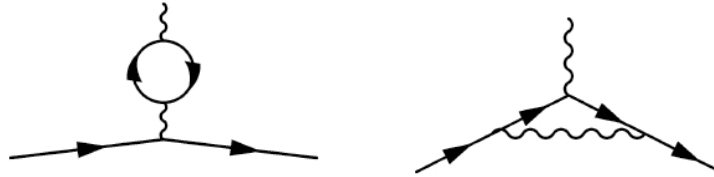


# Physics 531: Quantum Mechanics

“... I think I can safely say that nobody *understands* quantum mechanics.”

- Richard Feynman



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**Text:** *A Modern Approach to Quantum Mechanics* by John S. Townsend

**Lectures:** Monday, Wednesday, Friday at 9:30-10:45 am, Rigge G-09

**Final Exam:** Monday, December 9<sup>th</sup> 8-9:40 am (time to be extended)

**Course Webpage:** <https://blueline.instructure.com>

This semester we will delve into quantum mechanics, a beautiful yet decidedly strange theory of nature. As can be gleamed from the Feynman quote above, we may not fully understand what quantum mechanics really “means”, but no one can doubt that quantum mechanics and its relativistic extension, quantum field theory (QFT), are the most successful physical theories ever advanced by humanity. For example, in quantum field theory quantities like the magnetic moment of the electron can be calculated to an accuracy of one part in  $10^8$ , which probes distance scales down to  $10^{-13}$  cm and matches experimental results exactly (two of the 891 Feynman diagrams in the most accurate theoretical calculation are shown above). No other physical theory can claim such agreement between theory and experimental results. Learning how to calculate quantities in quantum mechanics is crucial; with quantum mechanics we can understand solid state electronics, cosmic ray showers in the atmosphere, cosmology and the history of the Universe, and a whole host of other subjects.

Quantum mechanics is a difficult and mathematically intensive theory and takes some work to learn. However, if you attend all class sessions and work through the problem sets, exercises, and projects you can and will learn and master this material. But remember, feel free to ask questions!. Although many professors (and textbooks) like to use the phrases “intuitively obvious” or “trivial” quantum mechanics is neither, especially when you’re seeing the material for the first time. If you have questions or are having problems, please come see me even if it’s not during office hours; if my door is open I’m more than happy to talk with you. I also check my e-mail regularly, but don’t expect an immediate reply if it’s 2 am the morning of an exam!

## **Course Learning Objectives**

- (1) Students will explain the development of quantum mechanics and the make arguments for the need for physics beyond the classical level, supported by physics literature, historical accounts, and physical phenomenon.
- (2) Students will apply the scientific method to the physics of the 20th century, progressing from a problem to a hypothesis to a underlying theory which can explain a diverse set of phenomenon.
- (3) Students will develop and successful apply the mathematical tools utilized in quantum mechanics such as linear algebra, differential equations, and Feynman bra-ket notation both in a theoretical and problem-based setting.
- (4) Students will use these mathematical tools to solve a variety of problems in quantum mechanics such as time evolution of the wave function, bound states of various potentials, the hydrogen atom, and operator and matrix treatments of angular momentum and spin.
- (5) Students will interact and work effectively as a member of a problem team.
- (6) Students will effectively communicate theoretical derivations and analyses and solutions to problems using written, oral, visual, and graphical communication.
- (7) Students will learn to write through a feedback and revision-based process several different styles of scientific papers including journal articles, review papers, and letters.
- (8) Students will demonstrate a capacity for self-directed learning, including goal setting, selection of learning strategies, time and effort regulation, motivation management, resource discovery, and self-reflection and self-assessment

## **Physics Departmental Learning Objectives:**

This course ties into and helps students realize the following physics department learning objectives:

- (1a) Students will demonstrate an improved understanding of the fundamental concepts in each of the major areas of physics.
- (1b) Students will be able to use concepts and techniques from more than one area of physics together to solve problems.
- (2a) Students will demonstrate a conceptual problem solving ability.
- (2b) Students will demonstrate a proficiency in the application of mathematics to physics.
- (3a) Students will be well prepared for graduate study.

## Course Structure

This course will be very different from the typical science courses you have encountered in your undergraduate studies. **There will be little to no lecture in this course.** Instead the pedagogical technique used most often will be that of problem based learning; a “problem” in 20th century physics will be presented (along with the accompanying physical evidence); this problem will be used to derive and develop the theory of quantum mechanics which will then be applied to similar yet unrelated problems as a test of the theory. Theoretical calculations will be compared to actual data to determine the accuracy of quantum theory. To develop a necessary foundation in new topics, some of class-time will be devoted to working through tutorials, solving problems, and gathering and assessing outside resources; all work will be done both individually as well as in teams.

Using problem based learning, our class time will be structured along the following pattern:

Problem/Physical Evidence  $\rightarrow$  Foundational Material  $\rightarrow$  Hypothesis  $\rightarrow$  Theory  $\rightarrow$  Applications

The course will be roughly divided into five modules each focussing on a different problem in quantum mechanics. Class sessions will be structured as a mixture of lectures, group work, problem solving exercises, and independent research. An optional (but highly recommended) recitation section will be scheduled which will give us additional time to work on tutorials, examples, and projects in your teams.

## Course Components and Evaluation

Weekly H.E.L.L.s: To provide the resources you’ll need to succeed in this course and to keep you on track for your projects, I will be providing you with a weekly Homework, Examples, Lectures, and Literature packet. These packets will include in-class tutorials you’ll be working through in groups, as well as homework problems, articles from the historical and physics literature, as well as thoroughly worked examples. Packets will also include reading assignments with my comments on what is critical and/or difficult in the text. The weekly packets are meant as a support structure for you in this new learning environment. However, as you develop the skills necessary to succeed in this environment I will slowly peel away the support structure! This means weekly packets towards the end of the semester will be much sparser as you will have the responsibility for finding, evaluating, and using the resources you’ll need to solve the problems we tackle in this course.

A word about Homework: I’ve always thought that hard-work and time-spent on homework is the single largest predictor of your success in a physics course. The best and only way to truly learn physics is through doing problems and re-working derivations. And by doing, I mean doing and re-doing them until they’re right no matter how long it takes. Since this is a 500 level course the homework will be challenging - I won’t lie to you. I don’t expect you to perfectly solve all of the

homework problems 100% of the time. However, I do expect you to come and find me when you have difficulties. My door is always open and I am happy to help however I can. There's nothing more frustrating (to an instructor) than half-baked homework solutions that are riddled with errors that could have been corrected by a 5 minute conversation with me. Also, I will provide solutions to homework problems, and you can learn quite a bit from carefully studying the homework solutions and determining exactly where you went wrong.

Homework will be included in each weekly H.E.L.L. packet, with the due date of various problems included in the packet and posted on Blueline (use the Calendar feature - it's quite useful!). We will be covering a great deal of material and will need to keep up the pace, so make sure you turn your assignments in on time. Collaboration with your fellow classmates (particularly team members) on the assignments is strongly encouraged; working in groups can be extremely effective in achieving a greater understanding of the subject material. However, I expect each of you to do your own work; copies of someone else's solutions will not be accepted. It is also cheating to use old homework solutions or to look up solutions in other textbooks. You will not learn the material this way!

**PBL Projects/Communication:** Each module or section of the course will be centered about an open-ended, physically interesting, and historically important problem which will address the key concepts of quantum mechanics. These PBL exercises or projects will frame our learning for the semester and will guide us in the background and the theory which we'll develop. In a typical physics course you see tools and then study phenomena; in this class we'll turn that paradigm upside-down and use the physical phenomena we want to model and investigate to determine which mathematical and physical tools are necessary. At the conclusion of each problem, groups will submit project/problem reports modeled after various styles of scientific papers which will detail their solutions to the quantum mechanical puzzles we began each module with. These reports/summaries will help you develop a critical and under-taught element of science: communication. Your problem summaries will present the problem, explain the context and historical importance of the problem, detail and explain your solution, and explain how the solution contributed to the development of the full theory of quantum mechanics. A major focus here will be your qualitative problem solving skills: why did you do what you did and can you explain it?

**Writing Assignments:** The first module of the course (solutions to the time-independent Schrodinger Equation) will culminate in a journal-type article (using the standard double column format from the physics journal Physical Review) of at least 5 pages in length. A draft will be due in the middle of September with a final version due shortly thereafter. The second module (time dependence in quantum mechanics) will culminate in a review-style article of at least 10 pages in length. A draft will be due after fall break with a revision due near the end of October. The third module will culminate in an informal, journal-club write up. The fourth and final module will culminate in the creation, revision, printing and presentation of a conference style poster.

Teamwork: A major component of work in the outside world and in professional physics is collaboration and teamwork. It is absolutely essential that you be able to function and work in the context of a team/group. To that end you will be constantly and consistently working in groups in this course. You will self-select into groups of 3 for each module of the course, rotating as necessary after each PBL project. You and your peers will evaluate your ability to function as a valuable group member. I'll provide information on expected group behavior and survey tools designed to enable group assessment and highlight group strengths and problem areas. Your ability to work as a team member will be assessed using the CATME online rubric.

Self-directed Learning: A critical aspect of Jesuit education is self-reflection. Here that self-reflection will take the form of an honest appraisal of your current educational state (i.e. your strengths and weaknesses) as well as your goals for this course and expectations of yourself. In particular, we will focus many of our reflections on your development of life-long learning skills. In this course you will have tremendous freedom in how and when you address the problems we will tackle. You will be responsible for managing your time and your effort, and for setting your own goals and figuring out how to meet those goals. In short, I want us together to pay attention to how your skills at independent learning are developing. You will evaluate your own development through a self-rating scale and self-reflective essays, and I'll provide my take on your development through feedback and a final narrative evaluation at the end of the course.

Quizzes: In order to maintain a level of individual responsibility and to encourage learning of basic skills in this course, each module will contain several quizzes. These quizzes will be taken individually, and will test basic competencies and operations. For example, one quiz might test your ability to find eigenvalues and eigenvectors of a matrix, while another might test your ability to manipulate Dirac bra-ket notation. Dates for quizzes will be announced in class and will occur on a timeline to be determined by the instructor. Make-up quizzes will be allowed in the case of an excused absence, however, all quizzes must be completed by the end of each module. Any quizzes not completed at this point will be counted as zeros.

Exams: There will no formal written exams for this course except for the final exam which will be a traditional, written, three-hour exam. Educational and psychological research shows that taking exams, particularly cumulative exams, is important for learning and long-term retention. Your final exams will also be compared against the scores of previous classes to demonstrate the viability and validity of this new teaching environment.

Grading: Your grade for this course will be determined according to the following weights (Note: Spectacular performance on the final may slightly alter the weights below in your favor).

Course Component	Percentage of Total Grade
Quizzes	15%
Homework	20%
Self-reflection and self-directed learning	10%
Problem Write-ups/Papers	40%
Final Exam	15%

Letter grades will be assigned based upon the following scale:

A	90 - 100	B+	85 - 89	B	80 - 84		
C+	75-79	C	70 - 74	D	60 - 69	F	< 60

In addition to a letter grade, I will also be providing you with written feedback at the end of the semester. This feedback will focus on your development as an independent learner and your successes/failures in meeting your self-assigned learning goals for the course.

Extra Credit: I will be giving you several instruments developed by the PER community to test and assess your understanding of quantum mechanics. Per department policy, you can earn up to five points of extra credit through high performance on the post-test. A score of 90-100% will earn you 5 extra credit points, a score of 80-89% will earn you 4, etc.

## Useful Resources

Here are a selection of other quantum mechanics text that I recommend and that you may wish to refer to from time to time:

P.A.M. Dirac, *The Principles of Quantum Mechanics* (Oxford, 1968): The first and in many ways the best. Very clearly explained since the author couldn't assume any prior knowledge of the subject matter.

Richard Feynman, R. Leighton, and M. Sands *The Feynman Lectures in Physics, Volume III* (Addison-Wesley, 1965): The third volume of the Big Red Books, written for sophomores at Cal-Tech. Wonderful insights into quantum mechanics, but some sophistication is needed to appreciate what is being said.

A.I.M. Rae, *Quantum Mechanics* (IOP, 2002): A short and concise but at the same time insightful text about quantum mechanics. It also has the virtue of being  $\approx$  \$30. I've used this book before for undergraduate quantum.

Amit Goswami, *Quantum Mechanics* (Waveland Press, 1997): A good, serviceable textbook - check it out if you'd like to see quantum with a different perspective than Griffith's.

Robert Scherrer, *Quantum Mechanics: An Accessible Introduction* (Pearson, 2006): This is the book for you if you struggle with the math behind quantum mechanics. Scherrer specifically includes several chapters or "mathematical interludes" on such topics such as complex numbers, linear operators, and linear algebra. A great basic resource if Griffiths or Townsend seem too mathematically sophisticated.

## **Legal notices from the College of Arts and Sciences**

### **Notices and Class Cancellation**

If it is necessary to cancel class at any time this semester (for example due to adverse weather) an official notification will be posted on the announcements section of our Blueline course page. However, since most class meetings will involve work in your problem groups, feel free to still meet; I expect you to use the time productively even if I am unable to be there! Furthermore, I will from time to time send e-mail messages to everyone in the course; since Blueline has only your Creighton University e-mail addresses, it is your responsibility to check your account or have your Creighton e-mail forwarded if you use another e-mail provider.

In the event of disruption of normal classroom activities due to an H1N1 flu outbreak or other emergency, the format for this course may be modified to enable completion of the course. In that event, you will be provided an addendum to this syllabus that will supersede this version. In the event of a contagious illness, please do not come to class if you are sick to avoid infecting other students; let me know immediately (electronically) and we will work together to make sure your assignments get completed and that you do not fall behind in the course.

### **Academic Honesty**

The students and faculty of the Creighton College of Arts and Sciences comprise an academic community established within the framework of Jesuit ideals and firmly rooted in the concept of integrity. To that end, all assignments, papers, and exams for this course are expected to be the original work of the individual student, unless the assignment is explicitly designated as a group assignment. Failure to comply with Creighton's Policy on Academic Honesty, as stated in the Undergraduate Issue of the Creighton University Bulletin, will result in a penalty that may range from a zero on the specific assignment to a grade of F for the course. Any incidents of academic dishonesty will be reported to the college and may result in further disciplinary action. Special note: it is cheating to consult old solutions for the homework or take-home exams. If it comes to my attention that solution sets that I distribute are being accessed by future students, I will simply stop distributing solutions, and the difficulty of the assigned homework may increase to compensate. Don't let this happen!

### **Students with Disabilities**

If you have a disability for which you need accommodation, you are encouraged to contact both your instructor and the Office of Disability Accommodations located on the 4th floor of the Old Gym (280-2166) as early as possible in the semester.