UNIVERSITY OF MARYLAND

Introduction to Quantum Mechanics: A Linear Algebra Approach (PHYS 360)

Term: *Fall/2024*
Professor: Robert Hilborn
Pronouns: he, him, his
Office Phone: 301-405-1000 (PSC 3109)
Email: rhilborn@umd.edu
Office Hours: TBD
Credits: 3
Course Dates: August 27 – December 5, 2024
Course Times: Tue.-Thur. 2:00 – 3:15 pm
Classroom: Hornbake 1108

Teaching Assistant:
Pronouns:
Email:
Office Hours:

Course Description

This course provides an introduction to quantum mechanics with a focus on applications in quantum information science and quantum computing. The course is designed for computer science, computer engineering, math majors, and others without previous college-level physics preparation. Some familiarity with linear algebra is assumed, but we will review the details as needed. This course is designed to be a gateway course for UMD's new Quantum Science and Technology Minor. It will also work well as a stand-alone course for those who want a taste of quantum computing and quantum information science and an introduction to quantum mechanics.

Learning Outcomes

After successfully completing this course, you will be able to:

- Explain the general principles of quantum information science and quantum computing in terms of the principles of quantum mechanics.
- Explain how quantum information science and quantum computing exploit the fundamental principles of quantum mechanics and why those principles allow for computational and information processing in ways not practical for classical computers.
- Explain quantum operations in terms of linear transformations and related concepts in linear algebra for several quantum systems currently used in quantum information science and quantum computing.
- Derive and explain the results of simple quantum circuits acting on input states by using matrices and column vectors as well as more abstract linear algebra relationships.

Required Resources

- Course Website: elms.umd.edu
- Book: *Quantum Physics for Quantum Computing: A Linear Algebra Approach* by R. Hilborn and A. Flarend. Draft (2024). Available on elms at no charge.
- No specific application/software packages are needed for this course.
- Total Estimated costs of required course materials: $0

Course Structure

This course will meet twice per week—Tuesdays and Thursdays 2:00-3:15 pm. The class meetings will consist of brief presentations by the instructor mixed with active participation by students. The student activities will include think-pair-share short questions, brief exercises, and group problem-solving. Help (Q&A) session(s) will be scheduled beginning in the second week of the semester.

Students will be expected to complete course readings before each class. There will be an opportunity to raise questions and make comments that will help shape what is discussed in class.

There will be weekly homework assignments. You are encouraged to work with other students in the class in completing the assignments, but you are expected to write your own explanations about how you solved the problems.

Near the end of the course, each student (perhaps working with other students) will complete a short project using the IBM QISKIT system and then writing a brief project report. This project will give you experience programming and running a quantum computer through a web browser.

Tips for Success

1. **Participate.** I invite you to engage deeply, ask questions, and talk about the course content with your classmates. You can learn a great deal from discussing ideas and perspectives with your peers and professor. Participation can also help you articulate your thoughts and develop critical thinking skills.
2. **Manage your time.** Students are often very busy, and I understand that you have obligations outside of this class. However, students do best when they plan adequate time that is devoted to course work. Block your schedule and set aside plenty of time to complete assignments including extra time to handle any technology related problems.
3. **Login regularly.** I recommend that you log in to ELMS-Canvas several times a week to view announcements, discussion posts and replies to your posts.
4. **Do not fall behind.** This class moves at a quick pace and each week builds on the previous content. If you feel you are starting to fall behind, check in with the instructor as soon as possible so we can troubleshoot together. It will be hard to keep up with the course content if you fall behind early in the term.
5. **Use ELMS-Canvas notification settings.** Pro tip! Canvas ELMS-Canvas can ensure you receive timely notifications in your email or via text. Be sure to enable announcements to be sent instantly or daily.
6. **Ask for help if needed.** If you need help with ELMS-Canvas or other technology, please contact IT Support. If you are struggling with a course concept, reach out to me and your classmates for support.

Policies and Resources for Undergraduate Courses

It is our shared responsibility to know and abide by the University of Maryland's policies that relate to all courses, which include topics like:

- Academic integrity
- Student and instructor conduct
- Accessibility and accommodations

- Attendance and excused absences
- Grades and appeals
- Copyright and intellectual property

Please visit www.ugst.umd.edu/courserelatedpolicies.html for the Office of Undergraduate Studies' full list of campus-wide policies and follow up with me if you have questions.

Course Guidelines

Names/Pronouns and Self-Identifications:

The University of Maryland recognizes the importance of a diverse student body, and we are committed to fostering inclusive and equitable classroom environments. I invite you, if you wish, to tell us how you want to be referred to in this class, both in terms of your name and your pronouns (he/him, she/her, they/them, etc.). Keep in mind that the pronouns someone uses are not necessarily indicative of their gender identity. Visit trans.umd.edu to learn more.

Additionally, it is your choice whether to disclose how you identify in terms of your gender, race, class, sexuality, religion, and dis/ability, among all aspects of your identity (e.g., should it come up in classroom conversation about our experiences and perspectives) and should be self-identified, not presumed or imposed. I will do my best to address and refer to all students accordingly, and I ask you to do the same for all your fellow Terps.

Communication with Instructor:

Email: If you need to reach out and communicate with me, please email me at rhilborn@umd.edu. Please DO NOT email me with questions that are easily found in the syllabus or on ELMS (i.e. When is this assignment due? How much is it worth? etc.) but please DO reach out about personal, academic, and intellectual concerns/questions. I will do my best to respond to emails within 24 hours.

ELMS: I will send IMPORTANT announcements via ELMS messaging. You must make sure that your email & announcement notifications (including changes in assignments and/or due dates) are enabled in ELMS so you do not miss any messages. You are responsible for checking your email and Canvas/ELMS inbox regularly.

Communication with Peers:

With a diversity of perspectives and experience, we may find ourselves in disagreement and/or debate with one another. As such, it is important that we agree to conduct ourselves in a professional manner and that we work together to foster and preserve a virtual classroom environment in which we can respectfully discuss and deliberate controversial questions. I encourage you to confidently exercise your right to free speech—bearing in mind, of course, that you will be expected to craft and defend arguments that support your position. Keep in mind that free speech has its limits and this course is NOT the space for hate speech, harassment, and derogatory language. I will make every reasonable attempt to create an atmosphere in which each student feels comfortable voicing their argument without fear of being personally attacked, mocked, demeaned, or devalued.

Any behavior (including harassment, sexual harassment, and racially and/or culturally derogatory language) that threatens this atmosphere will not be tolerated. Please alert me immediately if you feel threatened, dismissed, or

silenced at any point during our semester together and/or if your engagement in discussion has been in some way hindered by the learning environment.

Major Assignments

Homework Assignments

- Short questions and problems based on recent classroom work and readings.
- We will discuss the homework assignment schedule and procedures during the first week of classes.

Pre-class Reading

- You should complete the reading assignment before each class. The textbook is designed to introduce you to the concepts and provide examples. The class presentations will assume that you have read the material in the textbook and are ready for probing the concepts and their applications more deeply. You will also have an opportunity to submit questions or comments that will help shape the discussion in that class.

Participation & Engagement

- Active participation in class activities is expected.
- Completion of the pre-class reading is expected.

Mid-semester Exams

- We will have two mid-semester exams meant to provide you (and the instructor) with feedback about how you are doing with the course material. The exams will be based on selected Try Its (brief exercises found in the textbook). Details will be provided later in the semester. These two exams will be given during class time. Please see the course schedule below.

End-of-the semester Project

- As mentioned above, at the end of the semester you will complete a brief project programming and running a quantum computer through the IBM QUISKIT system. Details will be provided later in the semester. The report for the project will be due about 10 days before the end of the semester.

Final Exam

- We will have a final exam during the final exam period. The final exam will be based on selected Try Its (brief exercises found in the textbook). Final exam date to be determined by the University.

Grading Structure

Assignment	Percentage %
Homework	**20%**
Participation/Engagement	**20%**
Mid-semester Exams	**20% (10% each)**
End-of-the-semester Project and Report	**10%**
Final Exam	**30%**
Total	**100%**

Academic Integrity

For this course, some of your assignments will be collected via Turnitin on our course ELMS page. I have chosen to use this tool because it can help you improve your scholarly writing and help me verify the integrity of student

work. For information about Turnitin, how it works, and the feedback reports you may have access to, visit Turnitin Originality Checker for Students

The University's Code of Academic Integrity is designed to ensure that the principles of academic honesty and integrity are upheld. In accordance with this code, the University of Maryland does not tolerate academic dishonesty. Please ensure that you fully understand this code and its implications because all acts of academic dishonesty will be dealt with in accordance with the provisions of this code. All students are expected to adhere to this Code. It is your responsibility to read it and know what it says, so you can start your professional life on the right path. **As future professionals, your commitment to high ethical standards and honesty begins with your time at the University of Maryland.**

It is important to note that course assistance websites, such as CourseHero, or AI-generated content are not permitted sources unless the instructor explicitly gives permission. Material taken or copied from these sites can be deemed unauthorized material and a violation of academic integrity. These sites offer information that might be inaccurate or biased and most importantly, relying on restricted sources will hamper your learning process, particularly the critical thinking steps necessary for college-level assignments.

Additionally, students may naturally choose to use online forums for course-wide discussions (e.g., Group lists or chats) to discuss concepts in the course. However, collaboration on graded assignments is strictly prohibited unless otherwise stated. Examples of prohibited collaboration include: asking classmates for answers on quizzes or exams, asking for access codes to clicker polls, etc. Please visit the **Office of Undergraduate Studies' full list of campus-wide policies** and reach out if you have questions.

Finally, on each exam or assignment you must write out and sign the following pledge: ***"I pledge on my honor that I have not given or received any unauthorized assistance on this exam/assignment."*** If you ever feel pressured to comply with someone else's academic integrity violation, please reach out to me straight away. Also, ***if you are ever unclear*** about acceptable levels of collaboration, ***please ask***! To help you avoid unintentional violations, ***the following table*** lists levels of collaboration that are acceptable for each graded exercise. Each assignment will contain more specific information regarding acceptable levels of collaboration.

						
Homework Assignments	✓	✓	✓	---	✓	✓
Pre-class Quizzes	✓	✓	✓	---	✓	✓
Mid-semester Exams	✓					
Final Project	✓	✓	✓	✓	✓	✓
Final Exam	✓		---	---	---	---

Grades

I will be using a performance-based grading system. That means that the grading system is not competitive. If performance standards are met, all the students in the course could receive an A. Also, I recognize that all students have their own paces and styles of learning. For a performance-based system, the important point is your overall performance at the end of the semester. There will be multiple opportunities to get credit for revising homework solutions and missed questions on exams. I will work closely with you to help you attain the highest performance level. Once classes are underway, I will explain in more detail how the performance-based system will work.

All assessment scores will be posted on the course ELMS page. If you would like to review any of your grades (including the exams), or have questions about how something was scored, please email me to schedule a time for us to meet and discuss.

Late work will not be accepted for course credit so please plan to have it submitted well before the scheduled deadline. I am happy to discuss any of your grades with you, and if I have made a mistake, I will immediately correct it. Any formal grade disputes must be submitted in writing and within one week of receiving the grade. Final letter grades are assigned based on the percentage of total assessment points earned. To be fair to everyone I need to establish clear standards and apply them consistently, so please understand that being close to a cutoff is not the same as making the cut (89.99 ≠ 90.00). It would be unethical to make exceptions for some and not others.

Final Grade Cutoffs									
+	97.00%	+	87.00%	+	77.00%	+	67.00%	+	
A	94.00%	B	84.00%	C	74.00%	D	64.00%	F	<60.0%
-	90.00%	-	80.00%	-	70.00%	-	60.00%	-	

Course Outline

Week	Tuesday	Thursday	Comments
1 8/27-29	Introduction and overview Quantum states and polarized light	State vectors, state space, operators, matrices, column vectors	1st day of classes 8/26 Preface and Chapters 1-4
2 9/3-5	Qubits and polarized light, scalar products, orthogonality, normalization	Quantum measurements and probability	9/2 – Labor Day Chapters 4 and 5
3 9/10-12	Quantum gates and circuits	More gates and circuits	Chapter 6
4 9/17-19	Spin-1/2 systems, Bloch sphere, Uncertainty Relations	Changing basis states Three polarizer experiment	Chapters 7 & 8
5 9/24-26	Encryption protocols	**Exam #1**	Chapter 8
6 10/1-3	Multi-qubit states	Multi-bit states and entanglement	Chapter 9
7 10/8-10	Multi-qubit states and operators	Entanglement and correlations	Chapter 9
8 10/15-17	Multi-qubit gates No cloning theorem	Multi-qubit applications Quantum state teleportation	Chapter 10
9 10/22-24	Multi-qubit Hadamard gates Quantum algorithms Grover algorithm	Error correction	Chapters 11, 12, 13
10 10/29-31	RSA Encryption Shor algorithm Quantum Fourier Transform	**Exam #2**	Chapter 14, 15
11 11/5-7	Bell's Theorem	Time dependence in quantum mechanics	Chapter 17, 18
12 11/19-21	Magnetic precession and resonance	Magnetic precession and resonance	Chapter 19

13 11/19-21	Programming quantum computers	Number operators and ladder operators Quantum harmonic oscillator	Chapter 16, 20, 21
14 11/26	Quantum harmonic oscillator	**Thanksgiving Day**	Thanksgiving Break 11/27-12/1 Chapter 21
15 12/3-5	Density operators	Density operators and Mixed States	Project Reports due 12/2 Last day of classes 12/9 Chapter 22
			Final Exams 12/11-17 Date TBD by University

Note: This is a tentative schedule, and subject to change as necessary – monitor the course ELMS page for current deadlines. In the unlikely event of a prolonged university closing, or an extended absence from the university, adjustments to the course schedule, deadlines, and assignments will be made based on the duration of the closing and the specific dates missed.

Resources & Accommodations

Accessibility and Disability Services

The University of Maryland is committed to creating and maintaining a welcoming and inclusive educational, working, and living environment for people of all abilities. The University of Maryland is also committed to the principle that no qualified individual with a disability shall, on the basis of disability, be excluded from participation in or be denied the benefits of the services, programs, or activities of the University, or be subjected to discrimination. The **Accessibility & Disability Service (ADS)** provides reasonable accommodations to qualified individuals to provide equal access to services, programs and activities. ADS cannot assist retroactively, so it is generally best to request accommodations several weeks before the semester begins or as soon as a disability becomes known. Any student who needs accommodations should contact me as soon as possible so that I have sufficient time to make arrangements.

For assistance in obtaining an accommodation, contact Accessibility and Disability Service at 301-314-7682, or email them at **adsfrontdesk@umd.edu**. Information about **sharing your accommodations with instructors, note taking assistance** and more is available from the **Counseling Center**.

Student Resources and Services

Taking personal responsibility for your own learning means acknowledging when your performance does not match your goals and doing something about it. I hope you will come talk to me so that I can help you find the right approach to success in this course, and I encourage you to visit **UMD's Student Academic Support Services website** to learn more about the wide range of campus resources available to you.

In particular, everyone can use some help sharpening their communication skills (and improving their grade) by visiting **UMD's Writing Center** and schedule an appointment with the campus Writing Center.

You should also know there are a wide range of resources to support you with whatever you might need (**UMD's Student Resources and Services website** may help). If you feel it would be helpful to have someone to talk to, visit **UMD's Counseling Center** or **one of the many other mental health resources on campus**.

Notice of Mandatory Reporting

Notice of mandatory reporting of sexual assault, sexual harassment, interpersonal violence, and stalking: As a faculty member, I am designated as a "Responsible University Employee," and I must report all disclosures of sexual assault, sexual harassment, interpersonal violence, and stalking to UMD's Title IX Coordinator per University Policy on Sexual Harassment and Other Sexual Misconduct.

If you wish to speak with someone confidentially, please contact one of UMD's confidential resources, such as CARE to Stop Violence (located on the Ground Floor of the Health Center) at 301-741-3442 or the Counseling Center (located at the Shoemaker Building) at 301-314-7651.

You may also seek assistance or supportive measures from UMD's Title IX Coordinator, Angela Nastase, by calling 301-405-1142, or emailing titleIXcoordinator@umd.edu.

To view further information on the above, please visit the Office of Civil Rights and Sexual Misconduct's website at ocrsm.umd.edu**.**

Basic Needs Security

If you have difficulty affording groceries or accessing sufficient food to eat every day, or lack a safe and stable place to live, please visit **UMD's Division of Student Affairs website** for information about resources the campus offers you and let me know if I can help in any way.

Veteran Resources

UMD provides some additional supports to our student veterans. You can access those resources at the office of Veteran Student life and the Counseling Center. Veterans and active duty military personnel with special circumstances (e.g., upcoming deployments, drill requirements, disabilities) are welcome and encouraged to communicate these, in advance if possible, to the instructor.

Participation

- Given the interactive style of this class, attendance will be crucial to note-taking and thus your performance in this class. Attendance is particularly important also because class discussion will be a critical component for your learning.
- Each student is expected to make substantive contributions to the learning experience, and attendance is expected for every session.
- Students with a legitimate reason to miss a live session should communicate in advance with the instructor, except in the case of an emergency.
- Students who miss a live session are responsible for learning what they miss from that session.
- Additionally, students must complete all readings and assignments in a timely manner to fully participate in class.

Course Evaluation

Please submit a course evaluation through Student Feedback on Course Experiences to help faculty and administrators improve teaching and learning at Maryland. All information submitted to Course Experiences is confidential. Campus will notify you when Student Feedback on Course Experiences is open for you to complete your evaluations at the end of the semester. Please go directly to the **Student Feedback on Course Experiences** to complete your evaluations. By completing all of your evaluations each semester, you will have the privilege of

accessing through Testudo the evaluation reports for the thousands of courses for which 70% or more students submitted their evaluations.

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