Nondeterminism

One might theoretically consider a quantum jump via a deterministic and causal physical discontinuity, but such a jump would not need a statistical interpretation. Once the process itself is said to be governed by nondeterministic or noncausal physics, then a multitude of possible results must present themselves. Suppose on the contrary that only a single result presented itself—in such a case the physics would be deterministic and non-statistical and one might expect the physics to be fully governed by Schrödinger's equation.

One often sees reference to quantum theory as being strictly the application of Schrödinger's equation. However, even before the discovery of Schrödinger's equation, quantum theory was alive and well as the quantum of action was discovered twenty-five years previously. For example, in 1925, prior to the discovery of Schrödinger's equation, Bohr wrote [198]:

> *Planck demonstrated, retaining Boltzmann's account of the second law of thermodynamics, that the laws of heat radiation demand an element of discontinuity in the description of atomic processes quite foreign to the classical theories.*

This is similar to the argument that Bohr used in his debate [182, p. 75] with Schrödinger that his equation could not be universally valid.
Bohr also states [198]:

> *From these results it seems to follow that, in the general problem of quantum theory, one is faced not with a modification of the mechanical and electrodynamical theories describable in terms of the usual physical concepts, but with an essential failure of the pictures in space and time on which the description of natural phenomena has hitherto been based.*

Such statements by Bohr can be found to be repeated over-and-over in many of his works, throughout his lifetime. Until his death, Bohr appears to be unwavering in this respect.

The fact that Schrödinger's equation on its own fails to predict many phenomena and requires augmentation by Born's statistical rule was not seen as a coincidence by Niels Bohr. On the contrary, Born's rule was seen as a principle part of quantum theory for which both a nondeterministic as well as a deterministic description are two complementary methodologies that are both necessary for describing phenomenon in a full and complete manner.

After Born's rule and Schrödinger's equation became part of the Copenhagen Interpretation, von Neumann formalized the mathematics of quantum mechanics largely according to the Copenhagen Interpretation. There are two processes in von Neumann theory, Process 1 is the measurement process and Process 2 is the unitary

Schrödinger process.

Von Neumann considers the measurement process a primary process. Von Neumann [13, p. 349] contrasts the measurement process with Schrödinger's equation in a manner similar to Bohr's statements:

> *Another type of intervention in material systems, in contrast to the discontinuity, non-causal, and instantaneously acting experiments or measurements, is given by the time-dependent Schrödinger differential equation.*

Discerning Nondeterminism

Nondeterminism that occurs within a single system is subject to a probability interpretation. However, a single system that is predicted on average to evolve to a proper mixture under unitary evolution (for example in the process of external orthogonalization) cannot be distinguished from the case where the individual measurements occurred, each with the corresponding Born probability. On the other hand, when a quantum wave function impinges on more than a single detector, such as in the case when there are two devices in the Chapter 3 UMDT, it becomes possible to discriminate the cases of measurement from unitary evolution. In this case, the mixture that results must be considered an improper mixture under measurement.
The nondeterminism that results in the process of wave function reduction does appear to provide a means to distinguish unitary evolution from measurement when more than a single degree of freedom is present so that an improper mixture has resulted.