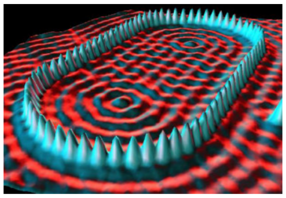
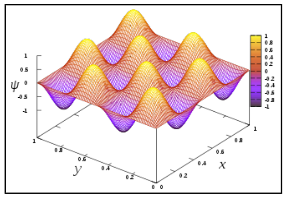
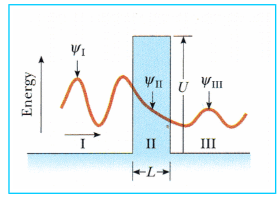
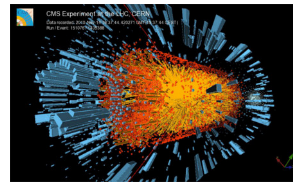
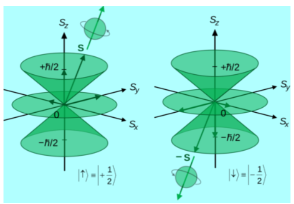
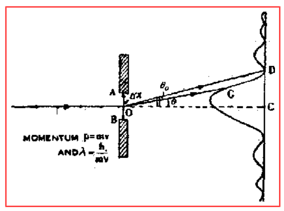
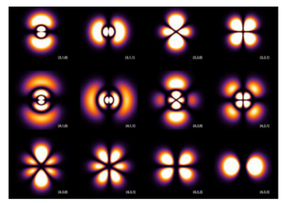
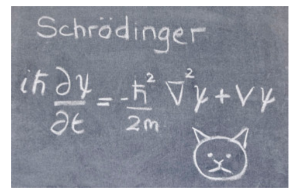







Physics 351
Quantum Theory

Fall Semester, 2021

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 **11:00 AM – 11:50 AM Eastern Time** in Hugel 017 each Monday, Wednesday, and Friday during the semester. 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.

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 – often by providing you with a first look at the material we'll be covering at the beginning of that 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. These modules are optional and do not count toward your grade in this course, but they are highly recommended for members of the class who want to get a jump-start on any given day's material.

Textbook:

The one required textbook for this course is

- David J. Griffiths and Darrell F. Schroeter, *Introduction to Quantum Mechanics*, 3nd 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).

<u>Homework Assignments</u>:

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. All of these exams will be take-home exams. The first will be made available on the course Moodle at the end of class (11:50 AM Eastern Time) on Wednesday, Oct. 6th and is due **on Friday, Oct. 8th at 5:00 PM Eastern Time**. The second will be made available on the Moodle at the end of class (11:50 AM Eastern Time) on Wednesday, Nov. 17th and is due on **Friday, Nov. 19th at 5:00 PM Eastern Time**. The final exam will be made available on the course Moodle on Tuesday, Dec 14th at 8:00 AM Eastern Time and is due by 8:00 PM Eastern Time on **Thursday, Dec. 16th 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, Nov. 8th**. 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 during our class meeting on **Friday, Dec. 10th**. 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. 22nd 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 **Tuesdays and Thursdays from**

11:00 AM – 12:00 noon Eastern, and on **Fridays from 1:00 – 2:00 PM and 4:00 – 5:00 PM Eastern** unless otherwise noted on the course web page. In order to minimize the risk of COVID-19 transmission, my office hours this semester will be held not in my office, but rather in Hugel 042, which is a larger, better ventilated room equipped with a HEPA filter. Alternatively, if you feel more comfortable attending office hours virtually, I will also have a Zoom meeting open during each of the time windows specified above. The link for this office-hours Zoom meeting is

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

The password is provided on the course Moodle. If I am meeting with another student – either in person or virtually – at the time you join this Zoom meeting, you may be placed in the waiting room for a bit before I am able to meet with you. However, if you and other students in the course have the same question, you can certainly meet with me as a group – and this applies to in-person office-hours meetings as well.

If you are unable to make it to these official office hours either virtually or in person, 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	25%
Mid-Term Exam 1	17%
Mid-Term Exam 2	17%
Final Presentation (Including Abstract)	17%
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-2021/Phys351-QuantumTheory-Fall-2021.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=21135

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.

COVID-19 Protocols:

In order to minimize the risk of COVID-19 transmission during class meetings, strict protocols will be followed. These requirements apply throughout the semester, regardless of what campus protocols happen to be in force at any given time. Any person present in the classroom during class meetings is **required to wear a mask at all times**, beginning from the moment that person enters the classroom. That mask must fit the wearer's face tightly and **cover the wearer's nose and mouth**. If your mask does not fit these criteria, you will be instructed to the classroom until you have acquired a mask that does. I urge all members of the class to wear a tightly fitting N95 (or KN95) respirator rather than a cloth mask or surgical mask in class meetings whenever possible. A cloth mask provides only limited protection, and a surgical mask provides only marginally better protection than a cloth mask. By contrast, an N95 respirator, when worn properly, provides a significant degree of protection both to you and others around you. I will be wearing an N95 mask in the classroom at all times. In accord with these precautions, eating and drinking will not be allowed during class meetings.

If you are experiencing COVID-19 symptoms and there is not a compelling alternative explanation for those symptoms (e.g., you feel fatigued because you stayed up all night working on a problem set), do not come to class meeting. Instead, inform me of the situation by email and get a COVID-19 test as soon as possible. If the test result is negative, you may attend subsequent class meetings. If the test results is positive, you are required by Lafayette protocols to isolate and may not attend class meetings until the isolation period is over. If this should occur, inform me immediately so that we can discuss how you will keep up with your work in this class during the isolation period. If you are experiencing COVID-19 symptoms and have not yet received your test result, or if you are isolation, you may attend office hours virtually, but not in person.

In the event that any member of the class adamantly refuses to abide by these safety protocols during any class meeting, class will be canceled effective immediately. The Dean of Students will be notified and all members of the class will receive instructions by email as to how and when we will make up for the rest of that class meeting.

Contingency Procedures for Virtual Class Meetings:

The default expectation is that all class meetings this semester will be held in person in Hugel 017. However, under certain circumstances (e.g., the campus closes due to a winter-weather emergency or your instructor tests positive for COVID-19 and is forced to isolate) we may temporarily be compelled to move those meetings online. If this should occur, the Zoom link that we will use for these class meetings is

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

The password is provided on the course Moodle. I will notify all members of the class by email as far in advance as possible if we need to switch to a virtual classroom environment at any point during the semester. The assumption is that if this should even happen, we will return to an in-person learning environment as soon as circumstances permit.

If we are ever temporarily forced to move to a virtual format, I would like us to be able to simulate the atmosphere of a physical classroom to whatever extent we can. For this reason, I would like to ask that you have your camera on during any virtual class meetings we end up having 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 would make having your camera on an issue for you, please reach out to me 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. If I do not see your actual hand, please raise your "digital hand."

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 challenging learning can be in such difficult and unpredictable times. I will do my best to be flexible in light of the difficult situations that you may encounter over the course of the semester, 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, the mode of instruction, etc., to all of you in a timely manner.

Despite all of this 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 8/30 – 9/3	**Probability and the Wavefunction** Griffiths & Schroeter: Ch. 1.1 – 1.6	HW0 (Due 9/3)
Week 2 9/6 – 9/10	**The Schrodinger Equation in 1D** Griffiths & Schroeter: Ch. 2.1 – 2.2, 2.4, 2.6	HW1 (Due 9/10)
Week 3 9/13 – 9/17	**Potential Barriers and the Harmonic Oscillator** Griffiths & Schroeter: Ch. 2.3, 2.5	HW2 (Due 9/17)
Week 4 9/20 – 9/24	**Linear Algebra and Hilbert Space** Griffiths & Schroeter: Ch. 3.1 – 3.3, Appendix A	HW3 (Due 9/24)
Week 5 9/27 – 10/1	**The Generalized Statistical Interpretation** Griffiths & Schroeter: Ch. 3.4 – 3.6	HW4 (Due 10/1)
Week 6 10/4 – 10/8	**The Schrodinger Equation in 3D** Griffiths & Schroeter: Ch. 4.1.1 – 4.2.1	Midterm I (Distributed 10/6, Due 10/8)
Week 7 10/11 – 10/15	**The Hydrogen Atom** Griffiths & Schroeter: Ch. 4.2.2 – 4.3.1	HW5 (Due 10/15)
Week 8 10/18 – 10/22	**Angular Momentum and Spin** Griffiths & Schroeter: Ch. 4.3.2 – 4.4.2	HW6 (Due 10/22)
Week 9 10/25 – 10/29	**Multi-Particle Systems and the Exclusion Principle** Griffiths & Schroeter: Ch. 4.4.3, 5.1.1 – 5.1.3	HW7 (Due 10/29)
Week 10 11/1 – 11/5	**Time-Independent Perturbation Theory** Griffiths & Schroeter: Ch. 7.1 – 7.4	HW8 (Due 11/5)
Week 11 1/8 – 11/12	**The Variational Principle** Griffiths & Schroeter: Ch. 7.5, 8.1 – 8.2	HW9 (Due 11/12) Presentation Topics
Week 12 11/15 – 11/19	**Chemical Bonding and the Structure of Solids** Griffiths & Schroeter: Ch. 5.3.2, 8.3	Midterm II (Distributed 11/17, Due 11/19)
Week 13 11/22 – 11/26	**Tunneling and the WKB Approximation** Griffiths & Schroeter: Ch. 9.1 – 9.2	Presentation Abstracts
Week 14 11/29 - 12/3	**Time-Dependent Perturbation Theory** Griffiths & Schroeter: Ch. 9.3, 11.1 – 11.2	HW10 (Due 12/3)
Week 14 12/6 – 12/10	**Contemporary Topics, Final Presentations** Griffiths & Schroeter: Ch. 12.1 – 12.2	HW11 (Due 12/10) Final Presentations
Final Exam Week		Final (Distributed 12/14, Due 12/16)