PHILOSOPHICAL ISSUES IN QUANTUM PHYSICS HPS/PL 125

Time: T/Th 1-2:30
Location: Baxter 127
Office Hours: M/F 10-11

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COURSE DESCRIPTION

In his *Character of Physical Law* lectures Feynman said:

> *"I think I can safely say that nobody understands quantum mechanics. … Do not keep saying to yourself, if you can possibly avoid it, 'But how can it be like that?' because you will get 'down the drain', into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that."*

We will address exactly this question: How can it be like that? What actual physical occurrences could explain the success of quantum theory? We will begin by looking at why this question is so much harder to answer in the case of quantum mechanics than, say, electromagnetism or classical mechanics. We will then examine, in depth, three proposals for what might really be going on: Ghirardi-Rimini-Weber (GRW) theory, the many-worlds interpretation, and Bohmian mechanics.

Along the way, we will see that understanding quantum mechanics requires addressing philosophical issues, such as: Are scientific theories supposed to tell us "how it can be like that" or just to make accurate predictions? What exactly are probabilities and how should they be employed in evaluating scientific theories? What makes you the same person that you were yesterday? Do laws of nature govern our universe or merely describe patterns in it?

Prerequisite: An introductory course in quantum mechanics (Physics 2b or Physics 12b).

TEXTBOOK

Quantum Mechanics and Experience (1992), Albert

ASSIGNMENTS

Research Paper (40%)

The central assignment for this course is a 3,000-4,000 word research paper due on the last day of class, 6/2. This is an opportunity to dive deep into the ideas about quantum mechanics you find most intriguing. A number of optional readings have been included on the syllabus for you to engage with in your research papers. You may use additional sources beyond those in the syllabus, but you are not expected to. You will receive further guidance on the research paper in class.

Project Proposal (10%)

You should begin working on your research paper early in the term. I encourage you to read ahead about topics you think you might be interested in. There will be no prompts for the research paper. You must find your own question to address. (I understand that it is harder for you this way. I want you to learn to ask good questions.) A two-page proposal is due on 5/5. If you'd like help brainstorming ideas for the paper, come to my office hours and I'll be happy to help.

Research Talk (10%)

On Saturday, 5/21, we will have a workshop where each student gives a 10 minute presentation on their research project (followed by five minutes of questions). The talks will be arranged by topic into four sessions. You are only required to attend the session in which you are presenting, but I encourage you to attend all of the sessions. The workshop is a chance for you to practice public speaking, to get feedback on your project from other students before turning in the research paper, and to refine your paper by hearing about how other students are approaching related questions.

Problem Sets (40%)
There will be four problem sets distributed throughout the term so that you have an opportunity to engage with all of the topics covered in the course, not just what you decide to work on for your research paper.

SCHEDULE

[*Note page numbers! Sometimes you don't have to read the whole chapter or article.*]

3/29 **An Introduction to the Measurement Problem and Six Proposed Solutions**

Optional: *Measure for Measure: Quantum Physics and Reality* (2014), Greene, Albert, Carroll, Goldstein, and Schack [video from the World Science Festival]

The Character of Physical Law (1965), Feynman, Chapter 6: Probability and Uncertainty – the Quantum Mechanical view of Nature
[also available as a video lecture]

3/31 **The Quantum Formalism**

Reading: Textbook, pg. 1-60
[Feel free to skim if this is familiar but please read pg. 1-16 and 30-38 carefully.]

4/5 **The Measurement Problem**

Reading: Textbook, pg. 73-92

Optional: "Against 'Measurement'" (1990), Bell

"Remarks on the Mind-Body Question" (1961), Wigner

"Three Measurement Problems" (1995), Maudlin

Introduction to Quantum Mechanics (2005), 2nd ed., Griffiths, Section 1.2 and Chapter 12: Afterword

4/7 **Non-Locality: The EPR Argument and Bell's Theorem**

Reading: Textbook, pg. 61-72

Optional: "What Bell Did" (2014), Maudlin [also available as a video lecture]

"Can Quantum-Mechanical Description of Reality be Considered Complete?" (1935), Einstein, Podolsky, and Rosen

"Bertlmann's Socks and the Nature of Reality" (1981), Bell

"Bell Inequality and Many-Worlds Interpretation" (2015), Vaidman

4/12 **Instrumentalism**

Reading: "Quantum Theory Needs No 'Interpretation'" (2000), Fuchs and Peres

Theory and Reality (2003), Godfrey-Smith, Chapter 12: Scientific Realism, pg. 173-186

Optional: "An Introduction to QBism with an Application to the Locality of Quantum Mechanics" (2014), Fuchs, Mermin, and Schack

Physics and Philosophy (1959), Heisenberg, Chapter 3: The Copenhagen Interpretation of Quantum Theory

4/14 **GRW I: When do Wave Functions Collapse?**

Reading: Textbook, pg. 92-111

Optional: "Are there Quantum Jumps?" (1987), Bell

"Parameter Diagrams of the GRW and CSL Theories of Wavefunction Collapse" (2012), Feldmann and Tumulka

❖Problem set 1 due.❖

4/19 **GRW II: Fundamental Randomness**

Reading: *Introduction to the Philosophy of Science* (1992), Earman and Salmon, Chapter 2: The Confirmation of Scientific Hypotheses, pg. 74-84

Optional: *Sneaking a Look at God's Cards* (2005), Ghirardi, Chapter 3: Quanta, Chance Events, and Indeterminism, pg. 62-66

"A Subjectivist's Guide to Objective Chance" (1980), D.K. Lewis

4/21 **GRW III: Ontology**

Reading: Quantum Non-Locality and Relativity (2011), 3rd ed., Chapter 10: New Discoveries and Deeper Insights: The View from 2010, pg. 224-239

"Elementary Quantum Metaphysics" (1996), Albert

Optional: "The Status of our Ordinary Three-Dimensions in a Quantum Universe" (2010), Ney

"On the Common Structure of Bohmian Mechanics and the Ghirardi-Rimini-Weber Theory" (2008), Allori, Goldstein, Tumulka, and Zanghì, Section 3

4/26 **Many-Worlds I: Life Without Collapse**

Reading: "The Everett Interpretation" (2013), Wallace

Optional: *The Hidden Reality* (2011), Greene, Chapter 8: The Many Worlds of Quantum Measurement

The Emergent Multiverse (2012), Wallace, Chapter 1: The Paradox of Measurement and First Interlude, pg. 11-14, 44-45, 103-110

"Many Worlds and Schrödinger's First Quantum Theory" (2010), Allori, Goldstein, Tumulka, and Zanghì

"'Relative State' Formulation of Quantum Mechanics" (1957), Everett

❖Problem set 2 due.❖

4/28 **Many-Worlds II: The Appearance of Collapse**

Reading: *Decoherence and the Quantum-to-classical Transition* (2007), Schlosshauer, Chapters 2 and 8, pg. 33-69, 336-340

Optional: "Decoherence and Ontology" (2010), Wallace

"Decoherence and the Transition from Quantum to Classical" (1991), Zurek

5/3 **Many-Worlds III: Identity and Uncertainty**

Reading: "Survival and Identity" (1976), D.K. Lewis, pg. 17-29

Optional: "Branching and Uncertainty" (2008), Saunders and Wallace

"Uncertainty and Probability for Branching Selves" (2007), P.J. Lewis

5/5 **Many-Worlds IV: Probability and Decision Theory**

Reading: "How to Prove the Born Rule" (2010), Wallace, Sections 1-6, 9-10

Optional: *The Emergent Multiverse* (2012), Wallace, Chapter 4: The Probability Puzzle and Second Interlude

"Understanding Deutsch's Probability in a Deterministic Multiverse" (2004), Greaves

❖Project proposals due.❖

5/10 **The Statistical Interpretation**

Reading: "The Statistical Interpretation of Quantum Mechanics" (1970), Ballentine, Sections 1.0, 1.2, 1.3, 4.1, 4.2, 6 (just the bit before 6.1), and 7

Optional: "Einstein's Interpretation of Quantum Mechanics" (1972), Ballentine

The Structure and Interpretation of Quantum Mechanics (1989), Hughes, Chapter 6: The Problem of Properties, Sections 6.4, 6.5, and 6.8

"The Quantum Measurement Problem: State of Play" (2007), Wallace, Section 6.1

5/12 **Bohmian Mechanics I: The Guidance Equation, Non-Locality, and Spin**

Reading: Textbook, pg. 134-176

Optional: "Bohmian Mechanics (Stanford Encyclopedia of Philosophy)" (2013), Goldstein

"What Happens in a Spin Measurement?" (1986), Dewdney, Holland, and Kyprianidis

LMUcast: FAQ on Bohmian Mechanics (2013), workgroup on Bohmian mechanics at Ludwig-Maximilians-Universität München

❖Problem set 3 due.❖

5/17 **Bohmian Mechanics II: Probability**

Reading: "Bohmian Mechanics as the Foundation of Quantum Mechanics" (1996), Dürr, Goldstein, and Zanghì

The Quantum Theory of Motion (1993), Holland, Section 3.6

Optional: *Bohmian Mechanics* (2013), Teufel [video lecture from QTWOIII]

"Beyond the Quantum" (2009), Valentini

5/19 **Bohmian Mechanics III: Ontology**

Reading: "Quantum States for Primitive Ontologists: A Case Study" (2012), Belot

Optional: "Bohmian Mechanics and the Meaning of the Wave Function" (1996), Dürr, Goldstein, and Zanghì

"Solving the Measurement Problem: De Broglie–Bohm Loses Out to Everett" (2005), Brown and Wallace

"Can the World be Only Wavefunction?" (2010), Maudlin [also available as a video lecture]

5/21 **Workshop** (Baxter 125)

Session I: 9-10:30
Session II: 10:30-12
Lunch
Session III: 2-3:30
Session IV: 3:30-5
❖Research talks presented.❖

5/24 **No Class**

5/26 **Laws of Nature**

Reading: *The Metaphysics Within Physics* (2007), Maudlin, Chapter 2: Why Be Humean?

Optional: "Quantum Entanglement, Bohmian Mechanics, and Humean Supervenience" (2014), Miller

"One World, One Beable" (2014), Callender
❖Problem set 4 due.❖

5/31 **Einstein's Views on Quantum Mechanics**

Guest lecture by Dennis Lehmkuhl. No Reading.

6/2 **Symmetries**

Reading: *Time and Chance* (2000), Albert, Chapter 1: Time-Reversal Invariance

Modern Quantum Mechanics (2011), 2nd ed., Sakurai and Napolitano, Chapter 4: Symmetry in Quantum Mechanics, pg. 284-286

Quantum Mechanics: A Modern Development (1998), Ballentine, Section 4.3: Galilei Transformation of Schrodinger's Equation

Optional: "On the Common Structure of Bohmian Mechanics and the Ghirardi-Rimini-Weber Theory" (2008), Allori, Goldstein, Tumulka, and Zanghì, Sections 1 and 4.2
❖Research papers due.❖

ATTENDANCE AND READING

Engaged participation and careful preparation are important to your success in this course. Learning to orally examine questions and present your own ideas in a skilled, accurate, professional, and persuasive manner is an invaluable skill in life. By engaging in class discussion you will improve your ability to do this and come to understand the material covered in the course better.

During discussion you will often find yourself disagreeing with other students. When this happens, strive to be respectful. If you can't understand why someone would believe *that*, then you have something to learn from your interlocutor. The most compelling arguments are offered by those who see the appeal of the other side.

Much of the time you spend learning philosophy will be spent reading and re-reading the texts. Reading philosophy is challenging. So is physics. Philosophy of physics can be especially impenetrable. I recommend that you re-read confusing parts of the text and take notes, bringing prepared questions with you to class or office hours.

The readings that are not from the textbook are all available on the course website (including optional readings and links to the videos). Readings should be completed in advance of the class meeting they are associated with.

LATE ASSIGNMENTS

Late assignments will receive a one letter grade deduction for each 48 hour period they are late. An extension may be granted if requested in advance of the due date for the assignment. In general, extensions will only be granted for reasons of religious observance, illness, or personal or family emergency.

SENIOR DITCH DAY

Should Ditch Day fall on a Tuesday or Thursday, class will be canceled and any assignments due will be due instead on the next day class is held. Each class session will be pushed back and class will be held on 5/24 (if Ditch Day happens after 5/24 I will email a revised schedule).

EMAIL

You can reach me at: csebens@gmail.com. Please only email me about logistical concerns: requesting extensions, scheduling additional office hours, etc. I find it is more effective to discuss course content face-to-face. I am happy to meet with you in office hours to discuss any philosophical questions and to schedule additional meetings as needed. Please do not hesitate to setup a meeting with me outside of office hours, especially if you'd like to discuss plans for your research paper.

SPECIAL ACCOMMODATIONS FOR STUDENTS WITH DISABILITIES

If you require any special arrangements for completing the course assignments or participating fully in class meetings, please let me know at the beginning of the course.

PLAGIARISM

You are encouraged to discuss your work with other students and even to share drafts with each other to get feedback. However, the work you submit should be your own. If you incorporate the ideas of others, cite those sources. Do not copy language too closely. Even when summarizing and paraphrasing cited sources, you must use your own language and present the ideas in an original way. Please ask me if you have any questions about what counts as plagiarism. More information on plagiarism is available on the Hixon Writing Center's website. If I have reason to believe that you have plagiarized, I will report the case to the Board of Control for review. If they determine that it is indeed a case of plagiarism, you will receive a zero on the assignment.