The Incompleteness of Quantum Mechanics

Both measurement and unitarity form the basis of Bohr's complementarity, and the Copenhagen Interpretation in which there are dual descriptions in Nature. Whether or not the measurement postulate plus Schrödinger unitarity are sufficient aspects in the full description of Nature is related to the question of the incompleteness of quantum mechanics.

One impact of the measurement problem is that the measurement postulate of von Neumann cannot follow from the second Schrödinger unitary postulate. Historically this was anticipated rather quickly. In fact, the inadequacy of a completely causal deterministic description had been argued by Bohr shortly after Schrödinger's equation was formulated in 1926 as will be further examined in Chapter 5. Born's rule was then proposed and found to agree with the results of experiment and was incorporated by von Neumann in 1932 into the two postulates of quantum mechanics [13]. Moreover, this methodology is what is used today in nearly every paper on quantum mechanics. Why then is the measurement problem so subtle to comprehend? Because the arguments that had been put forward by von Neumann and others are not operational methods that can distinguish Schrödinger unitary evolution from measurement. The arguments have not been fully convincing and one is often left to wonder what would happen in the limit as the number of particles composing the measurement device increases. One is left in the dark as to how to conduct an experiment that conclusively shows that the difference does not diminish with the size of the devices or the type of interactions or the types of particles, etc. In order to develop an operational method, it is necessary to show that there is a predicted experimental difference that does not approach zero as the number of particles grows, between measurement and Schrödinger unitary evolution, as has been demonstrated in Chapter 3. But that there is an experimentally observed difference between product states and entangled states was not generally known until after 1964 by Bell [110] and only for two qubits in a pure state.

Einstein believed that Quantum Mechanics is incomplete: “Is the Moon there when nobody looks,” he asks. Why would Einstein say such things? The reason should be clear by now. Schrödinger unitary evolution makes predictions of entangled states whereas product states are predicted under measurement. It has come to light in research by Howard [3] [111], which is discussed in Chapter 5, that Einstein understood the difference between product states and entangled states well before most. He believed that physical processes should be described by separable product states. And yet, Schrödinger unitary evolution does not make this prediction. Something does not seem quite right. Einstein's arguments with Bohr regarding the simultaneous existence of non-commuting quantities were faulty. However, the existence of simultaneous non-commuting quantities is not necessary to make Einstein's incompleteness argument. What would have sufficed is what we have demonstrated in Chapter 3. The argument that has been presented does not require the simultaneous existence of non-commuting quantities. Unfortunately, the detailed theory of entanglement (which was to become developed in the area of Quantum

Information) required to make this argument was not known at the time of the Bohr-Einstein debates.