Philosophy and the Measurement Problem

There are a substantial number of philosophical concepts that are relevant to the themes of the measurement problem as well as the ultimate resolution of the measurement problem. Philosophers often deal with issues of *Ontology* and *Epistemology*. Ontology is the philosophical study of the nature of being, becoming, existence or reality as well as the basic categories of being and their relations [112]. The measurement problem deals with the currently unknown problem of how an entangled state becomes a product state that is demanded under measurement. This is an ontological problem. As will be explained in more detail in Chapter 5, Einstein did not consider entangled states an adequate description of reality whereas he did consider product states an adequate description of reality. For Einstein, the measurement problem would have been a major issue in ontology. Furthermore, philosophers often categorize how a given theory explains Nature in terms of ontology.

Another important concept of philosophy that is relevant to measurement is the term “Epistemology.” Epistemology is a branch of philosophy that studies the nature of knowledge, justification, and the rationality of belief [113]. Bohr considers that measurement is a means by which knowledge comes about. Bohr wrote at length on issues of epistemology and its relationship to complementarity. A resolution of the measurement problem that goes beyond the current quantum theory could, therefore, have a major impact on epistemology.

Concepts of free will, determinism, and consciousness are also studied at length in philosophy. Issues of the physics of free will, determinism, and consciousness were examined by Aristotle, Descartes, and many others. It was believed by many physicists that these issues are related to the measurement problem. Hence, the resolution of the measurement problem may be expected to have major implications on these questions.

Unitarianism traditionally is the belief in a single God. Unitarianism is also a philosophy that rejects principles of dualism such as mind and matter. We will use the word in the sense of those that reject principles of dualism and furthermore believe that the motion of particles in Nature is fundamentally described by a single law. Unitarians in this sense often believe that all phenomena emerge from the evolution described by a unitary theory.

Assume Measurement has Occurred

There are a number of proposed solutions that do indeed explain Born’s rule very well, *given* that a measurement has occurred. The measurement postulate is a postulate that tells one how to proceed with state evolution, *given* that a measurement has already occurred and *given* it has occurred via a *given* Hermitian observable.

If a theory provides an explanation of how something came about *a posteriori* via a measurement, then has the measurement problem been resolved? If both Device 1 and 2 are bona fide measurement devices for which it is known that a measurement occurs, then one can at that point throw away the unitarily predicted state and substitute the state of the result predicted from the measurement postulate.

Let us examine what such an *a posteriori* theory would tell us regarding our Chapter 3 demonstration that distinguishes unitary evolution from measurement. Suppose that in our Device 1 and 2 we perform numerous experiments in which we slowly increased the number of atoms that compose the device. Perhaps when two particles are used, we find experimentally that Step 1 is verified to be evolving via Schrödinger's equation as the follow-up Step 2 and 3 give a correlation that agrees with the Bell correlation for maximally entangled particles. As an example to illustrate the logical issues of an *a posteriori* theory, suppose that 200 atoms are added in a particular configuration and after Step 1, it was suddenly found that the result is not commensurate with Schrödinger evolution. An *a posteriori* theory could substitute at this point the tensor product measurement state for the entangled state predicted under Schrödinger evolution. But such a substitution in an *a posteriori* theory is missing everything that is vital to the solution of the measurement problem. It does not tell us why this particular configuration produced measurement. It does not give us necessary and sufficient conditions of the physical phenomena under which non-Schrödinger evolution occurs versus when Schrödinger evolution occurs. It does not provide us with answers to Requirement 1.3 that the theory gives a prescription based on the underlying phenomena, be it nondeterministic or deterministic, for the evolution or change of states when a measurement occurs. An *a posteriori* prescription is based on knowing a measurement occurs and not based on the underlying phenomena. An *a posteriori* theory is able to satisfy Requirement 1.4, because it is based on what has already occurred. Hence the reader should understand that a satisfactory solution to the measurement problem must go well beyond simply providing an explanation of the predictions consistent with von Neumann's measurement postulate, i.e., given *a posteriori* knowledge that a measurement has occurred.

An *a posteriori* theory is nothing more than another interpretation, with no more predictive power then von Neumann's theory. Due to the results of Chapter 3, it is impossible for the Schrödinger predicted entangled state to be taken as the measurement state. Because of this, one will find interpretations that invariably have a step whereby Schrödinger's predicted state is thrown out and the measurement state is substituted. *A posteriori* theories seem to be most often put forward by individuals who strongly believe everything evolves according to Schrödinger's equation and have tried but failed to directly solve the measurement problem by showing an exact correspondence between measurement and Schrödinger unitarity. One should be keen to check how the theorist of an *a posteriori* justifies this substitution. Sometimes one finds justification via pejoratives such as "Of Course," or "Obviously" added for good measure in an attempt to ward off those who would question the validity of such a substitution.

Many philosophers define the measurement problem precisely as an *a posteriori* problem. For example, Lewis [114] defines the measurement problem as:

> *"The measurement problem, in a nutshell, is the problem that at the*

> *end of a measurement, there is nothing in standard quantum mechanics that represents the determinate outcome of the measurement" ... "A minimal condition for solving the measurement problem, then, is that a theory provides an explanation of our determinate measurement results."*
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At first glance, this seems like a reasonable definition of the measurement problem. However, on closer examination the definition assumes that the current *a posteriori* theory is satisfactory, and a minimal condition to resolve the measurement problem is some explanation of the determinate measurement results. As many or most philosophers appear (from our reading) to subscribe to Lewis's definition of the measurement problem, we will throughout the remainder of the book refer to such *a posteriori* definitions as the *Philosophers' Definition* of the measurement problem. The philosophers' definition is certainly a convenient definition for philosophers, as numerous philosophical theories can be proposed and analyzed using philosophical categorizations and philosophical analysis with little or no risk of being scientifically falsified—but only under the condition for which one has been *given* that a measurement has occurred.

The issues of who-what-when-where-and-why a measurement occurs are largely taken off the table by the use of the philosophers' definition, and yet such issues are primary fundamental physical issues that need to be addressed in the quantum measurement problem. Furthermore, our discussion in Chapter 3 shows why the *a posteriori* philosophers' definition is not sufficient to encompass the issues of incompleteness of current quantum mechanics that Einstein and others have voiced regarding the conflict between measurement and unitary evolution.

The definition that we propose requires that the issues of entanglement versus product state be addressed by the development of either a Category 1 or Category 2 physical theory and via physical experimentation that provides verification of the related requirements that have been elaborated on. As such a theory must address the physical reasons as to the who-what-when-where-and-why a measurement occurs, we will henceforth refer to our definition as the *Physical Definition* of the measurement problem

Necessary and Sufficient Conditions for Measurement

Consider a slightly modified *quantum locomotive* (originally presented in Chapter 2) for which the locomotive impinges on one of two doors, yours and your neighbor's. Suppose $|n_1\rangle_{D_1}$ represents the number of particles impinging on your door, and $|n_2\rangle_{D_2}$ on your neighbor's door. Assuming N is sufficiently large that its effect would be to smash through your door as if a locomotive is coming toward you, then the superposition state $(\,|N\rangle_{D_1}|0\rangle_{D_2}+|0\rangle_{D_1}|N\rangle_{D_2})/\sqrt{2}$ can be seen to represent a quantum locomotive.

If the state has just smashed through your door and you are aware that it is coming toward you rather fast, we would contend that this is a sufficient condition for measurement. On the other hand, a quantum locomotive smashing through your door is not a necessary condition for measurement. One might be under the impression that if one can specify a necessary and sufficient condition under which measurement occurs, then this would resolve the measurement problem.

Specifying a necessary and sufficient condition may or may not lead to fully resolving the measurement problem. For argument's sake, consider the condition of *irreversibility*. Suppose that it were found that true irreversibility is both necessary and sufficient for measurement to occur. In such a case, irreversibility can be considered to be a condition that is logically equivalent to the condition under which measurement occurs. But unless one can explain the physical conditions under which such true irreversibility occurs, one still has significant work to perform. On the other hand, suppose a theory predicts that a necessary and sufficient condition for measurement is the interaction of a photon with an atomic sample of .1-.2 mole of a particular category of molecules at a temperature of $20° - 25°$ Celsius and a pressure of 10-15 psi. Furthermore, suppose that the theory is experimentally verified. Then such a condition would certainly be more specific and relevant to meeting the conditions under which measurement occurs, compared to the use of an equivalent condition which occurs under completely unknown physical conditions. In the case of irreversibility, one has succeeded in replacing the unknown physical conditions under which measurement occurs with the unknown physical conditions associated with when irreversibility occurs. Generating necessary and sufficient conditions for measurement is an important tool; however, substituting one unknown condition for another unknown condition is hardly substantial progress regarding the measurement problem. In order to resolve the measurement problem via the use of equivalent conditions, one needs to substitute the unknown necessary and sufficient conditions under which measurement occurs via an equivalent but known and understood necessary and sufficient condition. This situation is comparable to Feynman's discussion of the physical meaning of force in Newton's Second Law, $F = ma$, in which he gives the example of attempting to explain the observation of an object changing its position by introducing the term "gorce," defined as that which causes an object's change in position [115, pp. (12-1)-(12-2)]. No predictions whatsoever can be made from such a definition. Instead, the physical meaning of force in $F = ma$ comes from relating force to specific independent underlying properties. Otherwise, $F = ma$ is an incomplete law. Similarly, a theory of the measurement problem must relate the act of measurement to underlying physical phenomena as in R1.3.

For All Practical Purposes, FAPP

Bell coined the phrase in the paper [116], "for all practical purposes, FAPP." Bell believed that the measurement postulate, with its replacement of the quantum predicted unitary state with the results obtained through measurement was (as far as he knew) acceptable for all practical purposes but did not appear to be acceptable in a theoretical manner. Bell [116] states:

Ordinary Quantum Mechanics (as far as I know) is just fine for all practical purposes.

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If ordinary quantum mechanics were correct and no alteration was ever needed, then the measurement problem would be an issue strictly for interpretation and might be an interesting problem in philosophy, but hardly worthy of substantial scientific investigation. What we can state from our developments so far, is that ordinary quantum mechanics cannot be considered to be complete at this time, because the measurement problem implies a contradiction that can be further investigated both experimentally via the UMDT of Chapter 3, as well as theoretically. A solution of the measurement problem, that is, of Category 1 would require a substantial revision of the current formalism. A solution that is of Category 2 would still require some augmentation of the current formalism. In either case, it does not appear that the current formalism can stand on its own.

It should also be noted that the general intent of Bell’s paper [116], which is sometimes quoted in an effort to justify the philosopher’s definition of the measurement problem, is actually recommending that an effort be made to go further than the current two postulates. Later Bell states for example, “Is it not good to know what follows from what, even if it is not really necessary FAPP?” and looks at several different theories.