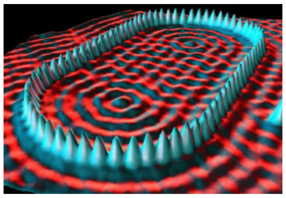
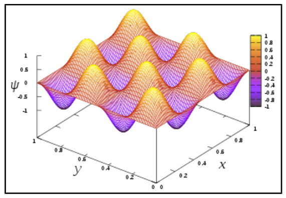
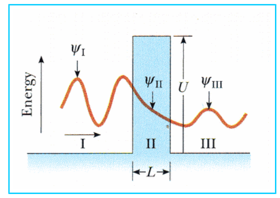
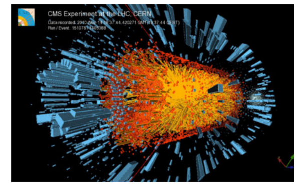
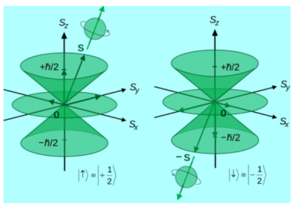
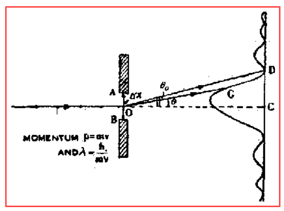
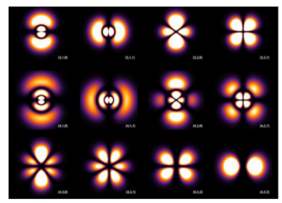
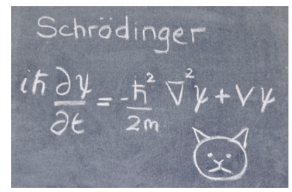






Physics 351
Quantum Theory

Fall Semester, 2020

Instructor:

Brooks Thomas
Email: thomasbd@lafayette.edu
Office: Hugel 020
Phone: (610) 330-5207

General Course Information

If you are already enrolled in this course, its central topic – quantum mechanics – is a subject about which you already know a great deal. In particular, in your Phys 215 course ("Introduction to Quantum Mechanics"), you followed the historical development of quantum mechanics and explored how phenomena like the photoelectric effect and the patterns of emission/absorption lines in atomic spectra compelled us to accept its strange and often counterintuitive implications. You also explored many of the *applications* of quantum mechanics – from the structure of chemical bonds to the radioactive decay of heavy elements to the bulk properties of matter in the solid state.

In this course, you will delve even deeper into quantum mechanics – from a *theoretical* perspective. In the process, you will be introduced, piece by piece, the full mathematical machinery necessary to characterize the dynamics of the wavefunction. For your efforts, you will be rewarded with a host of new insights into the way the world works at its most fundamental level. In particular, by the end of this course, you'll understand the fundamental differences between classical and quantum mechanics. You'll be able to formulate the equation of motion (the Schrödinger Equation) for different physical systems and solve this equation in order to describe the state of the system and predict how (and whether) it will evolve in time. In addition, you will also get a chance to hone some of the universal skills that transcend the subject matter and are crucial in practically *any* science field. For example, by the end of this course, you'll be able to reason through problems at a more sophisticated level, to communicate your reasoning to an audience of your peers, and to apply computational tools such as Mathematica and Python in order to solve problems numerically that cannot be solved analytically.

The requirements for this course include Phys 215 ("Introduction to Quantum Mechanics") and Phys 218 ("Oscillatory and Wave Phenomena"), as well as an understanding of multi-variable calculus, linear algebra, and the strategies for solving differential equations at the level of Math 264. However, we will also review many of the mathematical topics along these lines when we need them.

Components of the Course

The course will consist of class meetings, reading assignments in the text, problem sets, two mid-term exams, a final exam, and a final presentation. These are described more fully below.

Class Meetings:

Class meetings will be held from **8:00 AM – 8:50 AM Eastern Time** each Monday, Wednesday, and Friday during the semester. These meetings will all take place over the Zoom platform at the same link, which is

- https://lafayette.zoom.us/j/91454008697

The password is provided on the course Moodle. Regular attendance at these class meetings is expected. A schedule of topics to be covered each day is listed on the course web page. Much of the material covered in this course – and many of the homework problems that you'll be working through – are quite challenging. It is therefore important that you come to class prepared to ask questions and to engage in discussions. You should be aware that class meetings will involve not only my lecturing to you about the material covered in the readings (which is not necessarily the best way for me to help you learn the material), but a variety of other activities as well – the benefit you get out of which is directly proportional to the effort you put in.

I would like us to be able to simulate the atmosphere of a physical classroom to whatever extent we can under these circumstances. For this reason, I would like to ask that you have your camera on during class meetings and to use the "gallery view" option on Zoom so that we can all see each other and respond to each other's visual cues. I will do the same. That said, if there are extenuating circumstances which make having your camera on an issue for you, please reach out to me for any concerns about this expectation as soon as possible and we will work out an equitable solution. Please mute yourself when you are not speaking in order to reduce background noise. Please raise your actual hand in order to take part in the discussion until we find our rhythm. If I do not see your actual hand, please raise your "digital hand." We will review how to do this and how to use other features of Zoom during our first class meeting.

Asynchronous Fourth Hour:

The “Fourth Hour” associated with this class will be an asynchronous component involving a set of learning modules designed to prepare you for each class meeting. Each of these modules will consist of a short prerecorded lecture and some activities designed to give you a chance to check your understanding of the material presented. You are expected to complete each learning module before the corresponding class meeting, and doing so counts toward a portion of your grade in this course. However, I want to emphasize that the activities within these modules are structured such that you cannot lose points for “wrong” answers – only for not bothering to engage with them.

Textbook:

The one required textbook for this course is

- David J. Griffiths and Darrell F. Schroeter, *Introduction to Quantum Mechanics*, 3rd Ed. (Cambridge University Press, 2018).

In addition to this textbook, you may also find the following references useful for getting additional perspectives on the material we'll be covering in this course:

- John S. Townsend, *A Modern Approach to Quantum Mechanics*, 2nd Ed. (Univ Science Books, 2012).
- R. Shankar, *Principles of Quantum Mechanics*, 2nd Ed. (Plenum Press, 1994).
- Richard P. Feynman, Robert B. Leighton, and Matthew Sands, *The Feynman Lectures, Vol. III* (Addison Wesley, 1971).
- J. J. Sakurai, *Modern Quantum Mechanics*, Revised Ed. (Addison Wesley, 1993).

The first two texts are written at roughly the same level as Griffiths & Schroeter’s textbook, but simply take different approaches. The Feynman Lectures (the full text of which has also been made available for free online by Caltech) provide a unique and engaging approach to the subject from one of the greatest teachers of physics who ever lived. Sakurai's book is more advanced (it's a graduate-level text), but it's also very well written.

Finally, given the mathematical nature of the subject material and the variety of special functions we will encounter over the course of the semester, you may want to have a good reference volume on mathematical methods in physics on hand. For this, I recommend the following:

- Mary L. Boas, *Mathematical Methods in the Physical Sciences*, 3rd Ed. (Wiley, 2005).
- George B. Arfken, Hans J. Weber, and Frank E. Harris, *Mathematical Methods for Physicists*, 7th Ed. (Academic Press, 2012).

Homework Assignments:

Working through problems is an essential part of this course. There's no way of truly understanding quantum mechanics without delving in and *doing* quantum mechanics. For this reason, I will be assigning a number of homework problems each week which I feel provide practice with the most crucial aspects of the material we're covering in the course – or else, in certain cases, introduce new concepts altogether. A list of the problems included in each problem set will be provided on the course Moodle. Some of these problems will require nothing more than pen, paper, and a lot of careful thought; others will require computational resources like Mathematica or Python.

Each homework assignment is are due at 5:00 PM Eastern Time on the day indicated on the course web page (usually a Friday). Your work should be submitted in PDF format using the appropriate upload link on the course Moodle page. However, you do not need to typeset your homework in a fancy way. Writing your work out by hand on paper, scanning or photographing the pages, and converting the images to PDF format is perfectly acceptable. You may still turn in late homework for reduced credit (a 10% penalty for every 24 hours it is overdue) up until the beginning of the next class meeting. However, because we will frequently discuss homework problems during this class meeting, late homework will not be accepted after that time.

I encourage you to work together on homework problems with other students in the class. This can be a very productive way of expanding your own knowledge, and working with other people to solve problems is a big part of how science is really done. However, the work that you upload and turn in to me must be your own: it should reflect your own understanding and should be written up independently after all discussion between you and your peers is complete.

Midtern and Final Exams**:**

There will be two midterm exams given during the course, as well as a final exam at the end of the course. These tests are designed give you the opportunity to demonstrate how well you understand the material. The first midterm exam will be made available on the course Moodle at the end of class (8:50 AM Eastern Time) on Wednesday, Sept. 23rd and is due at the beginning of class (8:00 AM Eastern Time) **on Friday, Sept. 25th at 5:00 PM Eastern Time**. The second will be distributed at the end of class (8:50 AM Eastern Time) on Monday, Nov. 2nd and is due at the beginning of class (8:00 AM Eastern Time) on **Wednesday, Nov. 4th At 5:00 PM Eastern Time**. The final exam will be made available on the course Moodle on Tuesday, Dec 1st at 8:00 AM Eastern Time and is due by 8:00 PM Eastern Time on **Thursday, Dec. 3rd at 5:00 PM Eastern Time**. As with homework assignments, you will turn in your work on each completed exam in PDF format via an upload link on the course Moodle page.

Final Presentation:

In addition to the homework and the exams, I also want you to have the opportunity to explore your own interests and to gain a deeper appreciation of the quantum-mechanical principles that we're covering in this course. To that end, you will be undertaking a final presentation in this course in which you will delve more deeply into a of your own choosing. Public presentations are a part of just about every career in science and engineering – and in a lot of other situations in life as well – so getting practice preparing and giving one will be valuable no matter what you want to do.

Your presentation topic must be related to the quantum-mechanical principles we're covering in class. It can focus on an application of those principles to a particular physical system, for example, or on an alternative mathematical approach to a particular problem. It also must be a topic which lends itself to a sophisticated mathematical treatment at a level appropriate for this course. Beyond that, you are free to choose whatever presentation topic interests you. You will need to approve your presentation topic with me **by Monday, Oct. 26th**. If you're not sure what topic you'd like to pursue, I would be happy to meet with you and discuss possible ideas before that date.

Your presentation will be delivered to other members of the class over Zoom during our class meetings on either **Wednesday, Nov. 16th or Friday, Nov. 18th**. It must be a slide-based presentation (created using PowerPoint, Keynote, OOImpress, Beamer, etc.), and should be approximately 15 minutes in length. You should be sure to include a bibliography or list of works cited on your final slide. In addition to the presentation itself, you will also need to submit a formal abstract for your presentation, which will be due on Wednesday, Nov. 11th by 5:00 PM Eastern. As with homework assignments, you will turn in your abstract in PDF format via an upload link on the course Moodle page. I strongly encourage you to meet with me ahead of time to discuss both your presentation and your abstract.

Office Hours:

My official office hours this semester will be held on **Mondays from 9:00 – 10:00 AM Eastern, Tuesdays and Wednesdays from 3:00 – 4:00 PM Eastern, and Fridays from 1:00 – 2:00 PM Eastern** unless otherwise noted on the course web page. What this means in a distance-learning context is that I will have a Zoom meeting open during each of those time windows, and you should feel free to join the meeting at any time within those windows if you have questions about any aspect of the course. The link for this office-hours Zoom meeting is

- https://lafayette.zoom.us/j/99772595796

The password is provided on the course Moodle. Please note that this is a different link from the one we will be using for class meetings. The reason is that these office hours are open to students from all courses I am currently teaching. If I am meeting with another student at the time you join the Zoom meeting, I may ask you to wait in the waiting room for a bit. However, if you and other students in the course have the same question, you can certainly meet with me as a group.

If you are unable to drop by during these official office hours, you may also email me to make an appointment to meet at some other time. However, I recommend that you do this as far in advance as possible in order to ensure that we can find a time to meet.

Grading and the Honor Code

Course Grade:

Your grade in the course will be determined by the following criteria:

Homework	24%
Pre-Class Learning Modules	6%
Mid-Term Exam 1	16%
Mid-Term Exam 2	16%
Final Presentation (Including Abstract)	14%
Final Exam	24%

Intellectual Honesty:

When studying, or working on homework problems, I encourage you to work with other students. However, you may not consult a solutions manual or any other source for answers to the problems, and the final problem write-ups should be your own work. You are not permitted to work together on the take-home exams or to consult with anyone else about them until all exams have been turned in. However, while working on a take-home exam, you may freely refer to the textbook (Griffiths & Schroeter's *Introduction to Quantum Mechanics*), your notes, all handouts and other materials distributed in class, and a table of integrals. You may also use a graphing calculator and Wolfram Mathematica.

As always, you are expected to abide by the principles of intellectual honesty and academic integrity outlined in the Lafayette Student Handbook, which can be found at

- https://conduct.lafayette.edu/student-handbook/

Other Useful Information

Accessibility Services:

In compliance with Lafayette College policy and equal access laws, I am available to discuss appropriate academic accommodations that you may require as a student with a disability. If you are requesting accommodations, you must register with the Accessibility Services Office (administered by the Academic Resource Hub) for disability verification and for the determination of reasonable academic accommodations. Accessibility Services will then provide me with a document which outlines what those accommodations are. I cannot provide accommodations until I receive such a letter. Requests for academic accommodations must be made within the first two weeks of the semester, except in unusual circumstances, so that suitable arrangements can be made in a timely manner.

Informal Surveys:

As the semester progresses, I want to hear from you how you feel the course is going, what you like, what you don't like, what your concerns are, and how you think the course could be improved. Therefore, throughout the semester, you'll have the opportunity to fill out short surveys and informal evaluations on the course Moodle so I can get your feedback.

Course Communication:

This syllabus, a list of assigned readings and problem sets, and other course materials will be posted on the course web page, which can be found at

- http://workbench.lafayette.edu/~thomasbd/Phys351-QuantumTheory-Fall-2020/Phys351-QuantumTheory-Fall-2020.html

In addition to the course web page, there is also a Moodle page for this course which I will frequently use in distributing course materials, communicating with the class, etc. The Moodle page can be found at

- https://moodle.lafayette.edu/course/view.php?id=18750

Occasionally, it may be necessary for me to communicate additional information (scheduling changes, clarifications about homework problems, etc.) to the class as a whole. When I do so, I will use your official Lafayette email addresses for all course-related correspondence, so make sure to check your Lafayette email regularly.

Privacy Statement Concerning Course Materials and Classroom Recordings:

At Lafayette College, all course materials are proprietary and for class purposes only. This includes posted recordings of lectures, worksheets, discussion prompts, and other course items. Reposting such materials or distributing them through any means is prohibited. Such materials should not be reposted or distributed through any means. You must request my permission prior to creating your own recordings of class materials, and any recordings are not to be shared or posted online even when permission is granted to record. Permission will be granted only when sanctioned as an academic accommodation in an official letter from the Accessibility Services Office. If you have any questions about proper usage of course materials please ask me. Please also be in contact with me if you have any concerns with being recorded during the course.

Online discussions in Moodle occurring during synchronous class sessions should also remain private and not be shared outside of the course. Courses using Moodle will make student information visible to other students in this class. Student information in courses is protected by the Family Educational Right to Privacy Act (FERPA). Disclosure of student information to unauthorized parties violates federal privacy laws and it must not be shared with anyone outside the class. Questions can be referred to the Registrar's Office.

Mandatory Credit-Hour Statement:

The student work in this course is in full compliance with the federal definition of a four-credit-hour course. The full policy and practice statement can be found on the Registrar's Office website at

- http://registrar.lafayette.edu/additional-resources/cep-course-proposal/

In Closing

On a final note, I want to make it clear that I'm aware of how difficult learning can be in such difficult and unpredictable times. I will do my best to be flexible in light of the complex and varied situations that you are facing, and I ask that you be open with me about these situations and alert me to any issues that arise. I will likewise let you know if my own circumstances change and will do my best to communicate any changes to the course schedule (or to any other aspect of the syllabus) to all of you in a timely manner.

Despite all of this temporary uncertainty, we have a rewarding semester ahead of us in which we'll be grappling with the more fundamental uncertainties of quantum mechanics. True, the material we will be covering is challenging and quite abstract; however, it is also immensely rewarding. Quantum mechanics is the foundation upon which particle physics, solid-state physics, modern optics, and many other subfields of physics are built, and the basic philosophical questions it raises are as intriguing as its practical applications.

Course Schedule

The full, up-to-date schedule for the course, including due date for all assignments is available on the course web page.

Week	Topics and Readings	Due Dates
Week 1 8/17 – 8/21	**Probability and the Wavefunction** Griffiths & Schroeter: Ch. 1.1 – 1.6	HW0 (Due 8/21)
Week 2 8/24 – 8/29	**The Schrodinger Equation in 1D** Griffiths & Schroeter: Ch. 2.1 – 2.2, 2.4, 2.6	HW1 (Due 8/29)
Week 3 8/31 – 9/4	**Potential Barriers and the Harmonic Oscillator** Griffiths & Schroeter: Ch. 2.3, 2.5	HW2 (Due 9/4)
Week 4 9/7 – 9/11	**Linear Algebra and Hilbert Space** Griffiths & Schroeter: Ch. 3.1 – 3.3, Appendix A	HW3 (Due 9/11)
Week 5 9/14 – 9/18	**The Generalized Statistical Interpretation** Griffiths & Schroeter: Ch. 3.4 – 3.6	HW4 (Due 8/21)
Week 6 9/21 – 9/25	**The Schrodinger Equation in 3D** Griffiths & Schroeter: Ch. 4.1.1 – 4.2.1	Midterm I (Distributed 9/23, Due 9/25)
Week 7 9/28 – 10/2	**The Hydrogen Atom** Griffiths & Schroeter: Ch. 4.2.2 – 4.3.1	HW5 (Due 10/2)
Week 8 10/5 – 10/9	**Angular Momentum and Spin** Griffiths & Schroeter: Ch. 4.3.2 – 4.4.2	HW6 (Due 10/9)
Week 9 10/12 – 10/16	**Multi-Particle Systems and the Exclusion Principle** Griffiths & Schroeter: Ch. 4.4.3, 5.1.1 – 5.1.3	HW7 (Due 10/16)
Week 10 10/19 – 10/23	**Time-Independent Perturbation Theory** Griffiths & Schroeter: Ch. 7.1 – 7.4	HW8 (Due 10/23)
Week 11 10/26 – 10/30	**The Variational Principle** Griffiths & Schroeter: Ch. 7.5, 8.1 – 8.2	HW9 (Due 10/30) Presentation Topics
Week 12 11/2 – 11/6	**Tunneling and the WKB Approximation** Griffiths & Schroeter: Ch. 8.3, 9.1 – 9.2	Midterm II (Distributed 10/2, Due 10/4)
Week 13 11/9 – 11/13	**Time-Dependent Perturbation Theory** Griffiths & Schroeter: Ch. 9.3, 10.1, 12.1 – 12.2	HW10 (Due 11/13) Presentation Abstracts
Week 14 11/16 – 11/20	**Contemporary Topics, Final Presentations** Supplementary Readings TBA	HW11 (Due 11/20) Final Presentations
Final Exam Week		Final (Distributed 12/1, Due 12/3)