required to report any suspected instances of academic dishonesty to the Academic Judiciary. Faculty in the Health Sciences Center (School of Health Technology & Management, Nursing, Social Welfare, Dental Medicine) and School of Medicine are required to follow their school-specific procedures. For more comprehensive information on academic integrity, including categories of academic dishonesty please refer to the academic judiciary website at:
http://www.stonybrook.edu/commcms/academic_integrity/index.html

Critical Incident Management Statement
Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of University Community Standards any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn. Faculty in the HSC Schools and the School of Medicine are required to follow their school-specific procedures. Further information about most academic matters can be found in the Undergraduate Bulletin, the Undergraduate Class Schedule, and the Faculty-Employee Handbook.

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