Copenhagen Interpretation

Arguably the most well-known interpretation of quantum mechanics is the *Copenhagen Interpretation.* The Copenhagen interpretation has a remarkable history, and important details will be discussed later in Chapter 5. The Copenhagen interpretation is essentially that a deterministic description such as Schrödinger's equation cannot suffice to describe Planck's quantum of action that Bohr considered to be rooted in a process that, at best, can be modeled nondeterministically or statistically. Hence a deterministic description necessitates the augmentation by a nondeterministic statistical description in order to provide a full accounting of phenomenon. Such dual methods that are employed in the Copenhagen interpretation represent the principle of complementarity. Complementarity has also been applied to many other situations in Bohr's writings.

The reason that Bohr argued that the measurement process could at best be modeled by an external observer statistically was that he believed that the process of measurement requires an interaction between a device and a particle, which could be quite unpredictable and uncontrollable under certain circumstances. He considered that a measurement device generally possessed the qualities of classicality in terms of its possible readouts. Consider a device that is designed to measure momentum and provides two readout positions that indicates a range of distinct momentum values. If a particle is input with a momentum that corresponds precisely to one of the momentum readout values, then there is no uncontrollable interaction and the device directly reads out the momentum. On the other hand, suppose that a particle is input with a well-defined position. Then the particle will have a large uncertainty in its momentum and will exist as a superposition of numerous momentum states. Because of the Heisenberg uncertainty relationship, Bohr would expect that the device would still read-out one out of the many possible momentum values because of the impossibility of knowing the position and momentum simultaneously, which in turn causes the interaction to become uncontrollable and unpredictable. Hence the outcome can, from an external observer's perspective, at best be modeled probabilistically or statistically. Interestingly, position/momentum non-commutativity is also a form of complementarity. Hence in this example, position/momentum complementarity begets wave/particle complementarity.

Essentially because of this viewpoint, Bohr did not believe that it made sense to go further into a detailed deterministic description of the process of measurement. This is rather unfortunate, but the era of Quantum Information where entanglement plays a central role, was largely begun in a very significant manner only over the last twenty years.