Geneva Summer School in the Philosophy of Physics

Scientific Programme (public) 5-11 July 2009

Organizing Committee

Kevin Mulligan (Director), Department of Philosophy, University of Geneva

Philipp Keller, Department of Philosophy, University of Geneva

Vincent Lam, Department of Philosophy, University of Lausanne

Christian Wüthrich, Department of Philosophy, University of California, San Diego

1 Short Programme

Sunday, 5 July

Evening: Registration and welcome

Monday, 6 July

09:30-11:00 Albert 1

11:00-11:30 Coffee break

11:30-13:00 Wüthrich 1

13:00-14:30 Lunch

14:30-16:00 Gisin 1

16:00-16:30 Coffee break

16:30-18:00 Straumann 1

19:00-20:00 Dinner

Tuesday, 7 July

09:30-11:00 Bacciagaluppi 1

11:00-11:30 Coffee break

11:30-13:00 Gisin 2

13:00-14:30 Lunch

14:30-16:00 Groups

16:00-16:30 Coffee break

16:30-18:00 Wallace 1

19:00-20:00 Dinner

Wednesday, 8 July

09:30-11:00 Albert 2

11:00-11:30 Coffee break

11:30-13:00 Wallace 2

13:00-14:00 Lunch

14:00-19:00 Excursion

19:00-20:00 Dinner

Thursday, 9 July

09:30-11:00 Straumann 2

11:00-11:30 Coffee break

11:30-13:00 Wüthrich 3

13:00-14:30 Lunch

14:30-16:00 Lam 1

16:00-16:30 Coffee break

16:30-18:00 Podium

19:00-20:00 Dinner

Friday, 10 July

09:30-11:00 Straumann 3

11:00-11:30 Coffee break

11:30-13:00 Bacciagaluppi 2

13:00-14:30 Lunch

14:30-16:00 Albert 3

16:00-16:30 Coffee break

16:30-18:00 Roundtable

19:00-20:00 Dinner

Saturday, 11 July

09:30-11:00 Esfeld 1

11:00-11:30 Coffee break

11:30-13:00 Bacciagaluppi 3

13:00-14:30 Lunch

14:30 End

2 Notes on Speakers

David Z Albert is the Frederick E. Woodbridge Professor of Philosophy at Columbia University and the Director of the of the MA Program in the Philosophical Foundations of Physics at Columbia. He did his BA in Physics at Columbia College (1976) and his PhD in Theoretical Physics at the Rockefeller University (1981). He is the author of *Quantum Mechanics and Experience* and *Time and Chance* and has published many articles on the foundations of physics.

Guido Bacciagaluppi is Senior Lecturer in Philosophy at the University of Aberdeen. He studied mathematics at the ETH in Zurich and received his doctorate in philosophy from the University of Cambridge. He has previously worked at the Universities of Cambridge and Oxford, the University of California at Berkeley, the University of Freiburg (Germany), the IHPST, Paris, the Centre for Time at the University of Sydney. He has published extensively in various journals of physica and philosophy and is currently the subject editor in quantum mechanics for the *Stanford Encyclopedia of Philosophy*.

Michael Esfeld is Professor of Philosophy at the University of Lausanne. He has studied philosophy and history at the Universities of Freiburg (Germany), Lausanne, and Münster, where he took his PhD in 1994. He has taught at the ETH Zürich, and the Universities of Münster, Konstanz, Hertfordshire, Cologne and Lausanne. He has widely published and received numerous awards, including, most recently, the Cogito Award in 2008.

Nicolas Gisin is Professor of Physics at the University of Geneva. After a master in physics and a degree in mathematics, he received his PhD degree in Physics from the University of Geneva in 1981 for his dissertation in quantum and statistical physics. After his PhD, he was a postdoc at the University of Rochester, NY. After a stint in the industry (software and telecommunications), he returned to Geneva and to academia. He has widely published in physics.

Vincent Lam is a Junior Fellow in Epistemology and Philosophy of Science at the University of Lausanne, where he wrote his dissertation about space-time philosophy. He has previously studied theoretical physics at the Swiss Federal Institute of Technology. He has published in various journals in philosophy of physics.

Norbert Straumann is Professor of Physics at the University of Zürich. He studied physics and mathematics at the ETH Zürich, where he obtained all his degrees (except for a Doctor philosophiae honoris cause from the University of Bern). He has held postdocs and visiting positions at CERN, Bern, Amsterdam, and was Associate Professor at Duke University. Among others, he is the author of *General Relativity and Relativistic Astrophysics*, which has appeared in several editions and languages. His interests include general relativity, cosmology and astrophysics, and the history of physics.

David Wallace is a philosopher of physics at Oxford University. He holds a doctorate in physics from Oxford, but changed to philosophy and obtained a BPhil in Philosophy at Oxford in 2004. Since October 2005 he is a Tutorial Fellow at Balliol College, Oxford. He is currently working on a book on the Everett interpretation of quantum mechanics, parts of which will comprise his DPhil thesis in philosophy.

Christian Wüthrich is an Assistant Professor of Philosophy and Science Studies at the University of California, San Diego. He received his PhD in History and Philosophy of Science from the University of Pittsburgh after having read physics, mathematics, philosophy, and history and philosophy of science at Berne, Cambridge, and Pittsburgh. He has published in various journals in philosophy and in physics.

3 Long Programme

Sunday, 5 July

Registration and Welcome (Evening)

Monday, 28 July

Albert: "Introduction to the measurement problem" (9:30-11:00) **Albert 1**

The quantum-mechanical measurement problem is carefully set up, and a quick survey of various attempts at solving it is presented.

Background reading:

- David Z Albert, *Quantum Mechanics and Experience*, Harvard University Press, chapter 4 and the first two sections of chapter 5.

Wüthrich: "Bell's theorem, the GHZ theorem, and non-locality" (11:30-13:00) **Wüthrich 1**

Over the years, a number of theorems have been established that constrain the sort of stories that one can tell about physical systems and that are compatible with quantum mechanics. I will try to give an introduction to the precise statement and the significance of a number of these theorems. In this lecture, I plan to discuss Bell's theorem. the GHZ theorem, and non-locality, hopefully setting up the stage for Nicolas Gisin and other lectures that will follow later in the week.

Suggested readings:

- John Bell, "Bertlmann's socks and the nature of reality" in his *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press.
- N David Mermin, "Is the moon there when nobody looks? Reality and the quantum theory", *Physics Today* April 1985, 38-47.
- Gerd Grasshoff, Samuel Portmann, Adrian Wüthrich, "Minimal assumption derivation of a Bell-type inequality", *Brit J Phil Sci* **56** (2005): 663-680.

Gisin: "Experimental tests of quantum nonlocality" (14:30-16:00) **Gisin 1**

Suggested readings:

- Wolfgang Tittel and Gregor Weihs, "Photonic entanglement for fundamental tests and quantum communication", quant-ph/0107156
- Nicolas Gisin and Rob Thew, "Quantum Communication", *Nature Photonics* 1 (2007): 165-171.

Straumann: "The role of the exclusion principle for atoms to stars: A historical account" (16:30-18:00) **Straumann 1**

In a first historical part I shall give a detailed description of how Pauli discovered – before the advent of the new quantum mechanics – his exclusion principle. The second part is devoted to the insight and results that have been obtained in more recent times in our understanding of the stability of matter in bulk, both for ordinary matter (like stones) and self-gravitating bodies.

Suggested readings:

- Norbert Straumann, "The role of the exclusion principle for atoms to stars: A historical account", *International Review of Physics* **1** (2007): 184-196. quant-ph/0403199.

Tuesday, 7 July

Bacciagaluppi: "Fundamentals of decoherence" (9:30-11:00) **Bacciagaluppi 1**

In this lecture, we shall look at the phenomenon and theory of decoherence, at what it is and, at least formally, at how it relates to the emergence of classical structures in quantum mechanics. We shall also discuss how claims that decoherence as such, without reference to interpretations of quantum mechanics, should be able to solve the measurement problem, are misleading.

Suggested readings (for all three lectures by Bacciagaluppi):

- Guido Bacciagaluppi, "The Role of Decoherence in Quantum Mechanics", in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2008 Edition), plato.stanford.edu/entries/qm-decoherence/ (first published 2003).
- Maximilian Schlosshauer, "Decoherence, the measurement problem, and interpretations of quantum mechanics", *Reviews of Modern Physics* **76** (2004): 1267-1305. Also at arXiv:quant-ph/0312059.
- H D Zeh, "Basic concepts and their interpretation", revised edition of Chapter 2 of Giulini et al. (1996), *Decoherence and the Appearance of a Classical World in Quantum Theory* (Berlin: Springer). [Page numbers refer to the preprint available online at arXiv.org/abs/quant-ph/9506020, under the title "Decoherence: Basic Concepts and Their Interpretation".]
- H D Zeh, "The problem of conscious observation in quantum mechanical description", *Foundations of Physics Letters* **13** (2000): 221-233. Also at arXiv.org/abs/quant-ph/9908084.
- W H Zurek, "Decoherence and the transition from quantum to classical", *Physics Today* **44** (October 1991): 36-44. [Abstract and updated (2003) version available online at arXiv.org/abs/quant-ph/0306072, under the title "Decoherence and the Transition from Quantum to Classical—Revisited".]

- W H Zurek, “Negotiating the tricky border between quantum and classical”, *Physics Today* **46** (April 1993): 84-90.

Gisin: “Playing with general nonlocal correlations” (11:30-13:00) **Gisin 2**

Quantum correlations are very peculiar, especially those violating some Bell inequality. Gaining a deeper insight into such nonlocal quantum correlation is a grand challenge.

Children gain understanding of how their toys function by dismantling them into pieces. We shall follow a similar approach. We shall decompose the quantum correlations into simpler, more elementary, nonlocal correlations. Specifically, we like to present a model simulation of von Neumann measurements on arbitrary partially entangled states of two qubits. We shall also discuss Leggett’s model and understand why it is incompatible with quantum predictions. This work is part of the general research program that looks for nonlocal models compatible and incompatible with quantum predictions. The goal is to find out what is essential in quantum correlations.

Lam/Wüthrich: The technicalities of quantum mechanics (14:30-16:00) **Groups**

We will go over some of the relevant mathematical and technical background necessary to understand quantum mechanics. For this session, we will split up into two groups, one for the more introductory and one for the more advanced material. There are obviously many texts that would prepare you for this session, we just make a few suggestions. However, none of the readings will be presupposed.

Suggested readings:

- R.I.G. Hughes, *The Structure and Interpretation of Quantum Mechanics*, Harvard 1989 (Part I).
- Chris J Isham, *Lectures on Quantum Theory*, Imperial College Press, 1995.
- Rob Clifton, *Introductory Notes on the Mathematics Needed for Quantum Theory* (1996).

Wallace: “Many worlds? An introduction to the Everett interpretation” (16:30-18:00) **Wallace 1**

I will give a self-contained introduction to the Everett (many-worlds) interpretation as it is currently understood, stressing the theory’s claim to be a pure interpretation of the extant formalism. Along the way I’ll make the case for how decoherence defines a branching structure for a unitarily evolving quantum state, why these branches can be thought of as “worlds” in some reasonable sense, and what possible routes are available to explicate the role of probability in the theory.

Suggested readings:

- Wallace, David, “The interpretation of quantum mechanics”, in Rickles (ed.), *The Ashgate Companion to the New Philosophy of Physics* (Ashgate, 2008). Sections 1, 2 and 4. Available online as “Quantum mechanics: state of play”

Background reading on ontology and general issues:

- Saunders, Simon, “The Everett Interpretation, 50 years on”. Weblink
- Wallace, David, “Everett and Structure”, *Studies in the History and Philosophy of Modern Physics* **34** (2003): 87-105.

Background reading on probability:

- Greaves, Hilary, "Probability in the Everett Interpretation", *Philosophy Compass* **2**/1 (2007): 109-128.
- Lewis, Peter, "Probability in Everettian quantum mechanics", Available online at the Pitt archive
- Wallace, David, "A formal proof of the Born rule from decision-theoretic assumptions", http://arxiv.org/abs/0906.2718

Wednesday, 8 July

Albert: "Bohmian Mechanics and the GRW theory" (9:30-11) **Albert 2**

The most promising of the hidden variable approaches to the measurement problem (Bohmain Mechanics) and of the collapse approaches to the measurement problem (the GRW theory) are discussed in detail, and compared with one another.

Background reading:

- David Z Albert, *Quantum Mechanics and Experience*, Harvard University Press; the final 3 sections of chapter 5, and all of chapter 7.

Wallace: "Introducing QFT" (11:30-13:00) **Wallace 2**

I will try to give a sketch of the main principles behind quantum field theory (QFT). I'll work in a very mainstream framework (not the "Algebraic Quantum Field Theory" framework often seen in philosophy of physics) and I'll be fairly mathematically unrigorous: my aim is to provide as much clarity as possible about the conceptual basis of modern QFT.

Background reading:

- Wallace, David, "In defence of naivete: the conceptual status of Lagrangian quantum field theory", *Synthese* **151** (2006): 33-80.

Afternoon: Excursion

Plan: Cabane de la Tza (2h) or Cabane des Aiguilles Rouges (2h30)

Thursday, 9 July

Straumann: "A simple proof of the Kochen-Specker theorem on the problem of hidden variables" (9:30-11:00) **Straumann 2**

In this talk I present a simple derivation of an old result of Kochen and Specker, which is apparently unrelated to the famous work of Bell on hidden variables, but is presumably equally important. Kochen and Specker showed in 1967 that quantum mechanics cannot be embedded into a classical stochastic theory, provided the quantum theoretical probability distributions are reproduced and one additional highly desirable property is satisfied. This showed in a striking manner what were the difficulties in implementing the Einstein programme of a 'complete' version of quantum mechanics.

Suggested readings (in particular the Redhead):

- Michael Redhead, *Incompleteness, Nonlocality, and Realism, A Prolegomenon to the Philosophy of Quantum Mechanics*, Clarendon Press, Oxford (1987); Chapter 1.
- Norbert Straumann, "A simple proof of the Kochen-Specker theorem on the problem of hidden variables", arXiv:0801.4931, and references therein.

Wüthrich: "Gleason's theorem, Conway and Kochen's 'free will theorem,' and indeterminism" (11:30-13:00) **Wüthrich 2**

I plan to continue my excursion through the various theorems that constrain the physical stories compatible with quantum mechanics. I will pick up where we were left last time and hope to go over Gleason's theorem, the Kochen-Specker theorem, and the "free will" theorem by Conway and Kochen. This will initiate a discussion over whether nature herself is deterministic or indeterministic.

Suggested readings:

- N David Mermin, "Hidden variables and the two theorems of John Bell", *Review of Modern Physics* **65** (1993): 803-815.
- John H Conway and Simon Kochen, "The strong free will theorem", *Notices of the American Mathematical Society* **56** (2009): 226-232.

Lam: "Identity and individuality of quantum (field) systems" (14:30-16:00)**Lam 1**

The standard conception of nature considers the world as being made up of individuals that possess some intrinsic identity independently of one another. This lecture aims to discuss to what extent such conception is challenged by quantum (field) theory. The standard philosophical accounts of individuality are first introduced. I then discuss the different versions of the principle of identity of the indiscernibles. In particular I evaluate the recent claim according to which fundamental fermions and bosons are weakly discernible. Some aspects of the debate on identity and individuality are discussed for quantum field systems.

Suggested readings:

- F.A. Muller and Simon Saunders, "Discerning Fermions", *Brit. J. Phil. Sci.* **59** (2008): 499-548.

Further reading:

- Katherine Brading and Elena Castellani (eds.), *Symmetries in Physics: New Reflections*, Cambridge: Cambridge University Press, 2003; in particular chapters 12, 13, 16.
- Steven French and Decio Krause, *Identity in Physics: A Historical, Philosophical and Formal Analysis*, Oxford: Clarendon Press, 2006.
- Steven French and Michael Redhead, "Quantum physics and the identity of the indiscernibles", *Brit. J. Phil. Sci.* **39** (1988): 233-246.
- Michael Redhead and Paul Teller, "Particle labels and the theory of indistinguishable particles in quantum mechanics", *Brit. J. Phil. Sci.* **43** (1992): 201-218.

Albert/Wallace: Probability in the Everett interpretation (16:30-18:00) **Podium**

Before we go to dinner, David Albert and David Wallace will be the panelists in a podium discussion on the problem of defining and identifying probabilities in the Everett/many-worlds interpretation.

Friday, 10 July

Straumann: "On Pauli's invention of non-Abelian gauge theory in 1953" (9:30-11:00) **Straumann 3**

In a first part I shall give (for parts of the audience) an introduction to non-Abelian gauge theories. (The organizers asked me to do this). In a second part I shall sketch a remarkable story: There are documents which show that Wolfgang Pauli constructed in 1953 the first consistent generalization of the five-dimensional theory of Kaluza, Klein, Fock and others to a higher dimensional internal space. Because he saw no way to give masses to the gauge bosons, he refrained from publishing his results formally. This is still a largely unknown chapter of the early history of non-Abelian gauge and Kaluza-Klein theories.

Suggested readings:

- Lochlainn O'Raifeartaigh and Norbert Straumann, "Gauge theory: Historical origins and some modern developments", *Reviews of Modern Physics* **72** (2000): 1-23.

Bacciagaluppi: "Decoherence and interpretations of quantum mechanics" (11:30-13:00) **Bacciagaluppi 2**

In the second lecture, we look at how the formalism of decoherence relates to various interpretations of quantum mechanics, in particular no-collapse approaches such as de Broglie and Bohm's pilot-wave theory and Everett interpretations (with some subtle differences between many-worlds and many-minds). These approaches to quantum mechanics are crucial to understanding how decoherence can indeed lead to the emergence of classical behaviour from quantum mechanics. Conversely, decoherence is crucial to understanding how these approaches to quantum mechanics work in the fist place. (In the case of collapse approaches, the situation is somewhat different.)

For suggested readings, see Bacciagaluppi 1.

Albert: "Entanglement, non-locality, and special relativity" (14:30-16:00) **Albert 3**

Bell's argument for non-locality, and the various tensions between entanglement, non-locality, and special relativity are discussed.

Background reading:

- David Z Albert, *Quantum Mechanics and Experience*, Harvard University Press; chapter 3.

Roundtable discussion (16:30-18:00) **Roundtable**

Like the smaller groups and the podium discussion, this is a new, and somewhat experimental, format for GSSPP. The idea is that we all sit together and discuss the foundations of quantum mechanics, in attempt to structure the issues, synthesize the positions, and try to work out something of a conclusion of this week's intense work.

Saturday, 11 July

Esfeld: "Being ontologically serious about the measurement problem" (9:30-11:00) **Esfeld 1**

The paper argues for the following claims:

1. Quantum physics—and the measurement problem in particular—do not provide for any reason to abandon scientific realism.
2. Decoherence does not solve the measurement problem.
3. Everett-type solutions, though mathematically and physically elegant, do not constitute a serious ontology.
4. We need a solution that does justice to both quantum and classical properties, GRW being the most promising candidate for such a solution.

I'll then show how GRW fits into structural realism and spell out its ontological commitments, notably the commitment to dispositions (causal properties) and to a fundamental law that is not time-reversal invariant.

Suggested readings:

- Esfeld, Michael, "The modal nature of structures in ontic structural realism", *International Studies in the Philosophy of Science* **23** (2009): 179-194.

Further reading:

- Dorato, Mauro, "Properties and dispositions: some metaphysical remarks on quantum ontology", in A. Bassi, D. Dürr, T. Weber, and N. Zanghi (eds.), *Quantum mechanics: Are there quantum jumps? On the present state of quantum mechanics*, (American Institute of Physics Conference Proceedings 844). New York: American Institute of Physics, 139-157.
- Dorato, Mauro and Esfeld, Michael, "GRW as an ontology of dispositions", submitted to *Studies in History and Philosophy of Modern Physics*.
- Esfeld, Michael, "Quantum entanglement and a metaphysics of relations", *Studies in History and Philosophy of Modern Physics* **35B** (2004): 601-617.
- Esfeld, Michael and Lam, Vincent, "Moderate structural realism about space-time", *Synthese* **160** (2008): 27-46.
- Esfeld, Michael, "Humean metaphysics vs. a metaphysics of powers, forthcoming in Gerhard Ernst and Andreas Httemann (eds.), *Time, chance and reduction—philosophical aspects of statistical mechanics*, Cambridge: Cambridge University Press.
- French, Steven, "Structure as a weapon of the realist", *Proceedings of the Aristotelian Society* **106** (2006): 167-185.
- French, Steven and Ladyman, James, "Remodelling structural realism: quantum physics and the metaphysics of structure", *Synthese* **136** (2003): 31-56.
- Suárez, Mauricio, "Quantum propensities", *Studies in History and Philosophy of Modern Physics* **38B** (2007): 418-438.

Bacciagaluppi: "Decoherence—more specialised topics" (11:30-13:00) **Bacciagaluppi 3**

This final lecture will look at some research problems and/or more controversial aspects of decoherence in the philosophy of quantum mechanics. These may include more advanced applications of the theory of decoherence, aspects of how decoherence relates to time (a)symmetry, and the relevance of decoherence to collapse approaches to quantum mechanics such as the GRW theory.

For suggested readings, see Bacciagaluppi 1.