Philosophy 426: Philosophy of Physics: Quantum Mechanics
Fall 2023
TF 10:20–11:40am, 106 Somerset St., fifth floor seminar room
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There is no question that quantum mechanics is empirically successful. What the theory says about the world, though, remains controversial. We will look at different theories of quantum mechanics and examine a range of philosophical issues that arise for them. Topics include: the measurement problem; quantum nonlocality; the ontological status of the wavefunction; the fundamental ontology of the theory; the nature of probability; the compatibility of quantum mechanics with relativity. Throughout, special attention will be paid to the ontologies of different theories of quantum mechanics, realistically construed.

Readings

Required book: David Albert, *Quantum Mechanics and Experience*
Optional: Jeffrey Barrett, *The Conceptual Foundations of Quantum Mechanics*
All other readings are available on Canvas or an online address given below

Prerequisites

It is recommended that you have had some exposure to physics at either a high school or college level and that you have had at least one philosophy course.

Requirements and grading

Attendance and participation; reading. Assigned readings will not be very long, but they can be difficult. It is recommended that you read each assignment once before class and again afterward. Participation and attendance count for 10% of your final grade. Attendance is mandatory; since exam questions will be based on material covered in class, poor attendance is very likely to lower your grade. Note that if you miss a class it is *your responsibility* to get notes and announcements from a classmate.

Exams. Three take-home exams of short-answer questions, each 30% of your final grade.

Office hours

Friday 1:30-2:30pm or by appointment: 106 Somerset St. room 530.

Academic integrity

Each student in this course is expected to abide by the Rutgers University Principles 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 questions on exams; exams must be written up on your own. Exams 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 Rutgers' Principles of Academic Integrity is here:

`http://academicintegrity.rutgers.edu`

Course materials posted on the course website or handed out in hard copy are intellectual property belonging to the author. Students are not permitted to buy or sell any course materials without the express permission of the instructor. Such unauthorized behavior constitutes academic misconduct.

Schedule

Readings are listed by the date they will be discussed in class. Details are subject to change during the semester. Optional readings contain either further background or more advanced discussion.

Sept. 5: Introduction

Overview of quantum mechanics and the departure from classical mechanics. Photoelectric effect and two-slit experiments; wave-like and particle-like behavior; interference. Realist theories of quantum mechanics.

Reading: Feynman, "Quantum Behavior" secs. 1–5, available at
`https://www.feynmanlectures.caltech.edu/I_37.html`
Optional: Barrett ch. 1

Sept. 8 and 12: Quantum phenomena

Two-slit experiments; quantum-mechanical interference. Spin; experiments with spin boxes; two-path experiments; total-of-nothing box. Superposition.

Reading: Albert ch. 1
Optional: Barrett ch. 2

Sept. 15 and 19: Mathematical formalism: preliminaries

Vectors, operations on vectors, vector spaces; complex numbers and vector spaces; Dirac notation. Vector components and bases; linear operators and matrices; eigenvectors and eigenvalues; the eigenvalue equation.

Reading: Albert ch. 2 through p. 30
Optional: Barrett ch. 3; Ismael, "Quantum Mechanics," available at

https://plato.stanford.edu/entries/qm/

Sept. 22 and 26: THE STANDARD FORMULATION OF QUANTUM MECHANICS

The standard postulates and the standard way of thinking about them. Representing physical states and observables using the standard formalism. Illustrating the first two postulates with the formalism for spin. Incompatible observables; uncertainty principle; the standard way of thinking about superposition. Linearity and the dynamics.

Reading: Albert ch. 2 pp. 30–36

Optional: Barrett ch. 4

Sept. 29, Oct. 3, and Oct. 6: MORE ON THE POSTULATES AND FORMALISM

Hilbert space; Hermitian operators; commutators and incompatible observables. Probability and the Born rule. The collapse postulate and the nature of measurement on the standard theory. Position and momentum; the wavefunction.

Reading: Albert ch. 2 pp. 36–53

Oct. 10 and Oct. 13: DESCRIBING THE EXPERIMENTS

Midterm 1 posted Oct. 13; due by the end of class Oct. 20.

Systems with more than one degree of freedom; nonseparable states and entanglement. Describing spin-box and two-path experiments using the standard theory and formalism; the standard way of thinking about these experiments.

Reading: Albert ch. 2. pp. 53–60

Optional: Barrett ch. 5

Oct. 17 and Oct. 20: QUANTUM NONLOCALITY

Midterm 1 due Oct. 20.

EPR's argument; completeness and reality; quantum nonlocality. Bell's argument; what Bell showed. Quantum mechanics and relativity.

Reading: Albert ch. 3

Optional: Barrett ch. 6; Einstein, Podolsky, and Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?"; Aspect, "Bell's Inequality Test: More Ideal than Ever"

Oct. 24: The measurement problem

Measurement and collapse; the linearity of the dynamics. The measurement problem and the orthodox view.

Reading: Albert ch. 4

Optional: Barrett ch. 7; Scrödinger, "The Present Situation in Quantum Mechanics"

Oct. 27 and Oct. 31: Collapse theories

Collapse theories in general, GRW in particular. The orthodox theory as failing to answer the measurement problem. GRW's answer to the measurement problem.

Reading: Albert ch. 5, pp. 80–98 (skip the digression on pp. 84–92)

Optional: Bell, "Against 'Measurement' "

Nov. 3: Problems for collapse theories

Position eigenstates and energy conservation; revising GRW. The tails problem; the wavefunction and particles in collapse theories. Positionless measurements; microscopic measurements.

Reading: Albert ch. 5, pp. 99–111

Optional: Albert and Loewer, "Tails of Schrödinger's Cat"; Barrett ch. 8

Nov. 7 and 10: The bare theory; many minds

Midterm 2 posted Nov. 10; due by the end of class Nov. 17

What it feels like to be in a superposition; quantum mechanics without collapse. The dynamics with nothing added; the bare theory. Single minds and many minds; empirical adequacy and empirical coherence; making sense of probability in quantum mechanics.

Reading: Albert ch. 6 pp. 116–133

Optional: Barrett ch. 9; sec. 10.5

Nov. 14: Many worlds

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

Reading: Albert ch. 6 pp. 112–116; P. Lewis, "Uncertainty and Probability for Branching Selves" secs. 1–3

Optional: rest of Lewis; Barrett ch. 10; Saunders and Wallace, "Branching and Uncertainty"; Wallace, "A Prolegomenon to the Ontology of the Everett

Interpretation” secs. 3–4 and “Everett and Structure”

Nov. 17, 22, 28, and Dec. 1: Bohm's theory

Midterm 2 due Nov. 17.

Bohmian mechanics; hidden variables; the guiding equation; configuration space; effective collapse; the nature of probability in deterministic theories in general and Bohm's theory in particular. Bohm's account of two-slit and spin-box experiments.

Reading: Albert ch. 7

Optional: Barrett ch. 11; Goldstein, “Bohmian Mechanics,” available at `https://plato.stanford.edu/entries/qm-bohm/`

Dec. 5: Wavefunction realism

The ontological status of the wavefunction. The question of realism about the wavefunction; configuration space and ordinary space; the problem of the manifest image.

Reading: Albert, “Elementary Quantum Metaphysics” and “Wavefunction Realism”

Optional: Albert, “Quantum Mechanics and Everyday Life” (ch. 6 of *After Physics*); Ismael, “Space, Quantum Mechanics, and Bohm's Fish Tank” secs. 7.1 and 7.7; Ney, “Introduction” (esp. sec. 5) to *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*, “Separability, Locality, and Higher Dimensions in Quantum Mechanics,” and “Finding the Macroworld” (ch. 7 of *The World in the Wave Function*)

Dec. 8: Against wavefunction realism

The wavefunction, particles, and macroscopic objects in different theories of quantum mechanics. Primitive ontology as an approach to the metaphysics of quantum mechanics and physics in general; the wavefunction as nomological.

Reading: Allori, “Primitive Ontology and the Structure of Fundamental Physical Theories”

Optional: Albert, “Primitive Ontology” (ch. 7 of *After Physics*); Barrett ch. 12; Belot, “Quantum States for Primitive Ontologists”; Emery, “Against Radical Quantum Ontologies” and “Quantum Correlations and the Explanatory Power of Radical Metaphysical Hypotheses”; Hubert and Romano, “The Wave-Function as a Multi-Field”; Maudlin, “Completeness, Supervenience, and Ontology” pp. 3151 through the top of p. 3162 and “Can the World be

Only Wavefunction?" esp. pp. 121–125

Dec. 12: Quantum mechanics and scientific realism
Does quantum mechanics create particular trouble for scientific realism? Traditional arguments for and against scientific realism. Interpreting a physical theory; partially interpreted theories; underdetermination of interpretation by theory; fundamental vs. effective theories; ambiguity as a theoretical virtue. Theoretical equivalence and "deep metaphysics."

Reading: Jones, "Realism About What?" secs. 1, 2, 4; Ruetsche, "Getting Real about Quantum Mechanics"

Optional: Ruetsche, "Exegesis Saves: Interpreting Physical Theories" secs. 1–5; Saatsi, "Truth vs. Progress Realism about Spin" and "Scientific Realism meets Metaphysics of Quantum Mechanics"

Final exam posted Dec. 12; due Dec. 19.