

## Open System Approaches

An open system approach is one whereby the physical reason that a given configuration of particles  $|\Psi\rangle$  undergoes measurement is that the action of the particles when going into a superposition causes a phenomenon external to the closed system to exert a non-unitary back-action on the closed system that takes the form of measurement. For example, consider a unitary action for which the particles  $|\Psi\rangle$  evolve into a macroscopic superposition of distinct positions. One could posit that there is some fundamental principle that reacts to such a superposition by inducing a back-action on the system, in a manner that opposes the system superposition, and is of the form of a non-unitary measurement.

The idea that external interaction is responsible for measurement is related to the hypothesis that a closed system by itself will always evolve according to Schrödinger's equation. Such a view was indeed held by many of the progenitors of the Copenhagen interpretation of quantum theory. In such a view, something external must intervene in order for a system to collapse. According to Bohr, the uncontrollable interaction of a system with a macroscopic device causes collapse. Whether or not such an interaction was actually evolving according to Schrödinger's equation or not did not seem to be of much consequence or interest to Bohr. Rather, due to the uncontrollable interaction and Heisenberg's uncertainty relationships, the evolution was not predictable and could never be predictable, and therefore the best one could ever hope for would be a quantum mechanical measurement theory that provided a statistical account. That is, statistics are not just a convenient way of computing unitary evolution in the Copenhagen interpretation, it is imposed on the theory due to a fundamental impossibility of precisely knowing the entire particle behavior in the interaction of a system and macroscopic device.

Hence the rise of the development of open-system approaches can be identified with the proposition that all closed systems evolve via Schrödinger's equation. However, as we have seen in our Chapter 3 development, unitary evolution by itself is not a sufficient explanation of measurement. Hence open-system approaches must inevitably provide some additional non-unitary external mechanism or action that acts on the closed system to affect a measurement.

In the case of many-worlds theory, a system that evolves into a superposition evokes a reaction that causes a splitting of worlds and hence a back-action on the system for which a non-unitary measurement occurs. One might also consider that if a body with substantial mass is put into a stationary superposition of distinct locations, that there is a general relativistic back-action that modifies the non-relativistic quantum mechanical laws so that the superposition is no longer stationary. Such a back-action might conceivably effect a collapse similar to that proposed by Penrose and others.

One could also consider that there exist Category 2 type theories that are open system approaches. For example, suppose the environment when sufficiently coupled to a system in a superposition is simply impossible to reverse. That is, it is not only for all practical purposes (FAPP) reversible, but there is some yet to be discovered law for

which a particular unitary evolution would be intrinsically irreversible. One could postulate that in such a case, certain unitary state evolutions would be physically irreversible in principle, and the point that this would occur would be described by non-unitary evolution rather than unitary evolution. Related theories have been advocated, with various differences by Omnès [295] and others.

### *Considerations in Open Systems*

How are energy and other fundamental quantities conserved if a particle collapses due to an external reaction that opposes a particular system superposition? If the external source passes energy or momentum onto the system, then one would need to include the external phenomenon in order to consider conservation of energy and momentum. The consideration of no-perpetual motion as well no-decrease of entropy would also generally require taking the external source into consideration.

On the other hand, there are several considerations in open systems that can be directly applied to the system that is measured. Gauge invariance of measurement results should hold regardless of the reduction mechanism. No-signaling also must always apply. That there is no preferred frame and the equivalence principle are also valid considerations in open systems. Furthermore, Born's rule and Lüder's rule should also be met by open system solutions.

Another consideration in theories that utilize Everett's many-worlds interpretation (MWI) is the possibility of communication between universes, such as found in [677]. If a new universe occurs each time a measurement occurs, what is to prevent communication between distinct universes? A proposal in [678] suggests a technique to test signaling between worlds:

*See the print edition of The Quantum Measurement Problem for quotation.*

Measurement, in open system theory, is often explained when decoherence occurs. MWI does not provide a well-defined rationale for choosing one basis versus another for the act of splitting or branching. The use of decoherence to supplement Everett's theory does provide an approach whereby the splitting into different branches occurs for which the subsystem density matrix becomes in the process of decoherence diagonal or non-coherent in a particular (or preferred) basis.

Conservation laws are violated on any single trial in MWI, but are upheld on average. In terms of interaction-free measurement, Elitzur and Vaidman [107] also state that conservation laws are restored when all collapse possibilities are considered in the MWI:

*See the print edition of The Quantum Measurement Problem for quotation.*

If there is a violation of energy and momentum on individual trials, then this should be observable if experiments were conducted to establish whether or not energy and momentum are strictly upheld.

An issue that is often vague in open system approaches is precisely the conditions under which a measurement occurs. In open system theory, is complete decoherence required before a splitting of the worlds, or is partial decoherence allowed? If all the branches of a measurement can occur, one must explain how the Born rule comes about, while taking into account the possibility of re-combination of previous split worlds.

Energy-driven stochastic Schrödinger equations can be considered closed systems for the purposes of energy, momentum, and other fundamental considerations [255], one can also consider such solutions as open system solutions if there is an external source that causes the system to undergo stochastic non-unitary evolution. In such a case, the external source could contribute resources such as energy or entropy in order for the system plus external source to satisfy conservation laws. For example, to explain stochastic Schrödinger equations, an actual noise source is hypothesized to exist by Pearle in [232]. Using such a noise source, it was shown by Pearle that energy is conserved. With an external noise source, such stochastic reduction models are open systems insofar as measurement occurs on the system. In such a case, the source of such a noise source would need to be identified and established. If an infinite energy source simply is posited to exist that feeds the measurement process, then the question arises as to whether or not this poses a violation of the non-existence of perpetual motion machines.