PHIL 146: Philosophy of Physics

Topic: Foundations of Quantum Mechanics

Fall 2023. UCSD

Syllabus

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Version of September 24, 2023

1 Course Description

This course will provide an introduction to topics in the philosophy of physics, with a focus on the foundations of quantum mechanics.

2 Course Information

- Meeting time: MWF 11:00 - 11:50 am. First class on Fri Sept 29.
- Class location: Podemos Building (PODEM) 0133, in the new Theatre District Living and Learning Neighborhood, near 8th College
- Office hours (right after class): 15 minutes after each class.
- Office hours (in my office): Monday & Friday 10:00 - 10:45am. [You may attend in person person or via Zoom at 202-988-3478]
- Other times by appointment.
- Prerequisites: no formal requirements. But a solid high-school physics background is recommended. A college-level physics background would be helpful. If you do not have much background in mathematics or physics, you need to be prepared to work hard on problem sets, look up extra resources, and be ready to seek help from classmates and the instructor.

- Required texts:

  [ALB] David Albert, *Quantum Mechanics and Experience*, Harvard University Press, 1992.

  [MAU] Tim Maudlin, *Philosophy of Physics: Quantum Theory*, Princeton University Press, 2019.

  I recommend physical copies, but they are also available via the UCSD library digital collection

- Optional texts:

  J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, 1989.

  Tim Maudlin, *Quantum Non-Locality and Relativity*, 3rd edition. Wiley-Blackwell, 2011.

  Alyssa Ney and David Albert, *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*, Oxford University Press, 2013.

  Travis Norsen, *Foundations of Quantum Mechanics*, Springer, 2017.

3 Philosophy of Physics

Why study philosophy of physics? Well, Phil Physics is one of the most exciting areas of philosophy; it brings together philosophy and physics, and it intersects many domains, such as philosophy of science, metaphysics, epistemology, logic, and philosophy of language! If you wonder about the following questions, then this course is for you!

- What is the nature of space and time? What is the meaning of relativity?
- How to make sense of quantum mechanics?
- What is a physical field? What are particles?
- What is the meaning of probability in physical theories?
- What kind of things are laws of nature (such as Newton's laws and the Schrörindger equation)? What are symmetries and invariances?
- Why is mathematics so effective at describing the physical world, from medium-sized dry goods to fundamental physical theories?
- How does physics relate to the rest of the sciences such as biology and psychology?
- What is the place of the mind and of the consciousness in a physical world?

We won't be able to address all of these questions. We will focus on some questions having to do with quantum mechanics:

- What does quantum mechanics say mathematically?

- What does quantum mechanics say about the real world?
- Is quantum mechanics consistent?
- Does quantum mechanics imply that the moon is not there when nobody looks?
- What's the place of human observers and consciousness in a quantum world?
- Does quantum mechanics imply spooky action at a distance?
- Can we reconcile quantum mechanics with relativity?

These questions are also at the intersection of mathematical physics, foundations of chemistry, and theoretical physics. Since many of the philosophical issues can be appreciated without advanced background in mathematics or physics, I will not assume familiarity with advanced mathematical physics. But if you know some math and physics, that will certainly help. We have planned multiple Math/Physics Interludes where we will break things down so that students can be on the same page for the philosophical discussions. However, please be prepared to work hard! You will be expected to work through problem sets that involve a fair bit of mathematics. You won't be alone as you can collaborate with your classmates. I am always ready to help.

4 About Me

I am an associate professor of philosophy at UCSD. I am also a fellow of the newly established John Bell Institute for the Foundations of Physics. I did my graduate studies at Rutgers University, NJ, where I received a PhD in philosophy, a master in mathematical physics, and a graduate certificate in cognitive science. My research interests include: philosophy of physics, philosophy of science, philosophy of mathematics, metaphysics, and decision theory. I am also interested in philosophy of mind, philosophy of religion, and Chinese philosophy.

In philosophy of physics, I have done research on the foundations of quantum mechanics and statistical mechanics. I have published papers about the meaning of the quantum wave function, the fundamentality of physical space, the nature of density matrices, and a simple choice of the initial state of the universe. You can find out more about me on my website: www.eddykemingchen.net.

5 Learning Goals

Our main goal is to gain an understanding and appreciation of the philosophical issues about the foundations of quantum mechanics and the issues in philosophy of physics more generally.

6 Work and Grading

- Grade assignment: $100 \geq A+ \geq 98 \geq A \geq 92 \geq A- \geq 88 \geq B+ \geq 85 \geq B \geq 82 \geq B- \geq 78 \geq C+ \geq 75 \geq C \geq 72 \geq C- \geq 68 \geq D \geq 59 \geq F \geq 0$.

- Problem sets: 40%

  There will be weekly problem sets consisting of 3-5 questions. Some of the questions will involve mathematical derivations and proofs. Others will be more conceptual and testing your understanding of the definitions, concepts, and arguments in the readings / lecture. Weekly problem sets are the most important component of assessment for this class. Please be prepared to work hard on these. You are welcome to collaborate with each other, but you should not copy other students' answers. See Academic Integrity section for warnings about plagiarism.

  Weekly problem sets should be submitted on Canvas. Deadline: Sunday 5pm (San Diego time).

  There will be about seven problem sets. You get one freebie: your lowest grade will be dropped.

- In-class quizzes: 8%

  At the beginning of each class, there will be a short quiz about the readings assigned for that day. Attendance and class discussion are crucial for learning and doing well in this class. Please try not to miss classes.

- Participation: 2%

  I expect lively discussions. However, if you are usually quiet in class, you can choose to email me your thoughts or reflections before or after class. If you have any questions, please feel free to ask in class, after class, and during office hours.

- Midterm #1: 15%

  The take-home test will take place around Week 3. It will include no more than seven questions about the reading and lecture materials covered before.

- Midterm #2: 15%

  The second take-home test will take place around Week 7. It will include no more than seven questions about the reading and lecture materials covered before.

- Final exam: 20%

  The final exam will take place on December 12th at 11:30am-2:29pm.

- Extra credit presentations: 5%

  I think the best way for one to truly understand something is to teach it to others. There will be many options (10 minutes in each class) for you to do in-class oral presentations, such as a summary and a critique of the readings. However, you will be required to prepare PowerPoint slides and/or paper handouts. You are very encouraged to talk with me if you would like to present on any topic you find interesting. You will be rewarded a minimum of 1 and a maximum of 5 extra points towards your final grade.

- Zoom recordings: in-person attendance and discussion are crucial to your learning and success in this class. I will not record the lectures. If you miss a class, please try to get class notes from your classmates and visit my office hours to ask questions.

- Since this is an upper-level class, please feel free to visit my office hours to discuss your questions about the class materials. If you cannot come to my regular office hours, I am happy to make appointments with you to accommodate your schedule.
- Please do not be late. Please do not text or call on your phone, or surf the internet (Twitter, Facebook, Instagram) during class. A maximum of 10 points can be deducted from your final grade.
- Feedback on teaching. I plan to arrange for a teaching observation session from staff members of the Engaged Teaching Hub and UCSD Teaching and Learning Commons to get feedback on teaching and improve teaching effectiveness.

7 Academic Integrity

Here is the Integrity of Scholarship Agreement as stated on the UCSD Academic Integrity Office. Please follow these expectations in this course.

Students are expected to complete the course in compliance with the instructor's standards. No student shall engage in any activity that involves attempting to receive a grade by means other than honest effort, for example:

- No student shall knowingly procure, provide, or accept any materials that contain questions or answers to any examination or assignment to be given at a subsequent time.
- No student shall complete, in part or in total, any examination or assignment for another person.
- No student shall knowingly allow any examination or assignment to be completed, in part or in total, for himself or herself by another person.
- No student shall plagiarize or copy the work of another person and submit it as his or her own work.
- No student shall employ aids excluded by the instructor in undertaking course work.
- No student shall alter graded class assignments or examinations and then resubmit them for regrading.
- No student shall submit substantially the same material in more than one course without prior authorization. A student acting in the capacity of an instructional assistant (IA), including but not limited to teaching assistants, readers, and tutors, has a special responsibility to safeguard the integrity of scholarship. In these roles the student functions as an apprentice instructor, under the tutelage of the responsible instructor. An IA shall equitably grade student work in the manner agreed upon with the course instructor. An IA shall not make any unauthorized material related to tests, exams, homeworks, etc. available to any student.

Each student is responsible for knowing and abiding by UCSD's Policies on Integrity of Scholarship and Student Conduct. **Any student violating these policies will earn an 'F' in the course and will be reported to the University for the violation.** Authorized course assistance is available in person and electronically from the course instructor and instructional assistants.

8 Accessibility

I would like to make sure that everyone in the class feels safe and respected. If you have any particular need, please contact the UCSD Office for Students with Disabilities at the beginning of the semester. They will forward the necessary information to me. We can work out the details in person.

From the website of the UCSD Office for Students with Disabilities:

The Office for Students with Disabilities (OSD) at UC San Diego works with undergraduate, graduate, and professional school students with documented disabilities, reviewing documentation and, through an interactive process with the student, determining reasonable accommodations. Disabilities can occur in the following areas: psychological, psychiatric, learning, attention, chronic health, physical, vision, hearing, and acquired brain injuries, and may occur at any time during a student's college career. We encourage you to contact the OSD as soon as you become aware of a condition that is disabling so that we can work with you. Students registered with the OSD have the same responsibilities as other students: getting to class regularly, meeting with faculty and peers to study and learn, and finally demonstrating understanding and mastery of course content. OSD helps students with disabilities navigate that system by establishing a set of academic accommodations based on each student's individual disability. In order to receive support, students must schedule an appointment with the OSD to discuss obtaining reasonable accommodations based on their current, functional limitations, particularly as they pertain to a higher education academic setting.

9 Course Plan

This is a preliminary schedule; please check Canvas Modules for updates. There will be a reading quiz at the beginning of each class starting in Week 1. "[PDF]" just means the reading is uploaded as a PDF document and is available for download on the course Canvas website.

- **Week 0. Introduction.**

  9/29. What is philosophy of physics? What are some philosophical issues of quantum mechanics?

- **Week 1. Quantum Experiments.**

  10/2. MAU pp.1-10.

  10/4. MAU pp.10-22; ALB Ch1.

  10/6. MAU pp.22-35.

Problem set #1 due at 5:00pm Sunday, 10/8.

- **Week 2. Mathematical Interlude.**

  10/9. "An Overview of QM" pp. 260-269: vector spaces, linear spaces, eigenvalue problem; ALB pp.17-30.

  10/11. NO CLASS

  10/13. "An Overview of QM" pp. 269-278: complex numbers, dimensionality, inner product, orthonormal bases; (if time permits: time evolution of quantum states, composite systems)

Problem set #2 due at 5:00pm Sunday, 10/15.

- **Week 3. The Quantum Recipe**

  10/16. MAU pp.36-53.

  10/18. MAU pp.53-65. ALB pp 30-59.

  10/20. MAU pp.66-78.

Midterm #1 due at 5:00pm Sunday, 10/22.

- **Week 4. Bell's Theorem and Non-Locality**

  10/23. Maudlin, Quantum Non-Locality and Relativity, Ch1; ALB, Ch3. Chen, PDF

  10/25. ctd.

  10/27. ctd.

Problem set #3 due at 5:00pm Sunday, 10/29.

- **Week 5. The Measurement Problem**

  10/30. Bell, "Against Measurement" [PDF]

  11/1. ALB Ch4. Maudlin, "Three Measurement Problems" [PDF]

  11/3. The Copenhagen Interpretation, selections from Norsen [PDF]

Problem set #4 due at 5:00pm Sunday, 11/5.

- **Week 6. Collapse Theories**

  11/6. MAU pp.94-110. ALB ch.6.

  11/8. MAU pp.110-128. pp.128-135.

  11/10. NO CLASS (Veterans Day holiday)

Problem set #5 due at 5:00pm Sunday, 11/12.

- **Week 7. Pilot-Wave Theories**

  11/13. MAU pp.137-150. ALB ch.7.

  11/15. MAU pp.150-172.

  11/17. ctd.

Midterm #2 due at 5:00pm Sunday, 11/19.

- **Week 8. The Many-Worlds Interpretation**

  11/20. MAU pp.173-179.

  11/22. MAU pp.179-195. MAU pp.195-204.

  11/24. NO CLASS (Thanksgiving holiday)

Problem set #6 due at 5:00pm Sunday, 11/26.

- **Week 9. How to Solve the Measurement Problem?**

  11/27. The question of ontology.

  11/29. The problem of probability.

  12/1. The issue of locality.

Problem set #7 due at 5:00pm Sunday, 12/3.

- **Week 10. Meaning of the Wave Function**

  12/4. MAU pp.79-93. Chen, "Realism about the Wave Function" [PDF]

  12/6. ctd.

  12/8. Open discussion / review session.

  Final exam: 12/12. 11:30am-2:29pm.