SYLLABUS

FOUNDATIONS OF QUANTUM MECHANICS

PHYS453

Department of Physics

Schmid College of Science and Technology

Chapman University, Orange

SPRING 2018

Instructor

Prof. Matthew Leifer
Office Location: 112 Hashinger Science Center (SC)
Email: leifer@chapman.edu
Phone: (714) 744-7985
Office Hours: TBD

Class Information

Lecture Times: Mondays and Wednesdays 2:30-3:45pm
Location: Hashinger Science Center (SC) 103

Course Website

https://blackboard.chapman.edu

Recommended Textbooks

The foundations of quantum mechanics are a subject of current research and there is no undergraduate-level textbook that covers the entire subject. There is no required textbook for this course, but I will issue a list of recommended books that you might find helpful for different parts of the course. Most of them can be found in the library.

Description

Quantum mechanics is perhaps the most successful theory in all of physics, but the question of what it actually means has always been controversial. Ideas like multiple universes, signals that travel faster than light, and objects that do not have properties until you look at them, are common in the popular literature, and are taken seriously by some researchers too. Given the radical nature of these claims, it is perhaps surprising that these issues have been brushed aside by most of the physics community and relegated to "philosophy", rather than being investigated rigorously as scientific questions. This has begun to change in the past few decades, and the foundations of quantum theory are now an active area of research. The aim of this course is to show that, although we are far from settling the meaning of quantum theory, we can approach these questions by the usual methods of physics, i.e. proving mathematical results and doing experiments, and we have learned a lot by doing this over the past few

decades.

Topics to be covered include: Generalized probabilistic theories, the postulates of quantum mechanics, basic phenomenology of quantum mechanics (interference, no-cloning, and entanglement), the realism/antirealism debate in philosophy of physics, the Einstein-Podolsky-Rosen argument, the measurement problem, the generalized formalism of quantum theory, ontological models (including Spekkens' epistricted classical models), no-go theorems (Hardy's excess baggage theorem, contextuality, the reality of the quantum state, Bell's theorem, and the Colbeck-Renner theorem), the classical limit of quantum theory, and interpretations of quantum theory.

Course Learning Outcomes

After completing this course, students will be able to:

1. Recall the fundamental principles of quantum theory and explain how to use them.
2. Explain why the meaning of quantum theory is thought to be unclear.
3. Solve problems involving general quantum states, measurements, transformations, and entanglement using Dirac notation, tensor systems, and string diagrams.
4. Use the ontological models framework to determine properties that realist approaches to quantum theory must have.
5. Debate the merits of existing interpretations of quantum theory.
6. Communicate the results of current research in quantum foundations to a non-specialist audience.

The Course Learning Outcomes above will be measured by the ability to

1. Answer conceptual questions about quantum mechanics in class and discuss responses with classmates.
2. Solve problems on homework problems, and on the final exam.
3. Produce a popular science account (written article, podcast, video, etc.) of a recent result in quantum foundations.

Program Learning Outcomes

1. Demonstrate knowledge and understanding of basic mathematics and physical principles used to model natural phenomena.
2. Demonstrate ability to convey physical concepts with mathematical expressions and/or computation, and effectively derive quantitative predictions from a model through mathematical/computational analysis.
3. Demonstrate competency in using computer tools.
4. Demonstrate the ability to apply advanced knowledge of advanced mechanics, electromagnetism, thermodynamics and quantum physics to the solution of problems in physics.
5. Demonstrate the ability to effectively communicate information, scientific or otherwise, in both written and verbal form
6. Demonstrate the ability to write clear, organized and illustrated technical reports with proper references to previous work in the area.
7. Demonstrate the skills and motivation for continued self-education.

Policy on Working Together

Students may work together on homework assignments. However, after developing the idea, each student should work independently towards the final solution. Copying homework, either from a classmate or the internet, is plagiarism, which is a serious academic offense. Plagiarism or cheating in examinations will result in a final grade of F, or a more severe punishment.

Lecture Notes

Lecture notes will be posted on Blackboard after the lecture, so you do not need to take notes in class unless you want to. You should still bring pen or pencil and paper to class, as you will be asked to solve problems during class.

Homework

There will be five problem sets that contribute to your final grade, issued approximately every two weeks, starting on the first class of the second week of the semester. The homework schedule is included on the last page of this syllabus. Homework is due to be handed in during the Monday lecture, two weeks after it is issued, except for two breaks in the semester, for the APS March meeting and Spring Break, where you will have three weeks to complete homework.

Problem sets will be handed out during lecture and also posted on Blackboard. Written solutions may be handed in at the lecture, or scanned/written up on computer and emailed to leifer@chapman.edu

There will be no credit for homework that is handed in late, but extra credit homework may be assigned if a student has a legitimate reason for missing a deadline.

Popular Science Assignment

Most student assignments are only ever seen by the course instructor and possibly other students. By producing work for public consumption instead, students can build up a portfolio of work that is useful for showing future employers, and society in general, your skills and what you have learned.

Communicating science to a general audience is an important part of the job of a professional scientist. Accurately describing the counter-intuitive aspects of quantum theory at this level is a challenging task that is often done poorly even by professional science communicators. You will have a chance to try your hand at this by producing an account of recent research in the foundations of quantum mechanics, which will be posted publicly on the Schmid College blog. You will have six weeks to complete this task, with opportunities for feedback from the instructor and other students before you have to submit the final version. Adam Becker, a science writer who has recently written a popular book on the foundations of quantum mechanics, will also be on hand to advise you.The steps for completing this assignment are:

- Choose a talk on the foundations of quantum mechanics at the conference to be held at Chapman March 1-2 or at the March Meeting of the American Physical Society in Los Angeles March 5-9.
- Attend guest lecture (in class) by Adam Becker to learn about describing quantum theory to a

general audience.

- Find and read the research paper that your chosen talk if based on if it exists.
- Attend the talk, interview the speaker, and possibly other relevant researchers.
- Produce an account of the work for a general audience in any media (written article, podcast, video, etc.).
- Get written and oral feedback from the instructor and other students and then revise your account before submitting the final version.
- Submitted assignments will be posted on the Schmid College blog.

This assignment will be evaluated on the following criteria:

- Includes an explanation why work is interesting in a way that would draw in a general audience.
- The science is explained accurately using common language/diagrams/other visualizations without the use of unexplained technical jargon or mathematics.
- Appropriate criticism of the claims of the authors of the work is included, e.g. if the authors claim exaggerated implications for their work then quotes from researchers with critical views are included.
- The account contains all relevant citations, e.g. quotations are properly sourced and the original work is cited.

Exams

There will be a take-home, open-book, final exam. Students are expected to work on their exam on their own. The due date will be strictly enforced unless there are serious extenuating circumstances, e.g. bereavement or illness. The exam dates are as follows:

- Final: Issued Monday May 7, Due Friday May 25 at 11:59pm PDT

Because the due date for the final is after the semester ends, this must be scanned and emailed to the instructor at leifer@chapman.edu unless it is handed in to the instructor before the end of finals week.

Course Grade

Your overall grade will be determined by a weighted combination of your grades on the following assessments:

- Homework: 30%
- Popular Science Assignment: 30%
- Final Exam: 40%

The grade boundaries will be:

A	A-	B+	B	B-	C+	C	C-	D+	D	D-	F
90-100	85-90	80-85	75-80	70-75	65-70	60-65	55-60	50-55	45-50	40-45	0-40

Grade boundaries may be adjusted downwards in order to avoid students missing a boundary by a very small amount. Extra credit homework may be assigned if there is widespread misunderstanding of a

homework or exam question, or if a student has a legitimate reason for missing work.

Chapman University's Academic Integrity Policy

Chapman University is a community of scholars that emphasizes the mutual responsibility of all members to seek knowledge honestly and in good faith. Students are responsible for doing their own work and academic dishonesty of any kind will be subject to sanction by the instructor/administrator and referral to the university Academic Integrity Committee, which may impose additional sanctions including expulsion. Please see the full description of Chapman University's policy on Academic Integrity at www.chapman.edu/academics/academicintegrity/index.aspx.

Chapman University's Students with Disabilities Policy

In compliance with ADA guidelines, students who have any condition, either permanent or temporary, that might affect their ability to perform in this class are encouraged to contact the Office of Disability Services http://www.chapman.edu/students/health-and-safety/disability-services/index.aspx. If you will need to utilize your approved accommodations in this class, please follow the proper notification procedure for informing your professor(s). This notification process must occur more than a week before any accommodation can be utilized. Please contact Disability Services at (714) 516-4520 if you have questions regarding this procedure, or for information and to make an appointment to discuss and/or request potential accommodations based on documentation of your disability. Once formal approval of your need for an accommodation has been granted, you are encouraged to talk with your professor(s) about your accommodation options. The granting of any accommodation will not be retroactive and cannot jeopardize the academic standards or integrity of the course.

Equity and Diversity Statement

Chapman University is committed to ensuring equality and valuing diversity. Students and professors are reminded to show respect at all times as outlined in Chapman's Harassment and Discrimination Policy http://www.chapman.edu/diversity/_files/harassment-and-discrimination-policy.pdf. Any violations of this policy should be discussed with the professor, the Dean of Students http://www.chapman.edu/students/dean-of-students/index.aspx and/or otherwise reported in accordance with this policy.

Student Support at Chapman University

Over the course of the semester, you may experience a range of challenges that interfere with your learning, such as problems with friend, family, and or significant other relationships; substance use; concerns about personal adequacy; feeling overwhelmed; or feeling sad or anxious without knowing why. These mental health concerns or stressful events may diminish your academic performance and/or reduce your ability to participate in daily activities. You can learn more about the resources available through Chapman University's Student Psychological Counseling Services here: https://www.chapman.edu/students/health-and-safety/psychological-counseling/

Fostering a community of care that supports the success of students is essential to the values of Chapman University. Occasionally, you may come across a student whose personal behavior concerns or worries you, either for the student's well-being or yours. In these instances, you are encouraged to contact the Chapman University Student Concern Intervention Team who can respond to these concerns and offer assistance:
https://www.chapman.edu/students/health-and-safety/student-concern/index.aspx

While it is preferred that you include your contact information so this team can follow up with you, you can submit a report anonymously. 24-hour emergency help is also available through Public Safety at 714-997-6763.

Class Schedule

Final exam due Friday, May 25 at 11:59pm PDT

Week	Monday	Wednesday
1: 01/29 – 02/02	Introduction Mathematical Background	Mathematical Background
2: 02/05 – 02/09	Generalized Probabilistic Theories	Generalized Probabilistic Theories Hwk 1 issued
3: 02/12 – 02/16	Postulates of Quantum Mechanics	Philosophical Background
4: 02/19 – 02/23	Phenomenology of Quantum Mechanics Hwk 2 issued	Guest Lecture Hwk 1 due
5: 02/26 – 03/02	Orthodoxy, EPR and the Measurement Problem Assignment choices finalized	Tensor Spaces
6: 03/05 – 03/09	APS March Meeting	APS March Meeting
7: 03/12 – 03/16	Tensor Spaces Hwk 3 issued	Generalized Formalism Hwk 2 due
8: 03/19 – 03/23	SPRING BREAK	SPRING BREAK
9: 03/26 – 03/30	Assignment peer review	Generalized Formalism
10: 04/02 – 04/06	Epistricted Theories Hwk 4 issued	Ontological Models Hwk 3 due
11: 04/09 – 04/13	Contextuality	Ψ-ontology Assignments due
12: 04/16 – 04/20	Bell's Theorem Hwk 5 issued	Colbeck-Renner Theorem Hwk 4 due
13: 04/23 – 04/28	The Classical Limit	The Classical Limit
14: 04/30 – 05/04	Interpretations of Quantum Theory	Interpretations of Quantum Theory Hwk 5 due
15: 05/07 – 05/11	Interpretations of Quantum Theory Final Exam issued	Interpretations of Quantum Theory