Quantum Time: Abstracts

Valia Allori, *Philosophy, Northern Illinois University*

What does Quantum Mechanics tell us about Time?

Abstract. In this paper I analyze some of the questions that arise when considering what constraints, if any, Quantum Mechanics poses on the nature of time. In orthodox quantum mechanics there is no operator associated with time: does that mean time is not measurable, does it mean it does not exist? How does the situation changes considering theories like Bohm or GRW? What about chronons, the time quanta? Finally, in some recent versions of Quantum Gravity time seems to disappear: is that so?

Abhay Ashtekar, *Institute for Gravitation & the Cosmos, Penn State*

Time and Initial Conditions in Cosmology

Abstract. I will review the issue of Time and the Beginning in classical and quantum cosmology. Specifically, I will illustrate the use of relational time in cosmology, introduce Penrose's idea of constraining the initial conditions at the Big Bang via a 'Weyl curvature hypothesis', explain how the issue of the Beginning is dramatically altered because of the resolution of the Big Bang singularity in loop quantum cosmology and conclude by discussing a quantum generalization of the Weyl curvature hypothesis that naturally constrains the initial conditions in inflationary loop quantum cosmology. As with any paradigm shift, many of the older questions cease to be meaningful and new issues and challenges arise. These, I hope, will provide material for stimulating discussions during the workshop.

Adam Caulton, *Philosophy, Cambridge*

Adventures Off Mass-Shell

Abstract. What is the correct possibility space for a given particle of a quantum field? The firm orthodoxy, initiated by Wigner in 1939, is that we should look to the irreducible representations of the Poincar group. But the justifications for this are murky. Instead, I argue that we have reason to consider "larger" state spaces than are normally considered. On one approach along these lines, the state space represents entire four-dimensional histories rather than instantaneous states, most of which are "off mass-shell", in that the relativistic mass condition is violated. One upshot of this approach is that time observables may easily be defined.

Sean Gryb, *Theoretic High Energy Physics, Radboud University Nijmegen*

Symmetry and Evolution in Quantum Gravity

Abstract. A key obstruction for obtaining a non-perturbative definition of quantum gravity is the absence of a sensible quantum representation of spacetime refoliations. We propose that these difficulties can be avoided by accepting that evolution, in General Relativity, involves real physical change. This simple principle, combined with the requirement of local scale invariance, leads us to a particular (formal) quantization of General Relativity, inspired by the "Shape Dynamics" formulation of classical gravity, with both a well-defined notion of symmetry and global time evolution.

Louis H. Kauffman, *Mathematics, University of Illinois at Chicago*

Discrete Time and Quantum Mechanics

Abstract. Consider discrete physics with a minimal time-step τ. Let the position of a particle be denoted by $q^n = q(n\tau)$. For a given value of position q, let q' denote the value at the next time step.

That is $q'(t) = q(t+\tau)$. Consider simple observations of this discrete system. The clock must tick for an observation of momentum $p(t) = mv(t)$ where $v(t) = (q(t+\tau) - q(t))/\tau$. Thus $p = m(q' - q)/\tau$, and the observation of momentum requires a time step, a tick of the clock. For simplicity, assume that no tick of the clock is needed for an observation of position. Then we see at once that the operations of observing position and momentum do not commute. With this understanding of the non-commutativity of position and momentum, we can write $[q, p] = m(\Delta q)^2/\tau$. If we replace τ by $i\tau$ (Wick rotation) then $[p, q] = im(\Delta q)^2/\tau$. We note that if Δq is taken to be L, the Planck length, τ the Planck time and m the Planck mass, then $\hbar = m(\Delta q)^2/\tau$. Thus $[p, q] = i\hbar$, and we have recovered from considerations of discrete observation, the fundamental Heisenberg commutator for position and momentum in quantum mechanics. It is the purpose of this talk to explore relationships of non-commutativity, time and quantum mechanics from the standpoint of discrete physics.

Thomas Pashby, *History and Philosophy of Science, Pittsburgh*

Time Observables in Classical and Quantum Mechanics

Abstract. The problem with time observables in quantum mechanics is Pauli's Theorem, a no-go result often thought to rule them out. However, in recent years Pauli's Theorem has come to be seen as a mere obstacle rather than a prohibition, and the problem of defining useful time observables in quantum mechanics has become a hot topic in the foundations of quantum theory. We show that there are deep analogies between the situation in classical and quantum mechanics by proving a classical version of Pauli's Theorem and demonstrating how it constrains the definition of classical time observables and their quantum counterparts.

Laura Ruetsche, *Philosophy, University of Michigan*

Warming up to the Thermal Time Hypothesis

Abstract. TBA

Noel Swanson, *Philosophy, Princeton*

Deciphering the Algebraic PCT Theorem

Abstract. Any local, relativistic QFT must be invariant under a combined reflection symmetry that reverses the direction of time, flips spatial handedness, and conjugates charge. Why does this seemingly ad hoc assemblage of operations always yield a perfect symmetry? Using tools from algebraic QFT, I argue that PCT symmetry can be explained in terms of a single global reflection operation on quantum statespace. In addition, I offer a critique of an alternative explanation given by Hilary Greaves. Whereas Greaves maintains that the PCT Theorem is a fundamentally relativistic result, I contend that it only emerges from the fruitful marriage of relativity and quantum mechanics.

Ken Wharton, *Physics and Astronomy, San Jose State University*

Dynamic Propagators vs. Block-Universe Path Integrals

Abstract. The path integral is a non-dynamical technique for calculating quantum probabilities that is conceptually and mathematically distinct from canonical quantum mechanics (CQM). This distinction can be drawn from several perspectives, including time-symmetry, boundary conditions, and the philosophy of time. Nevertheless, physicists tend to ignore these distinctions by zeroing in on the Feynman propagator, which can have same dynamical interpretation as CQM. This may be because we are unused to solving problems in the all-at-once/block-universe perspective required by the full path integral, and are more comfortable with analysis of dynamical systems. I will argue that this bias has steered us away from lines of research that promise a deeper understanding and explanation of quantum theory.