Advanced Topics in Philosophy of Physics: Philosophy of Quantum Mechanics

Philosophy 658, Fall 2016, M 1:10–4:10, Philosophy seminar room

J. North (j.north@rutgers.edu), T. Sider (sider@rutgers.edu)

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 each of them. 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):

Albert, *Quantum Mechanics and Experience*

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

Optional books (on reserve at the library):

Albert, *After Physics* (it is recommended that you get this book as well, especially if you plan to attend Albert's seminar next semester)

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

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*

Background

We will assume some high school physics, and 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.

Requirements and grading

Take-home midterm exam (largely expository), handed out in class on October 10 and due by email October 31, 40%. Seminar paper, roughly 20 pages double-spaced, due by email 12/23. Please clear your paper topic with us in advance.

Office Hours

JN: Monday 11:00am–12:00pm, 106 Somerset St, room 530
TS: Thursday 11:30am–12:30pm, 106 Somerset St, room 534

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 weeks will be decided on the basis of student interest and our progress during the first part of the class.

September 12: 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; spin experiments. Realist, observer-independent theories of quantum mechanics. Superposition.

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

September 19, September 26: The formalism and the postulates

Complex numbers; vectors and vector spaces; vector addition and multiplication by scalars; complex and real vector spaces; state vectors; Dirac notation. Superposition states, the uncertainty principle, incompatible observables. The mathematical formalism for spin. Linear operators, Hermitian operators, eigenvectors, eigenvalues, the eigenvalue equation; vector bases; commutators; matrices; inner products, probability, probability amplitudes. The postulates of quantum mechanics; the dynamics, the Born rule, the collapse postulate.

Albert ch. 1; ch. 2 through p. 43

(Optional: Ismael, "Quantum Mechanics," available at:

`http://plato.stanford.edu/entries/qm/`

Ghirardi chs. 2–4; Maudlin, "An Overview of Quantum Mechanics": the last section of *Quantum Non-Locality and Relativity*)

October 3: THE MEASUREMENT PROBLEM AND THE ORTHODOX VIEW

Quantum mechanical measurement and the collapse postulate. Multi-particle systems, product states, entangled states. Linearity of the dynamics and the measurement problem. The orthodox view of quantum mechanics. Maybe begin EPR.

Albert ch. 4; first section of ch. 5

Bell, "Against 'Measurement" excerpts

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

October 10: THE EPR ARGUMENT AND BELL'S THEOREM

Midterm handed out.

More on multi-particle systems; product states; entanglement; singlet state. The EPR argument; the question of the completeness of quantum mechanics; quantum nonlocality. The lessons of Bell's theorem.

Albert ch. 3; ch. 2 pp. 47-52

(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"; Bell, "On the Einstein-Podolsky-Rosen Paradox"; Einstein, Podolsky, and Rosen, "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?"; Ghirardi ch. 8; Ghirardi ch. 10; Maudlin, "Bell's Theorem: The Price of Locality," ch. 1 of *QNLR*)

October 17, October 24: COLLAPSE THEORIES

The wavefunction; position, momentum, energy; coordinate space, physical space, statespace, configuration space; describing two-path experiments using the formalism. Modifying the dynamics in response to the measurement problem; collapse theories in general, GRW in particular. The possibility of experimental evidence of collapse; energy conservation. The tails problem; wavefunction ontology, particles, and ordinary objects in collapse theories. The possibility of measurements that don't get recorded in macroscopic position states; the possibility of belief states that remain in superpositions.

Albert, rest of ch. 2; ch. 5

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

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

October 31: Bare theory, many minds

Midterm due by email.

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 and Loewer, "Interpreting the Many-Worlds Interpretation")

November 7: Bohmian mechanics; special guest S. Goldstein

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?")

November 14, November 21: Many worlds

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

Albert, "Probability in the Everett Picture" (in *After Physics*)

Greaves, "Probability in the Everett Interpretation"

Wallace, "Everett and Structure"

(Optional: Bell, "Six Possible Worlds of Quantum Mechanics"; P. Lewis, "Uncertainty and Probability for Branching Selves"'; Wallace, "A Prolegomenon to the Ontology of the Everett Interpretation" in *The Wave Function*)

November 28, December 5: 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 for a physical theory; manifest and scientific images of the world; ordinary objects in a quantum world.

Albert, "Elementary Quantum Metaphysics"

Albert, "Quantum Mechanics and Everyday Life"; "Primitive Ontology" (in *After Physics*)

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

Maudlin, "Completeness, Supervenience, and Ontology"

(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"; Belot, "Quantum States for Primitive Ontologists"; Dorr, "Finding Ordinary Objects in Some Quantum Worlds" and "Some Notes on Probability in Quantum Mechanics"; 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"; North, "The Structure of a Quantum World"; Wallace and Timpson, "Quantum Mechanics on Spacetime I: Spacetime State Realism")

December 12: Catch up or further topic

Further topics: Identity and individuality; parts and wholes; the direction of time; issues that arise from combining relativity and quantum mechanics, such as the nature of causation (narratability failure will be discussed next term in Albert's class); Humeanism in a quantum world; Humean approach to the wavefunction.