HPS 1108F: Philosophy of Quantum Mechanics

Fridays 10-12, IN313

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General description

Quantum mechanics is one of the main pillars of modern physics. It applies to a very broad range of physical phenomena extremely successfully. Yet, about a century after its birth, it is still difficult to make a good sense of the picture it portrays of the physical reality. The standard way of interpreting the mathematical formalism of quantum mechanics is riddled with various difficulties. There are other ways to interpret this formalism and there are other theories of the quantum realm, but similarly they all involve various puzzles. In the course, we shall study the foundations of quantum mechanics and some alternative quantum theories, and try to understand the radical difference between the classical and the quantum pictures of the physical reality. Our main focus will be on philosophical and conceptual questions rather than technical details, and we shall assume no prior background in quantum mechanics.

Assignments and Grades

Class participation: 20%.
Essay 1 (ca. 3000 words): 30%. Submission date: October 26, 2007.
Essay 2 (ca. 5000 words): 50%. Submission date: December 7, 2007.

Readings

The Main Readings are mandatory. The Further Readings are intended for those who would like to broaden their knowledge beyond the basic course requirements and may also provide ideas and background for the course essays. The bulk of the Main Readings are from the course textbooks (available at the U of T bookstore, the U of T libraries and in various online stores) and the *Stanford (online) Encyclopedia of Philosophy*. Other Main Readings will be posted on the course blackboard. Some of the Further Readings are from the course textbooks or online, whereas others are available at the U of T libraries, electronic journals, or will be posted on the course blackboard. The lecture handouts and other useful teaching materials will also be posted on the course blackboard.

Course textbooks

1. Albert, D. Z. (1992), *Quantum Mechanics and Experience* (Cambridge, Mass.: Harvard University Press). ISBN: 0-674-74113-7. [Albert]

2. Ghirardi, G. C. (2005), *Sneaking a Look at God's Card: Unraveling the Mysteries of Quantum Mechanics* (Princeton University Press) ISBN: 0-691-13037-X [Ghirardi]

Other recommended introductory books

3. Hughes, R. I. G. (1989), *The Structure and Interpretation of Quantum Mechanics* (Cambridge, Mass.: Harvard University Press). ISBN: 0-674-84392-4 (pbk). ISBN: 0-674-84391-6. [Hughes]

The first part of Hughes' book gives an excellent introduction to the mathematical foundations and the main interpretative rules of standard quantum mechanics, yet it is probably more demanding than Albert's book for those of you who have no mathematical background.

4. Baggott, J. (1992), *The Meaning of Quantum Mechanics* (Oxford: Oxford University Press) ISBN: 0-19-855575-X [Baggott]

5. Isham, C. (1995), *Lectures on Quantum Theory* (London: Imperial College Press). ISBN: 1860940013 [Isham]

Technically, Isham's book is more demanding than (1)-(4).

6. Sklar, L. (1992), *Philosophy of Physics* (Boulder: Westview Press). ISBN: 0-8133-0625-6.

Sklar's book is a general introduction to the philosophy of physics.

Some more specialized books

7. Maudlin, T. (1994), *Quantum Nonlocality and Relativity*. (Oxford: Blackwell). ISBN: 0631232214 (2nd edition: February 2002) [Maudlin]

Maudlin's book focuses on the curious non-local influences between distant physical systems that quantum theories predict, and the difficulties in reconciling these non-local influences with relativity theory. The book also contains an excellent philosophical introduction to the special theory of relativity and its account of space-time structure. The 2nd edition also includes an accessible overview of quantum mechanics.

8. Barrett, J. A. (2001), *The Quantum Mechanics of Minds and Worlds*, (Oxford, NY: Oxford University Press. ISBN 0-19-924743-9 [Barrett]

Most of the book focuses on the so-called 'many-worlds' and 'many-minds' interpretations of quantum mechanics (as well as some so-called 'relative-state' interpretations of quantum mechanics). The first two chapters introduce quantum mechanics and its standard interpretation.

More advanced books

9. Bohm, D. (1951), *Quantum Theory* (New York: Dover Publications). ISBN: 0-486-65969-0 [Bohm]

This is an excellent, advanced introduction to standard quantum mechanics.

10. Bub, J. (1999), *Interpreting the Quantum World*, (Cambridge: Cambridge University Press). ISBN: 0-521-65386-x (pbk). [Bub]

Bub was Bohm's PhD student. His book, which won the prestigious Lakatos award, focuses on some of the main interpretations of quantum mechanics, in particular the family of the (so-called) 'modal interpretations' of quantum mechanics. It contains a fundamental result about the structure of an important class of quantum theories, the so-called 'no-collapse' interpretation/theories.

11. Redhead, M. L. G. (1987), *Incompleteness, Nonlocality, and Realism* (Oxford: Clarendon Press). ISBN: 0-19-824937-3. [Redhead]

This is one of the most important books on non-locality in quantum mechanics. It includes an elegant yet demanding introduction to the mathematical foundations of quantum mechanics.

12. Bell, J. S. (1987), *Speakable and Unspeakable in Quantum Mechanics*, 2nd edition (Cambridge: Cambridge University Press). [Bell] 0-521-52338-9

This is a collection of papers by the famous physicist John S. Bell. It is one of the most important and influential books in the foundations of quantum mechanics. John Bell was a physicist but he had a big influence on both physicists and philosophers of physics. His famous Bell's theorem reveals one of the most important and intriguing characteristics of the quantum realm, the (apparent) curious non-local influences between distant physical systems.

Tentative course structure[1]

1. *Introduction to the course* *Week 1: Sept 14*

Main readings

- [Ghirardi], Chapter 1.
- [Albert], Chapter 1.

2. *Standard Quantum Mechanics and its standard interpretation* *Weeks 2-3: Sept 21 Sept 28*

- The formalism and its standard interpretation
- Examples of how the 'standard' interpretation accounts for quantum phenomena

Main Readings

- [Albert], Chapters 2 and 4.

Further readings

- Ismael, J., "Quantum Mechanics", *Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qm/
- [Ghirardi], Chapter 4.
- [Hughes], Part I.
- [Maudlin], Appendix.
- [Barrett], pp. 18-55.
- [Redhead], Chapter 1.*
- [Bohm]*
- [Bub], Appendix.*
- [Isham], Chapters 1-7.*
- Clifton, R. (1996), "Introductory Notes on the Mathematics Needed for Quantum Mechanics".*

3. *Entanglement and the measurement problem* *Week 4: Oct 5*

- Entanglement
- The measurement problem
- The collapse postulate
- The main ideas of 'hidden-variables' theories
- Instrumentalism

[1]Demanding readings will be denoted by '*'.

Main reading
- [Albert], Chapter 4.

Further readings
- [Ghirardi], Chapter 15.
- [Bell], Chapters 1, 4, 7 and 17.*
- Maudlin, T. (1996), "Three Measurement Problems", *Topoi* 14, pp. 7-15.*
- Ghirardi, G. C., "Collapse Theories", *Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qm-collapse/#MacObjPro
- Barrett, J., "Everett's Relative Space Formulation of QM", *The Stanford Encyclopedia of Philosophy*, Section 2. http://plato.stanford.edu/entries/qm-everett/#2
- Berkovitz, J., "Action at a distance in quantum mechanics", *Stanford Encyclopedia of Philosophy*, Sections 1, 2 and 5.1.1. http://plato.stanford.edu/entries/qm-action-distance/

4. *The Einstein-Podolsky-Rosen argument for the incompleteness of the standard interpretation of quantum mechanics* *Week 5: Oct 12*

Main readings
- [Ghirardi], Chapter 8.

Further readings
- Einstein, A., Pdolosky, B. and Rosen, N. (1935), "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", *Physical Review* 47, 777-780. http://prola.aps.org/pdf/PR/v47/i10/p777_1
- Bohr, N. (1935), "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", *Physical Review* 47, 696-702. http://prola.aps.org/pdf/PR/v48/i8/p696_1
- [Albert], Chapter 3.
- [Ghirardi], Chapter 7.
- [Redhead], Chapter 3.
- Redhead, M. and P. La Rivière: 1997, "The Relativistic EPR Argument" in R.S. Cohen, M. Horne and J. Stachel (eds.), *Potentiality, Entanglement and Passion-at-a-Distance* (Dordrecht: Kluwer).*
- Ghirardi, G. C. and Grassi, R (1994), "Outcome Predictions and Property Attribution: the EPR Argument Reconsidered", *Studies in the History and Philosophy of Modern Physics* 25, 397-423.*

5. *The 'Hidden-variables' Program: Bohmian Mechanics* *Week 6: Oct 19*

- Von Neumann's no-go proof
- The Kochen & Specker theorem
- Bohmian mechanics

Main readings
- [Albert], Chapter 7, pp. 134-170.
- [Ghirardi], Chapter 9, pp. 195-200.

Further readings
- [Ghirardi], Chapter 9, pp. 200-225.
- Goldstein, S., "Bohmian Mechanics", *Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qm-bohm/
- Kochen, S. and Specker, E. (1967): "The Problem of Hidden Variables in Quantum Mechanics", *Journal of Mathematics and Mechanics* 17, 59-87.*
- Held, Carsten, "The Kochen and Specker Theorem", *The Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/kochen-specker/

- [Redhead], Chapters 5 and 6.*
- Mermin, N. D. (1990): "Quantum Mysteries Revisited", *American Journal of Physics* 58, 731-34.
- Mermin, N. D. (1990): "Simple Unified Form of the Major No-Hidden Variables Theorems", *Physical Review Letters* 65:,3373-76.
- Berkovitz, J., "Action at a distance in quantum mechanics", *Stanford Encyclopedia of Philosophy*, Section 5.3.1. http://plato.stanford.edu/entries/qm-action-distance/

6. *Collapse theories: The GRW models* *Week 7: Oct 26*

Main reading
- [Albert], Chapter 5.

Further readings
- [Ghirardi], Chapters 17 and 19.
- Ghirardi, G. C., "Collapse Theories", *The Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qm-action-distance/
- Berkovitz, J., "Action at a distance in quantum mechanics", *Stanford Encyclopedia of Philosophy*, Section 5.1.2. http://plato.stanford.edu/entries/qm-action-distance/
- [Bell], Chapter 21: "Are there quantum jumps?" (An alternative presentation of the GRW collapse theory)*
- Albert, D. Z. and Lower, B. (1996), "Tails of Schrodinger's Cat", in R. Clifton (ed.), *Perspectives on Quantum Reality* (Dordrechet: Kluwer).
- Clifton, R. and Monton, B. (1999), "Losing Your Marbles in Wavefunction Collapse Theories", *British Journal for the Philosophy of Science* 50, pp. 697-717.
- Bassi, A. and Ghirardi, G. C. (1999). "More about dynamical reduction and the enumeration principle", *British Journal for the Philosophy of Science*, 50, 719–734.
- Bassi, A. and Ghirardi, G. C. (2001), "Counting marbles: Reply to Clifton and Monton", *British Journal for the Philosophy of Science*, 52, 125–130.
- Lewis, P. J. (2004), "Interpreting Spontaneous Collapse Theories". http://philsci-archive.pitt.edu/archive/00001928/

7. *The 'many-worlds' and 'many-minds' interpretations of QM* *Week 8: Nov 2*

Main readings
- [Barrett], pp. 149-179.

Further readings
- Barrett, J., "Everett's Relative-State Formulation of Quantum Mechanics". http://plato.stanford.edu/entries/qm-everett/
- Vaidman, Lev, "Many-Worlds Interpretation of Quantum Mechanics". http://plato.stanford.edu/entries/qm-manyworlds/
- Wallace, D. (2003), "Everett and Structure", *Studies in the History and Philosophy of Modern Physics* 34, 87-105.
- Berkovitz, J., "Action at a distance in quantum mechanics", *Stanford Encyclopedia of Philosophy*, Section 5.3.3. http://plato.stanford.edu/entries/qm-action-distance/
- [Baggott], pp. 194-201.
- Everett, H. (1957), *On the Foundations of Quantum Mechanics*, thesis submitted to Princeton University, March 1, 1957, in partial fulfillment of the requirements for the Ph.D. degree.*
- Everett, H. (1957), "'Relative State' Formulation of Quantum Mechanics", *Reviews of Modern Physics* 29, 454-462.*
- Everett, H. (1973), "The Theory of the Universal Wave Function", in B. de Witt and N. Graham (eds.), *The Many-Worlds Interpretation of Quantum Mechanics* (Princeton, 1973).*

8. *Bell's theorem, non-locality and relativity theory* *Weeks 9-10: Nov 9 Nov 16*

Main readings
- Berkovitz, Joseph, "Action at a distance in quantum mechanics", *Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qm-action-distance/ and references therein

Further readings
- Bell, John (1987), *Speakable and Unspeakable in Quantum Mechanics* (Cambridge University Press), especially Chapters 1, 2, 4, 7, 8, 10 and 16.
- [Maudlin]
- [Redhead], Chapters 4, 6 and 8*.
- Butterfield, J. N. (1992), "Bell's Theorem: What it takes", *British Journal for the Philosophy of Science 43*, 41-83.
- [Ghirardi], Chapters 10 and 11.

9. *Decoherence and our classical-like nature of experience* *Week 11: Nov 23*

Main readings
- Bacciagaluppi, G., "The Role of Decoherence in Quantum Mechanics", *The Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qm-decoherence/
- [Barrett], Chapter 8, pp. 221-232.

Further readings
- Zurek, Z. H. (2003), "Decoherence and the Transition from Quantum to Classical – Revisited". http://front.math.ucdavis.edu/0306.4072
- Joos, E., Zeh, H. D., Kiefer, C., Giulini, D. Kupsch, J. and Stamatescu, I. O. (2003) (2nd ed.), *Decoherence and the Appearance of a Classical World in Quantum Theory* (New York: Springer).*
- [Bub], Chapter 8, Section 8.1. (pp. 212-223), and the Appendix.*

10. *Quantum teleportation and quantum information* *Week 12: Nov 30*

Main readings
- [Ghirardi], Chapter 13.

Further readings
- Bub, J., "Quantum Entanglement and Information", *The Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/entries/qt-entangle/#Bib
- Nielsen, M. A. and Chuang, I. L. (2000), *Quantum Computation and Quantum Information* (Cambridge University Press).*

11. *Underdetermination of theory by observation* *Week 13: Dec 7*

Main readings
- Cushing, J. (1998), *Philosophical Concepts in Physics: The Historical Relations Between Philosophy and Scientific Theories* (Cambridge University Press), pp. 345-355.

Further readings
- Psillos, S. (1999), *Scientific Realism* (Routledge), Chapter 8: "Underdetermination undermined", pp. 162-176.
- Kuhn, T. (1977), "Objectivity, Value Judgment, and Theory Choice", in M. Curd and J. A. Cover (eds.), *Philosophy of Science: The Central Issues* (W. W. Norton), pp. 102-118.

- Lauden, L. and Leplin, J. (1991), "Empirical Equivalence and Underdetermination", in M. Lange (ed.), *Philosophy of Science: An Anthology* (Oxford: Blackwell), pp. 248-261.
- Duhem, P. (1954), *The Aim and Structure of Physical Theory,* Princeton Univ. Press), Chapter VI: "Physical Theory and Experiment", Sections 1-3 & 8-10.
- Quine, W. V. (1953), "Two Dogmas of Empiricism", *Phil. Rev.* 60, 20-43.

12. *On the applicability of mathematics in nature* *Week 13*

Main readings

- Steiner, M. (1998), *On the Applicability of Mathematics in Nature as Philosophical Problem* (Camb., Mass: Harvard University Press), pp. 1-11 and 136-146.

Further readings

- Steiner, M. (1998), *On the Applicability of Mathematics in Nature as Philosophical Problem* (Camb., Mass: Harvard University Press).
- Colyvan, M. (2001), "The Miracle of Applied Mathematics", *Synthese* 127, 265-277.
- Bangu, Sorin (2006), "Steiner on the Applicability of Mathematics and Naturalism", *Philosophia Mathematica* (III) 14, 26-43.
- Morrison, M. (2000), *Unifying Scientific Theories: Physical Concepts and Mathematical Structures* (Cambridge University Press).