Topics in the Philosophy of Physics: Philosophy of Quantum Mechanics

Spring 2014

Philosophy 4850/6850, Physics 4482/7682

Th 2:40-4:30, Goldwin Smith G24

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There is no question that quantum mechanics is empirically successful. What the formalism says about the world, however, remains controversial. In this course, we will look at different theories of quantum mechanics and discuss a range of philosophical issues that arise for the different theories. Topics include: the measurement problem, quantum non-locality, the ontological status of the wavefunction, the fundamental ontology of the theory, recovering the manifest image from the theory, the nature of probability, the relative fundamentality of parts and wholes, the direction of time. Throughout, special attention will be paid to the ontology of the different theories, realistically construed.

Readings

Required book (available at the bookstore and on reserve at the library):

Albert, *Quantum Mechanics and Experience*

Other readings are available on the course website (address given out in class)

Optional books (available at the bookstore and on reserve at the library):

Bell, *Speakable and Unspeakable in Quantum Mechanics*, 2nd edition

Ghirardi, *Sneaking a Look at God's Cards*, revised edition

Maudlin, *Quantum Non-Locality and Relativity*, 3rd edition (e-book at library)

Ney and Albert, eds., *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*

Some physics textbooks for reference (on reserve at the library):

Eisberg and Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles*

Griffiths, *Introduction to Quantum Mechanics*

Shankar, *Principles of Quantum Mechanics*

Prerequisites

I will assume that you have had some high school physics. I assume that you have had some exposure to calculus, including differentiation of functions of more than one variable, but this needn't be at your fingertips: we will review what we need during the first few classes. It will help if you have also had some exposure to vectors, matrices, and complex numbers, but we will review this. I assume no background in philosophy, although one previous course is recommended.

Requirements and grading

Reading, attendance, participation, and homework. Required reading for each class. (There may be a few homework problems, graded on a satisfactory/unsatisfactory basis, depending on students' backgrounds.) Participation and attendance (and any homework) count for 10% of your final grade. Participation in class discussion can only help your grade; lack of participation won't hurt your grade. Attendance is mandatory. Note that if you miss a class, it is *your responsibility* to get notes and announcements from a classmate.

Written work. Three options for graded written work:

1. Take-home midterm exam and take-home final exam. The exams will consist of around 5 questions with two-page answers each. Questions will ask you to explain and evaluate the views and arguments discussed in class. You will need to be able to critically evaluate these views; you will not need to come up with anything like your own theory of quantum mechanics, nor will you be asked to reproduce lots of mathematics. The exams are intended to test your basic comprehension of some difficult material.

   The midterm exam will be handed out in class March 6 and due in class March 13; the midterm counts for 40% of your grade. The final exam will be handed out the last day of class, May 1, and due two weeks later, 5pm May 15; the final counts for 50% of your grade.

2. Take-home midterm exam as above (40% of your grade) and final paper of 8-10 pages on a topic of your choice, due on May 15 (50% of your grade).

3. One final paper, around 20 pages, on a topic of your choice, due May 15 (90% of grade).

Options 1 and 2 are open to all students in the class. Students with no background in the material are encouraged to take option 1. Option 3 is reserved for graduate students, except in special cases; if you are an undergraduate interested in this option, you need to get my approval early on in the semester. Paper topics for options 2 and 3 must be cleared with me in advance. *Turn in your work on time; I will not accept late papers or exams except in extraordinary circumstances.*

Academic integrity

Each student in this course is expected to abide by the Cornell University Code of Academic Integrity. Any work submitted by a student in this course for academic credit will be the student's own work. For this course, collaboration is allowed in discussing homework questions, paper topics, and exam questions. Papers, exams, and homework submitted for credit must be entirely your own work. If you quote or use an idea from another source, *you must cite it*. More information on Cornell's Code of Academic Integrity can be found here: http://www.theuniversityfaculty.cornell.edu/AcadInteg/index.html

Office Hours

Tuesday 1:00-2:00pm, 235 Goldwin Smith Hall

Schedule

Details are subject to change during the semester. Readings are listed by the date on which they will be discussed. Topics for the last few weeks may change depending on student interest and our progress during the first part of the class. *Note*: there will be no class on January 30.

January 23: Introduction

Introduction to quantum mechanics. Overview of the theory and its experimental evidence, including the photoelectric effect and two-slit experiments; wave-like and particle-like behavior of light and matter; realist, observer-independent theories of quantum mechanics.

Feynman, "Quantum Behavior" (from *Feynman Lectures on Physics, Vol. 1*)
(Optional: Ghirardi ch. 1)

January 30: No class

February 6: The formalism

Overview of complex numbers; vectors and vector spaces; vector addition and multiplication by scalars; complex and real vector spaces; matrices; state vectors; Dirac notation. Superposition states, the uncertainty principle, incompatible observables. Spin experiments; begin the mathematical formalism for spin.

Albert ch. 1; begin ch. 2
Ismael, "Quantum Mechanics," available at:
`http://plato.stanford.edu/entries/qm/`
(Optional: Ghirardi chs. 2-4; Maudlin, "An Overview of Quantum Mechanics" (the last section of *Quantum Non-Locality and Relativity*))

February 13: Linking the formalism up to the physics

The mathematical formalism for spin; linear operators, Hermitian operators, eigenvectors, eigenvalues, the eigenvalue equation; vector bases; commutators;

matrices, matrix multiplication; inner products, probability, probability amplitudes. The postulates of quantum mechanics; the dynamics (Schrödinger equation), measurement outcomes, the eigenstate-eigenvalue link; Born rule; superposition states.

Albert ch. 2 through p. 43

February 20: The measurement problem and the orthodox view

Recap of the basic postulates of quantum mechanics and the main points from the math; quantum mechanical measurement and the collapse postulate. Multiparticle systems, product states, entangled states. Linearity of the dynamics; the measurement problem; the orthodox understanding of quantum mechanics.

Albert ch. 4

Bell, "Against 'Measurement'" excerpts

(Optional: Ghirardi chs. 5-7, 15; Schrödinger, "The Present Situation in Quantum Mechanics")

February 27: The EPR argument

Midterm exam handed out in class; due in class in two weeks, on March 13.

Product states; multi-particle systems; entanglement. Singlet state; the Einstein-Podolsky-Rosen argument; the question of the completeness of quantum mechanics; quantum non-locality.

Albert, the rest of ch. 2; start ch. 3

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

(Optional: Bell, "On the Einstein-Podolsky-Rosen Paradox"; Ghirardi ch. 8)

March 6: The lessons of Bell's theorem

Review EPR argument. Bell's theorem; the lessons of Bell's theorem.

Albert ch. 3

(Optional: Albert and Galchen, "Was Einstein Wrong?: A Quantum Threat to Special Relativity"; Aspect, "Bell's Inequality Test: More Ideal than Ever"; Bell, "Bertlmann's Socks and the Nature of Reality"; Ghirardi ch. 10; Maudlin, "Bell's Theorem: The Price of Locality," ch. 1 of *QNLR*)

March 13: Collapse theories

Midterm exam due in class.

The wavefunction; position, momentum; coordinate space, physical space, statespace, configuration space; describing the two-path experiments. Modifying the dynamics in response to the measurement problem; collapse theories in general, the GRW theory in particular. The possibility of experimental evidence of collapse; energy conservation, begin discussing the tails problem.

Albert ch. 5 (continue with this next class)

(Optional: Bell, "Are There Quantum Jumps?"; Ghirardi 16.8, 17)

March 20: Problems for collapse theories

The tails problem; Albert and Loewer's response to the tails problem; fundamental ontology, particles, and ordinary objects in GRW in particular and collapse theories in general. The possibility of measurements that don't get recorded in macroscopic position states; the possibility of belief states that remain in superpositions.

Albert ch. 5 (continued)

Albert and Loewer, "Tails of Schrödinger's Cat"

March 27: The bare theory and many minds

What it "feels like" to be in a superposition; the dynamics with nothing added; the bare theory. Single minds and many minds. Empirical adequacy; making sense of probability in quantum mechanics.

Albert ch. 6

(Optional: Albert, Loewer, "Interpreting the Many-Worlds Interpretation")

April 10: Class canceled

April 17: Many worlds

Everettian or many-worlds theories of quantum mechanics; making sense of probability in many-worlds theories; preferred basis; the role of decoherence.

P. Lewis, "Uncertainty and Probability for Branching Selves"

(Optional: Bell, "Six Possible Worlds"; Greaves, "Probability in the Everett Interpretation"; Wallace, "A Prolegomenon to the Ontology of the Everett Interpretation" in *The Wave Function*)

April 24: Bohmian mechanics

Deterministic quantum mechanics and "hidden variables"; the guidance equation, effective wavefunction, effective collapse; the nature of probability in deterministic theories in general and in Bohm's theory in particular.

Albert ch. 7

(Optional: Bell, "On the Impossible Pilot Wave"; Ghirardi, ch. 9; Goldstein *et al*, "Naive Realism about Operators"; Goldstein, "Bohmian Mechanics," available at: `http://plato.stanford.edu/entries/qm-bohm/`; Maudlin "What Could Be Objective about Probabilities?")

May 1: Bohm meets Everett

The measurement problem as a problem for ordinary objects; combining features of Bohmian mechanics and many-worlds; Bohmian threads; the nature of probability.

Dorr, "Finding Ordinary Objects in Some Quantum Worlds"

(Optional: Dorr, "Some Notes on Probability in Quantum Mechanics")

May 7, 5pm (at Northstar): The ontology of the wavefunction

The ontological status of the wavefunction; different ontologies for GRW and Bohm's theory; primitive ontology, fundamental and nonfundamental ontology; local beables. Physical space, configuration space, the wavefunction's space; different notions of completeness of a physical theory; the manifest and scientific images; ordinary objects in a quantum world; emergence and ground.

Albert, "Elementary Quantum Metaphysics"

Allori *et al*, "On the Common Structure of Bohmian Mechanics and the Ghirardi-Rimini-Weber Theory"

Maudlin, "Completeness, Supervenience, and Ontology"

North, "The Structure of a Quantum World"

(Optional: Allori, "Primitive Ontology and the Structure of Fundamental Physical Theories" in *The Wave Function*; other papers in that book; Bell, "The Theory of Local Beables" and "Quantum Mechanics for Cosmologists"; Ney, "Fundamental Physical Ontologies and the Constraint of Empirical Coherence: A Defense of Wave Function Realism" and "The Status of Our Ordinary Three Dimensions in a Quantum Universe"; Wallace, "Everett and Structure"; Wallace and Timpson, "Quantum Mechanics on Spacetime I: Spacetime State Realism")