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DECOHERENCE IN QUANTUM MECHANICS AND QUANTUM COSMOLOGY

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ABSTRACT

In the search for a theory of the initial condition of the universe, quantum mechanics must be applied to the universe as a whole. For this the "Copenhagen interpretations" of quantum mechanics are insufficiently general. Characteristically these interpretations assumed that there was a division of the universe into "observers" and "observed", that the outcomes of "measurements" were the primary focus of scientific statement, and, in effect, posited the existence outside of quantum mechanics of the quasiclassical domain of familiar experience. However, in a theory of the whole thing there can be no fundamental division into observers and observed. Measurements and observers cannot be fundamental notions in a theory that seeks to describe the early universe where neither existed. In a unified theory of cosmology there is no fundamental basis for a separate classical physics. Copenhagen quantum mechanics must, therefore, be generalized to apply to cosmology.

This talk sketched a quantum mechanics for closed systems adequate for cosmology developed in joint work with Murray Gell-Mann.[1,2,3] This framework is an extension and clarification of that of Everett[4] and builds on several aspects of the post-Everett development. It builds especially the work of Zeh[5], Zurek[6], Joos and Zeh[7], and others on the interactions of quantum system with the larger universe and on the ideas of Griffiths[9], Omnès[10], and others on the requirements for consistent probabilities for histories.

Three forms of information are necessary for prediction in the quantum mechanics of a closed system. In an approximation in which quantum spacetime is ignored, these are the Hamiltonian, the initial density matrix of the universe, and the information specifying particular histories. The most general objective of quantum theory is the prediction of the probabilities of the individual histories in a set of alternative histories for the universe. However, the characteristic feature of a quantum theory is that not every set of histories that may be described can be assigned probabilities because of quantum interference. Probabilities can be assigned only to sets of histories for which there is negligible interference between the individual histories in the set as a consequence of the initial density matrix of the universe and the Hamiltonian governing its dynamics. Such sets of histories are said to decohere.

Histories described at an arbitrarily fine-grained level do not decohere; some coarse graining is necessary for decoherence. Coarse-graining was described in the talk and the decoherence functional that measures the level of decoherence for sets of alternative coarse-grained histories was introduced. Mechanisms for decoherence were reviewed in simple models. Habitual decoherence was argued to be widespread in the universe for coarse-grained histories defined by certain quasiclassical variables.

A quasiclassical domain is roughly a set of alternative coarse-grained histories that is as refined as possible consistent with decoherence and has individual branches that are defined by quantities that are similar from one time to the next correlated in time mostly according to classical deterministic laws. The problem of precisely defining quasiclassical domains was discussed. The question of whether or not the universe exhibits a quasiclassical domain like the one of familiar experience is a calculable one in quantum cosmology given a suitably precise definition, the Hamiltonian of the elementary particles and the initial density matrix of the universe. In particular, the variables that describe classical physics and the form of its phenomenological equations of motion should be deriv-

able from that Hamiltonian and the initial condition.[10]

A measurement situation is one in which a variable becomes correlated with a quasiclassical operator of the "quasiclassical domain". The theory of measurements in quantum mechanics was discussed from this point of view. The recovery of the Copenhagen formulation of quantum mechanics as an approximation to the more general framework appropriate in measurement situations was described. An "observer" (or information gathering and utilizing system, IGUS) was treated as a complex adaptive system that evolves to utilize the relative predictability of a "quasiclassical domain".

The talk concluded that resolution of many of the problems of interpretation presented by quantum mechanics is not to be found within the theory *in general* but rather through an examination of the universe's initial condition and the emergent features that it, together with the Hamiltonian of the elementary particles, implies. Quantum mechanics may be best and most fundamentally understood in the context of quantum cosmology.

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