PHY 390 – Quantum Mechanics

Fall 2023

Instructor:	Rafid Mahbub	**Time:**	M T W Th F 10:30 – 11:20 am
Email:	mahbub@gustavus.edu	**Place:**	Olin 219

Course Pages: Moodle class page

Office Hours: I am flexible with office hours. You can drop by Olin 212 anytime as long as I am in the office. I usually take lunch break from 12:30 to 1:30 pm. So there is a big chance that I will not be available during that one hour.

Lectures and weekly work: The class will meet five times a week for 50 minutes at 10:30 am. The first four meetings of the week will consist of lectures while Fridays will be reserved for weekly problem solving sessions and the midterm exam. The Friday problem solving session will consist of one or two problems that you are encouraged to solve as groups. If the opportunity arises, we may also spend one or two of these sessions learning how to numerically solve the Schrödinger equation and simulate simple quantum systems. There will be one problem set uploaded every Friday (roughly), which will be due the next Friday. The problem sets will contain four to six problems that will form the core of this course – both in terms of learning and grade allotment. The problems will be based on the content of the particular week and may often involve excursions into sub fields of physics where quantum mechanics is heavily applied.

Although you are required to hand in your own homework solutions, you are encouraged to work with your peers. In this way, you will learn the content of the problem sets most effectively. To aid me in grading, you are advised to show as much calculation detail as possible. More often than not, you will be able to tell which steps are redundant. However, setting up a complicated integral and arriving at its result in the following line will look suspicious. Sometimes integrals, and similar objects, might be too complicated to necessitate the use of known results, in which case it is perfectly fine. You are encouraged to use Mathematica to check whether your answer is correct. However, the priority must always be on arriving at a solution by hand.

Main References: The lectures will follow the notes that have been uploaded to Moodle. The sequence of the notes largely follows that of the first, and main, reference.

- A Modern Approach to Quantum Mechanics – John S. Townsend **(required)**
- Introduction to Quantum Mechanics – David J. Griffiths
- David Tong: Lectures on Quantum Mechanics

David Tong's lecture notes come highly recommended. His webpage also contains lecture notes on numerous other physics courses that he has taught over the years at DAMTP Cambridge, some of which might be of interest to you.

Objectives: The primary objective of this course is to learn 'how to do quantum mechanics'. As such, the course will heavily rely on the development of mathematical tools (mostly linear and operator algebra) to study, analytically solve and interpret simple quantum systems. Of primary interest will be learning how to handle quantum states and use them to compute quantities of interest, such as those which turn out to be outcomes of measurement processes, all the while developing intuition behind the mathematical structures that are used to describe them. Since the core of quantum mechanics, even at an introductory level, relies on linear algebra (both finite dimensional and functional cases), some familiarity with the subject is expected. However, we will have ample opportunity to review all the necessary mathematical components.

To aid in understanding quantum mechanics and learning how to do it, reading and problem solving are mandatory exercises. Quantum mechanics feels like learning how to use a new tool and you are expected to get better by repeated exposure. It is also a subject that can confuse you to no end, especially if you are inclined to explore the more philosophical aspects of the subject. As a result, we will forgo such discussions and focus on what is important for a practical course on quantum mechanics.

Prerequisites: The essential prerequisites for this course are PHY 225 (Quantum Universe) and PHY 370 (Advanced Mathematical Methods). Moreover, you will often require some classical mechanics and electromagnetism, but a thorough review in these is not required. Above and beyond course prerequisites, what is most important is 'maturity'.

Tentative Course Outline: The following is only a tentative outline of the course. Completion of the different sections each week will depend on many factors.

- **Week 1 (09/04 to 09/10):** Stern-Gerlach experiment; preliminary mathematical formalism; spin-1/2 systems
- **Week 2 (09/11 to 09/17):** Spin-1/2 systems continued; rotations and matrix mechanics
- **Week 3 (09/18 to 09/24):** Matrix mechanics continued; more mathematical formalism; angular momentum
- **Week 4 (09/25 to 10/01):** Angular momentum algebra with more focus on spin-1/2 systems
- **Week 5 (10/02 to 10/08):** Quantum dynamics; time evolution of two-state quantum systems, studying magnetic resonance and ammonia molecule as examples
- **Week 6 (10/09 to 10/15):** Introduction to tensor product states; multiparticle spin-1/2 systems with an emphasis on two-particles; the hyperfine effect
- **Week 7 (10/16 to 10/22):** Addition of angular momentum; entanglement and EPR; Midterm on Friday the 20th; Fall break starts on the 21st
- **Week 8 (10/23 to 10/29):** Fall break ends on the 24th; Wave mechanics in position and momentum basis; some basic functional analysis with differential operators; Schrödinger equation
- **Week 9 (10/30 to 11/05):** Wave mechanics continued; bound and scattering states in simple potentials
- **Week 10 (11/06 to 11/12):** The harmonic oscillator; solutions using operator algebra and Schrödinger equation; the classical limit
- **Week 11 (11/13 to 11/19):** Quantum mechanics in three dimensions; introduction to orbital angular momentum and its algebra
- **Week 12 (11/20 to 11/26):** Central potentials and the hydrogen atom; Thanksgiving
- **Week 13 (11/27 to 12/03):** Solution of the three dimensional Schrödinger equation in Coulomb potential; hydrogen atom orbitals and their visualization

- **Week 14 (12/04 to 12/10):** Time-independent perturbation theory (contingent upon completion of the previous topics)
- **Week 15 (12/11 to 12/17):** Review and take home final

Grading and evaluation: The grading scheme for the course is: problem sets (30%), midterm (30%) and take home final (40%). The letter grade boundaries are: A ($> 90\%$), A- ($\geq 85\%$ to $< 90\%$), B+ ($\geq 80\%$ to $< 85\%$), B ($\geq 75\%$ to $< 80\%$), B- ($\geq 70\%$ to $< 75\%$), C+ ($\geq 65\%$ to $< 70\%$), C ($\geq 60\%$ to $< 65\%$), C- ($\geq 55\%$ to $< 60\%$), D+ ($\geq 50\%$ to $< 55\%$), D ($\geq 45\%$ to $< 50\%$) and F ($< 45\%$)

The midterm exam will be held on week 7 during class hours. The final exam will be take home. Upon deciding on a date, the final exam questions will be made public in Moodle. You will be able to work on the solutions the entire day, being able to use additional resources like your notes and previous problem sets. The solutions should be turned in to my box in the mailroom the following day by 10 am. The final exam problems will be similar to homework problem sets. But there will be multiple problems given that you will have an entire day to finish writing the solutions.

Attendance: You are expected to regularly attend all the classes. You will be responsible for missing important announcements/deadlines in the event of absences.

Incomplete: In the event of extenuating circumstances preventing you from meeting homework submission deadlines or sitting for exams, you will be given an incomplete grade.

Academic Honesty: Having signed and agreed to abide by the College's Honor Code, students thereby pledge that, in all academic exercises, examinations, papers, and reports, they shall submit their own work. In the context of this course, students are expected to collaborate and to discuss their out-of-class assignments. However, submitting under one's own name work that is merely copied from another is a violation of the Honor Code. Furthermore, seeking outside assistance during exams is expressly forbidden. A full description of the Academic Honesty Policy and the Honor Code can be found in the Academic Catalog.

Requesting Accomodations: Gustavus Adolphus College is committed to ensuring equitable and inclusive learning environments for all students. If you have a disability and anticipate or experience barriers to equal access, please speak with the accessibility resources staff about your needs. A disability may include mental health, attentional, learning, chronic health, sensory, physical, and/or short-term conditions. Students with a documented elevated risk of COVID-19 may also request academic accommodations. When appropriate, staff will guide students and professors in making accommodations to ensure equal access. Accommodations cannot be made retroactively; therefore, to maximize your academic success at Gustavus, please contact them as early as possible. Accessibility resources staff are located in the Academic Support Center (https://gustavus.edu/asc/accessibility/). Accessibility Resources Coordinator, Katy Clay, (clayk@gustavus.edu), can provide further information.

Mental Wellbeing: The Gustavus community is committed to and cares about all students. Strained relationships, increased anxiety, alcohol or drug problems, feeling down, difficulty concentrating, and/or lack of motivation may affect a student's academic performance or reduce a student's ability to participate in daily activities. If you or someone you know expresses such mental health concerns or experiences a stressful event that can create barriers to learning, Gustavus services are available to assist you, and include online options. You can learn more about the broad range of confidential health services available at https://gustavus.edu/counseling/ and https://gustavus.edu/deanofstudents/services/.