Philosophy 165/265 -- Philosophy of Physics
Philosophical Issues in Quantum Mechanics

Stanford University, Spring Quarter 2006
Tues.-Thurs. 1:15 – 2:30

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I. TOPICS TO BE COVERED: The first third of the course will introduce the vector space formalism of QM and quantum dynamics, together with conceptual problems regarding the uncertainty principle, wave-particle duality, quantum measurement, spin, and their treatment within the so-called "Copenhagen interpretation" of quantum mechanics, and the related doctrine of complementarity. We next turn to the issue of quantum entanglement as raised by Einstein and Schrödinger in the 1930s. Here we will focus on the famous Einstein-Podolsky-Rosen paper of 1935 and on the complexities of Bohr's response to Einstein, and then examine a well-known theorem on EPR-type experimental set-ups due to Bell in the 1960s according to which no hidden variables theory satisfying a certain locality condition (apparently assumed by EPR) can reproduce all the predictions of quantum mechanics. In the last third of the course, we will survey several live variations of, or interpretive options for, standard quantum mechanics: Bohmian mechanics, "spontaneous collapse" theories, and Everett's 'relative-state' interpretation with its "many worlds"/ "many minds" variants. We will end by scrutinizing a current view known as "decoherence" that seeks to explain the emergence of the world of classical physics and everyday objects from quantum physics.

II. PREREQUISITES: Some background in philosophy, physics or mathematics will be helpful. No detailed knowledge of quantum physics or advanced mathematics is presumed, but students will benefit from possession of a modicum of "mathematical maturity" (roughly equivalent to a familiarity with single-variable calculus or the metatheory of first-order logic) that will assist them in digesting the quantum formalism. *Leave math anxiety at the door.*

III. READINGS.

Required:

1) Jim Baggott. *Beyond Measure. Modern Physics, Philosophy and the Meaning of the Quantum Theory.* Oxford UP, 2004. Paper.

Recommended:

2) David Z. Albert. *Quantum Mechanics and Experience.* Harvard UP, 1992. Paper.

Both books are available from the Stanford bookstore.

Other required and recommended readings are in these books, placed on RESERVE in Tanner Library in Bldg. 90.

• John S. Bell. *Speakable and Unspeakable in Quantum Mechanics.* Second edition. Cambridge UP, 2004, or first edition, Cambridge UP, 1987.

• Mara Beller. *Quantum Dialogue: The Making of a Revolution.* University of Chicago Press, 1999.

• James T. Cushing (ed.). *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem.* University of Notre Dame Press, 1989.

• _____. *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony.* University of Chicago Press, 1994.

• Arthur Fine. *The Shaky Game: Einstein, Realism and the Quantum Theory.* Second Edition. University of Chicago Press, 1996. Paper. Tanner has 1st ed. (1986)

• Max Jammer. *The Philosophy of Quantum Mechanics; The Interpretations of Quantum Mechanics in Historical Perspective.* NY: John Wiley and Sons, 1974.

• P.A. Schilpp (ed.), *Albert Einstein: Philosopher-Scientist.* Evanston, IL: Northwestern UP, 1949.

• John Wheeler and Wojciech Zurek (eds.). *Quantum Theory and Measurement.* Princeton University Press, 1983.

In addition to the above, a number of articles from the on-line *Stanford Encyclopedia of Philosophy* will be used. Still others will be posted on the course website or are available to Stanford students through JSTOR at the SU Libraries website.

IV. COURSE REQUIREMENTS.

There will be a take-home midterm, in addition to a final term paper. Graduate students in philosophy will be expected to produce a more substantive final paper. I am not interested nearly so much in length as in content and engagement with the subject matter. All who attend should be prepared to respond to questions, and to actively participate in discussion. There is no final.

V. EVALUATION. The midterm exam is 40%, the final paper is 50% of the grade for the course. The remaining 10% will be based on class participation. Late papers will not be accepted without proper (medical, emergency) excuse.

VI. FORMAT. This is a lecture course; most if not all notes from the lectures will be posted on the Stanford CourseWork website. With several exceptions, I shall endeavor to lecture for no more than 45-50 minutes, leaving the remaining time of each class meeting open for questions and discussions.

VII. SCHEDULE OF LECTURES/DISCUSSIONS.

April 4th: Introduction.

6th: From Classical to Quantum. The Two Slit and Stern-Gerlach Experiments.

(Readings: Baggott, Part I; Albert, Ch. 1.)

11th: The Quantum Formalism I.

(Readings; Baggott, Ch. 4; Albert Ch. 2; see also the article by Jenann Ismael, "Quantum Mechanics" in the on-line *Stanford Encyclopedia of Philosophy.*)

13th: The Quantum Formalism II.

(Readings, as above.)

18th: The Born Rule. Heisenberg's Uncertainly Principle.

(Readings: Jammer, Ch. 3; Beller, Chs. 4-5; Jan Hilgevoord and Jos Uffink, "The Uncertainty Principle" in the on-line *Stanford Encyclopedia of Philosophy.)*

20th: Quantum Measurement and the "Collapse" of the Wave Function.

(Readings: Baggott, Ch. 5; Albert, pp. 73-84.)

25th: The Emergence of the Copenhagen Interpretation, and Complementarity.

(Readings: Bohr (1928), "The Quantum Postulate and the Recent Development of Atomic Theory" (the "Como Lecture"), pp. 87-126 in Wheeler and Zurek (1983); Baggott, Ch. 6; Beller, Ch. 6; Jammer, Ch. 4.)

April 27th: Entanglement and Nonlocality: EPR.

(Readings: Einstein-Podolsky-Rosen (1935), "Can Quantum Mechanical Description of Physical Reality Be Considered Complete?", in Wheeler and Zurek (1983), 138-141; Arthur Fine, "The Einstein-Podolsky-Rosen Argument in QM", in the on-line *Stanford Encyclopedia of Philosophy*; Albert, Ch.3.)

May 2nd: Entanglement: Schrödinger.

(Readings: Schrödinger (1935), "The Present Situation in Quantum Mechanics", in Wheeler and Zurek (1983), 152-167; also posted on course website; Arthur Fine, *TSG,* Ch. 5.)

4th: Bohr's Response to EPR. ***Take-Home Midterm Distributed***.

(Readings: Bohr (1935), "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", in Wheeler and Zurek (1983), 145-151; Bohr (1949), "Discussion With Einstein on Epistemological Problems in Atomic Physics", in Wheeler and Zurek (1983), 9-49, or in Schilpp (1949), 201-241; Beller, Ch. 7.)

9th: Bohm's version of EPR and Bell's Theorem. ***Midterm Due at 1:15 pm.***

(Readings: Baggott, Chs. 8-9; Bell, "Bertlmann's Socks and the Nature of Reality", in *SUQM,* Second edition ONLY, 2004, 139-158.)

11th: Philosophical Reactions to Bell's Theorem.

(Readings: Abner Shimony, "Bell's Theorem", Section 7, in the on-line *Stanford Encyclopedia of Philosophy* ; also Shimony, "Search for a Worldview Which Can Accommodate Our Knowledge of Microphysics", and Arthur Fine, "Do Correlations Need To Be Explained?", both in Cushing (ed.) (1989), 25-37, and 175-194; N. David Mermin, "The Ithaca Interpretation of QM", arXiv:quant-ph/9609013 v1 17 Sept 1996, also posted on course website; Henry Pierce Stapp (1972), "The Copenhagen Interpretation", *American Journal of Physics* **40**, 1098-1116, posted on course website.)

16th: Bohmian Mechanics.

(Readings: Baggott, Ch. 11; Albert, Ch. 7; Sheldon Goldstein, "Bohmian Mechanics", in the on-line *Stanford Encyclopedia of Philosophy;* Cushing (1994), *passim.)*

May 18th: Collapse Theories.

(Readings: Baggott, pp. 234-236; Albert, Ch. 5; Giancarlo Ghiradi, "Collapse Theories", in the on-line *Stanford Encyclopedia of Philosophy.)*

23rd: Everett's Relative State Interpretation, Many Worlds and Many Minds.

(Readings: Baggott, Ch. 14; Jeffrey Barrett, "Everett's Relative State Formulation of QM" and Lev Vaidman, "The Many Worlds Interpretation of QM, both in the on-line *Stanford Encyclopedia of Philosophy*; Albert, Ch. 6 and Ch. 8.)

25th: Continuation.

30th: Decoherence.

(Readings: Baggott, pp. 228-234; Guido Bacciagaluppi, "The Role of Decoherence in QM", in the on-line *Stanford Encyclopedia of Philosophy*; Arthur Fine and Maximilian Schlosshauer, "Decoherence and the Foundations of QM", to appear in James Evans and Alan Thorndike (eds.), *New Views of Quantum Mechanics; Historical, Philosophical, Scientific.* University of Chicago Press, not yet published. Available on course website.)

June 1st: Continuation.

6th: Summary.

13th: ***Final Papers Due at 12:00 noon.***