Philosophical Foundations of Quantum Mechanics

Christian Wüthrich Phil 246, Spring 2009

Class schedule:	Tu 1:00-3:50pm, HSS 7077 (Philosophy seminar room)
Website:	`http://philosophy.ucsd.edu/faculty/wuthrich/`
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After having equipped ourselves with the necessary mathematical tools, we will plunge into a careful study of the venerable mystery of quantum nonlocality. In exactly what sense is nonlocality enshrined in the theorems by Bell and by Kochen and Specker? Any solution of the measurement problem in quantum mechanics (another venerable mystery)—indeed any future physical theory—must acknowledge this nonlocality. Nonlocality is disconcerting not only because it contravenes our deeply engrained intuitions, but also because it stands in a stark tension to relativity. But both quantum mechanics (and with it, nonlocality) and special relativity have given us the most accurate empirical predictions we have ever had from physical theories. This seminar will focus its attention on this tension and track down how it plays out in all the most important interpretations of quantum mechanics available today: hidden variables/Bohmian mechanics, collapse theories/GRW, and many-worlds interpretations and recent developments of Everett's original proposal.

Prerequisites: As announced earlier, I plan to do this at an intermediate level, i.e. I am assuming that students will have something like my Phil 146 under their belt. Alternatively, if you have worked through most of David Albert's book, or have done something equivalent, or are prepared to work extra hard to make up for that. In particular, I assume that students are familiar with the basics of the theory and its formalism (as presented e.g. in the second chapter of Albert), what the measurement problem is, and what the basic interpretational options are.

Required texts

All mandatory readings will be made available through e-reserves or online. The Stanford Encyclopedia of Philosophy entries are downloadable from `http://plato.stanford.edu/`. Go to the course web page for links. I have also ordered four books, which you might consider buying at the bookstore:

- Tim Maudlin, *Quantum Non-Locality*, Blackwell Publishing (2002)
- Michael Redhead, *Incompleteness, Nonlocality and Realism*, Clarendon Paperbacks (1987)
- R.I.G. Hughes, *The Structure and Interpretation of Quantum Mechanics*, Harvard University Press (1989)
- Jeffrey Barrett, *The Quantum Mechanics of Minds and Worlds*, Oxford University Press

Course requirements and evaluation

In order to obtain credit for this class, participants must give class presentations and submit a term paper by Thursday, 11 June 2009.

Tentative schedule

Please note that the topics listed may not map as directly to the dates given, as some will take longer than others. The reading list is tentative and may still change, in particular upon popular demand.

(1) Mathematical foundations (31 March)

I will present, mostly on the blackboard, materials on the mathematical foundations. We won't quite start with Adam and Eve, and perhaps move quickly through the basic formalism and concepts, in order to have more time for a bit advanced topics such as density operators, tensor-product spaces, and Gleason's theorem.

- You should start to read work through R.I.G. Hughes, *The Structure and Interpretation of Quantum Mechanics*, Harvard 1989 (Part I).

Obviously, you can also work through other texts—there are many good sources.

(2) Mathematical foundations 2 (7 April)

I will continue my blackboard presentation on the mathematical foundations.

- You should work through the rest of R.I.G. Hughes, *The Structure and Interpretation of Quantum Mechanics*, Harvard 1989 (Part I).

(3) Nonlocality and Bell's theorem (14 April)

- Maudlin, T., *Quantum Non-Locality and Relativity*, Blackwell 2002 (2nd edition). (Ch. 1, "Bell's theorem: The price of locality", 6-28)
- Redhead, M., *Incompleteness, Nonlocality, and Realism*, Oxford 1987 (Ch. 4, "Nonlocality and the Bell inequality", 82-118)

(4) Nonlocality and the Kochen-Specker paradox (21 April)

- Redhead, M., *Incompleteness, Nonlocality, and Realism*, Oxford 1987 (Ch. 5, "The Kochen-Specker paradox", 119-138)
- Redhead, M., *Incompleteness, Nonlocality, and Realism*, Oxford 1987 (Ch. 6, "Nonlocality and the Kochen-Specker paradox", 139-152)

Further study:

- Straumann, N., "A simple proof of the Kochen-Specker theorem on the problem of hidden variables", http://arxiv.org/abs/0801.4931
- Held, C., 2006, "The Kochen-Specker Theorem", Stanford encyclopedia: http://plato.stanford.edu/entries/kochen-specker/

(5) Hidden variables, Bohmian mechanics (28 April)

- Mermin, N. D., 1993, "Hidden Variables and the Two Theorems of John Bell," *Reviews of Modern Physics* 65: 803-815.
- Barrett, J.A., "The Persistence of Memory: Surreal Trajectories in Bohm's Theory," *Philosophy of Science* 67 (2000): 680-703.

Further study:

- Dürr, D., S. Goldstein, and N. Zanghi, "Quantum equilibrium and the origin of absolute uncertainty", *Journal of Statistical Physics* 67 (1992): 843-907.
- Goldstein, S., 2006, "Bohmian mechanics", Stanford encyclopedia: http://plato.stanford.edu/entries/qm-bohm/

(6) Collapse theories (5 May)

- Albert, D. and B. Loewer, "Tails of Schrdinger's cat", in R. Clifton (ed.), *Perspectives on Quantum Reality*, Kluwer 1996.
- Allori, V., S. Goldstein, R. Tumulka, and N. Zanghi, "On the common structure of Bohmian mechanics and the Ghirardi-Rimini-Weber theory", *British Journal for the Philosophy of Science* 59 (2008) 353-389

Further study:

- Ghirardi, G., "Collapse theories", Stanford encyclopedia: http://plato.stanford.edu/entries/qm-collapse/

(7) Nonlocality and special relativity (12 May)

Depending on who will be in the seminar, we will go over Chapter 2 ("Relativity and space-time structure", 29-60) in Tim Maudlin's *Quantum Non-Locality and Relativity* as an introduction to special relativity.

- Maudlin, T., *Quantum Non-Locality and Relativity*, Blackwell 2002 (2nd edition), (Ch. 7, "Points of view", 189-222, and perhaps other chapters)

Further study:

- Albert, D.Z. and R. Galchen, "Was Einstein wrong?: A quantum threat to special relativity", *Scientific American*, February 2009.

(8) Nonlocality and special relativity 2 (19 May)

A recent debate:

- Tumulka, R., "Collapse and relativity", in A. Bassi, D. Drr, T. Weber and N. Zangh (editors), *Quantum Mechanics: Are there Quantum Jumps? and On the Present Status of Quantum Mechanics*, AIP Conference Proceedings 844. American Institute of Physics (2006), 340-352.
- Maudlin, T., "Non-Local Correlations in Quantum Theory: Some Ways the Trick Might be Done", *Einstein, Relativity, and Absolute Simultaneity*, ed. Quentin Smith and William Lane Craig, Routledge 2007, 186-209.

(9) Everett and many worlds (26 May)

- Barrett, J., *The Quantum Mechanics of Minds and Worlds*, Oxford 1999 (Ch. 3, "The theory of the universal wave function"; Ch. 6, "Many worlds")
- Saunders, S., "Time, quantum mechanics, and probability", *Synthese* 11 (1998): 373-404.

Further study:

- Everett, H., " 'Relative state' formulation of quantum mechanics", *Reviews of Modern Physics* 29 (1957): 454-462.
- Barrett, J., 2008, "Everett's relative-state formulation of quantum mechanics", Stanford encyclopedia: http://plato.stanford.edu/entries/qm-everett/
- Vaidman, L., 2002, "Many-worlds interpretation of quantum mechanics", Stanford encyclopedia http://plato.stanford.edu/entries/qm-manyworlds/

(10) Extensions and developments of Everett (2 June)

We will do a subset of the following:

- Albert, D. and B. Loewer, "Interpreting the many worlds interpretation", *Synthese* 77 (1988): 195-213. (Many minds)
- Barrett, J., *The Quantum Mechanics of Minds and Worlds*, Oxford 1999 (Ch. 7, "Many minds")
- Wallace, D., "Everettian rationality: defending Deutsch's approach to probability in the Everett interpretation", *Studies in the History and Philosophy of Modern Physics* 34 (2003): 415-439.
- Wallace, D., "Everett and structure", *Studies in the History and Philosophy of Modern Physics* 34 (2003): 87-105.
- Greaves, H., "Probability in the Everett interpretation", *Philosophy Compass* 2 (2007): 109-128.