Philosophy of Physics: Quantum Mechanics
Fall 2024
F 12:15-3:00pm
Jill North (j.north@rutgers.edu)

There is no question that quantum mechanics is empirically successful. What the theory says about the world remains controversial. In this course, 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 nature of probability; compatibility of quantum mechanics with relativity; theoretical equivalence. The primary goal of the course is to cover the background necessary to follow current philosophical debates, particularly in the metaphysics of quantum mechanics, at a level aimed at students without prior exposure to quantum mechanics, who have had some high school physics and mathematics.

Readings.

Book: David Albert, *Quantum Mechanics and Experience*. Other readings are available on Canvas or online as noted below.

Optional books: see the references listed here:
`https://plato.stanford.edu/entries/qm/`. Optional chapters from Barrett's *The Conceptual Foundations of Quantum Mechanics* in particular are listed below, along with optional articles (on Canvas or at an address noted below).

Requirements and grading. Written work totaling about 20–25 pages, chosen from among a take-home midterm (10 pages); take-home final (10 pages); final paper (either a shorter paper of about 10 pages, or a regular seminar paper). Please clear paper topics with me in advance. Graduate students taking the course for non-research paper credit may choose to do either the midterm or final or shorter final paper.

Office hours. Tuesday 2:30-3:30pm or by appointment, room 530.

Schedule. Readings are listed by the date they will be discussed in class. Details are subject to change during the semester. Please check the syllabus on Canvas regularly.

Sept. 6: Introduction to quantum mechanics

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

Reading: Albert ch. 1

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

Sept. 13: Experiments with spin boxes; mathematical preliminaries

Experiments with spin boxes; two-path experiments; superposition. Complex numbers; vectors, operations on vectors, vector spaces; Dirac notation.

Reading: Albert ch. 1

Optional: Barrett ch. 2

Sept. 20: More mathematical formalism; the standard postulates

Vector components and bases. Linear operators and matrices; eigenvectors and eigenvalues; the eigenvalue equation. The standard postulates and the standard way of thinking about them. Illustrating with the formalism for spin.

Reading: begin Albert ch. 2

Optional: Ismael, "Quantum Mechanics," at `https://plato.stanford.edu/entries/qm/`

Sept. 27: More on the postulates and formalism

The standard postulates; the standard way of thinking about superposition. Hilbert space; Hermitian operators; commutators and incompatible observables; the uncertainty principle. Linearity and the dynamics. Probability and the Born rule. The nature of measurement.

Reading: continue Albert ch. 2

Optional: Barrett ch. 3

Oct. 4: Finishing the formalism

Position, momentum, and the wavefunction. Systems with more than one degree of freedom; product states; nonseparable states; entanglement; the singlet state. Characterizing spin boxes.

Reading: continue Albert ch. 2

Optional: Barrett ch. 4

Oct. 11: Describing the experiments

Describing spin boxes and two-path experiments with the standard theory and formalism. Overview of EPR.

Reading: finish Albert ch. 2; begin Albert ch. 3

Optional: Barrett chs. 5

Oct. 18: Nonlocality: EPR and Bell

Midterm handed out; due Nov. 1.

EPR's argument; completeness and reality; nonlocality. Bell's argument and the lessons of Bell's theorem.

Reading: Albert ch. 3; Maudlin, "What Bell Did"

Optional: Aspect, "Bell's Inequality Test: More Ideal than Ever"; Barrett ch. 6; Einstein, Podolsky, and Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?"; Mermin, "Bringing Home the Atomic World: Quantum Mysteries for Anybody"; Norsen, "Bell's Theorem" (*Foundations of Quantum Mechanics* ch. 8)

Oct. 25: Class cancelled

Nov. 1: The measurement problem and collapse theories

Midterm due Nov. 1.

The measurement problem and the standard theory as failing to answer the problem. Collapse theories in general, the GRW theory in particular. GRW's answer to the measurement problem. Position eigenstates and energy conservation; revising GRW. The tails problem; the wavefunction and particles in collapse theories. Positionless measurements; microscopic measurements.

Reading: Albert chs. 4–5

Optional: Albert and Loewer, "Tails of Schrödinger's Cat"; Barrett chs. 7–8; Bassi, Dorato, and Ulbricht, "Collapse Models: A Theoretical, Experimental and Philosophical Review"; Bell "Against 'Measurement' " excerpts; Schrödinger, "The Present Situation in Quantum Mechanics"

Nov. 8 and 22: Bohm's theory; special guest Shelly Goldstein, Nov. 22

Bohmian mechanics. Hidden variables; the guiding equation; configuration space; effective collapse and the effective wavefunction. The nature of probability. Bohm's account of and spin and two-path experiments; contextual properties. Particles and the wavefunction.

Reading: Albert ch. 7; Feynman, "Probability and Uncertainty: the Quantum Mechanical View of Nature" (ch. 6 of *The Character of Physical Law*); Goldstein, "Bohmian Mechanics," at

`https://plato.stanford.edu/entries/qm-bohm/`

Optional: Barrett ch. 11

Nov. 15: No class

Nov. 27 The bare theory; many minds

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

Reading: Albert ch. 6 starting from p. 116

Optional: Albert and Loewer, "Interpreting the Many-Worlds Interpretation"; Barrett ch. 9, 10.5

Dec. 6: Many worlds

Everettian or many worlds theories of quantum mechanics. Making sense of probability in many worlds; the question of a preferred basis; the role of decoherence; emergent ontology; functionalism about ordinary objects.

Reading: Albert ch. 6 pp. 112–116 and "Probability in the Everett Picture" (ch. 8 of *After Physics*); P. Lewis, "Uncertainty and Probability for Branching Selves" secs. 1–3; Wallace, "The Emergence of Multiplicity" (ch. 2 of *The Emergent Multiverse*)

Optional: Barrett ch. 10; Greaves, "Probability in the Everett Interpretation"; Saunders and Wallace, "Branching and Uncertainty"

Dec. 13 (makeup class): Wavefunction realism

Final handed out; due Dec. 20. Final papers due before the spring semester.
Considerations for and against wavefunction realism. Configuration space and ordinary space; the problem of the manifest image/the macro-object problem. The wavefunction, particles, and macroscopic objects in different theories of quantum mechanics. The aim of a separable and local fundamental metaphysics. The primitive ontology approach.

Reading: Albert, "Elementary Quantum Metaphysics"; Allori, "Primitive Ontology and the Structure of Fundamental Physical Theories"; Emery, "Against

Radical Quantum Ontologies"; Ney, "Finding the Macroworld" (ch. 7 of *The World in the Wave Function*)

Optional: Albert, "Quantum Mechanics and Everyday Life" (ch. 6 of *After Physics*); Barrett, 8.4–8.5 and ch. 12; Belot, "Quantum States for Primitive Ontologists"; Ismael, "What Entanglement Might Be Telling Us: Space, Quantum Mechanics, and Bohm's Fish Tank"; Ismael and Schaffer, "Quantum Holism: Nonseparability as Common Ground"; Maudlin, "Completeness, Supervenience, and Ontology"; Ney, "The Virtues of Separability and Locality" and "The Causal Role of Macroscopic Objeccts" (chs. 3 and 6 of *The World in the Wave Function*); Sider, "3D in High-D"; Wallace and Timpson, "Quantum Mechanics on Spacetime I: Spacetime State Realism"