Transactional Interpretation

The transactional interpretation (TI) was put forward by J. Cramer in 1986 [163]. Before describing the transaction interpretation, we first examine how Cramer defines the measurement problem. In the paper [164], Cramer states that it is not the case that a clever experimentalist could go into the laboratory and determine which interpretation is correct by testing experimental predictions. Moreover, that interpretations are transformable or equivalent [158]:

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

Cramer also believes that interpretations cannot be tested experimentally [158]:

> *My discussion of quantum mechanics interpretations stressed the point that the interpretation of a mathematical formalism cannot be tested experimentally and must be judged on other grounds.*

For which Cramer confirms the above statement does include the TI, see for example [165]. It should by now be clear to the reader that Cramer believes the measurement problem is defined via the philosophers' measurement problem. However, there most definitely is a physical measurement problem that we have defined for which experimental tests are needed to resolve the problem. Cramer desires to reproduce the orthodox formalism via an interpretation and not to augment the formalism as we claim is required to resolve the measurement problem. Cramer's understanding of the measurement problem appears similar to that of Lewis's at least in the sense that no augmentation of the formalism is required for its resolution.

Due to Cramer's conceptual attitude toward the measurement problem, one cannot expect that the transactional interpretation will meet the Requirements R1.1-R1.4 for a Category 1 theory or R2.1-R2.3 for a Category 2 theory. And this is correct, for it will be shortly demonstrated that TI is just another *a posteriori* theory which provides an interpretation of how a measurement occurred, *given* that a measurement has occurred. This common *a posteriori* theme has now been repeated several times when interpretations are proposed by Unitarians that simply define the measurement problem in a manner similar to the philosopher's definition.

The TI proposes that there is a nonlocal transaction that occurs when any quantum measurement occurs. The mechanics of the transaction are likened to a *handshake* that occurs via an exchange of advanced and retarded wave solutions. Such solutions were proposed in the *absorber theory* of Wheeler and Feynman. The TI utilizes concepts from the absorber theory of Wheeler and Feynman. Consider a particle that travels from an emitter to an absorber. There are three stages that describe a quantum event in TI [164]. First, the emitter sends out an *offer* wave Ψ to the absorber. In the second stage, the absorber sends out a *confirmation* wave in response to the offer wave, a confirmation wave that is the complex conjugate of the offer wave, Ψ^*. The emitter's offer wave is sent backward in time so that at the moment that the particle might be emitted, there exists an overlap $\Psi\,\Psi^*$ between the offer wave and confirmation wave. At this point, this overlap represents a probability that is used to determine if the offer wave is accepted. The offer is either accepted or rejected in the third stage of TI. Once accepted, energy is transferred from the emitter to the absorber. If not accepted, the process is begun again. The transaction when completed constitutes a quantum event.

In terms of TI, it is explained in [163] that Born's probability law is a statement for which the probability of particular transaction is proportional to the magnitude of the echo corresponding to the transaction that is received by the emitter. It does appear that TI has succeeded in reproducing Born's rule, *given* that a measurement has occurred. Hence TI appears to be a valid solution to the philosophers' definition of the measurement problem. However, the physical measurement problem demands that one fulfill several requirements, among these the conditions under which a measurement occurs.

In this regard, it might be asked whether or not photon absorption or emission is a sufficient condition for measurement. Consider the photon cavity QED experiments of Haroche [121, p. 281] for which $\pi/2$ microwave pulses are used to produce superpositions of atom and photon states. If photon absorption were truly a measurement in such cases, it would not be possible to conduct a second $\pi/2$ pulse and always end up in the same initial state. Additionally, the successful quantum computing experiments in NMR and other areas where $\pi/2$ pulses are successfully utilized strongly indicates that such superpositions are already occurring. That is, the atom-photon goes into an entangled state, for example $(|0\rangle_{\text{atom}}\,|1\rangle_{\text{field}} + |1\rangle_{\text{atom}}\,|0\rangle_{\text{field}})/\sqrt{2}$, which is not indicative of a measurement i.e., the factual occurrence $|0\rangle_{\text{atom}}\,|1\rangle_{\text{field}}$ or non-occurrence $|1\rangle_{\text{atom}}\,|0\rangle_{\text{field}}$ of a photon emission. Moreover the fact that superposition eigenstates, which were predicted by the Jaynes-Cummings model [166] in light-matter interaction, have been experimentally confirmed spectroscopically in experimentation with microwave cavities [167] [168], optical cavities [169] and also more recently in circuit QED [170]. Additionally, time dynamics have been shown to be in agreement with collapse and revivals as predicted by the unitary Jaynes-Cummings rotating wave model [171] were confirmed experimentally in 1987 [172]. Taken together, such work provides rather strong evidence that neither photon absorption nor emission alone can be considered a sufficient condition for resolving the measurement problem. Moreover, the experiments by Haroche [173], in which superpositions of $|0\rangle_{\text{atom}}\,|1\rangle_{\text{field}}$ and $|1\rangle_{\text{atom}}\,|0\rangle_{\text{field}}$ have been produced and confirmed, put the proverbial final nail in the coffin regarding either photon absorption or emission as a sufficient condition for measurement, which is often considered by many as a measurement event and used in proposed solutions to the measurement problem.

Let us examine what TI provides when examining the Chapter 3 UMDT. Since photon absorption does not appear to be a sufficient condition for a measurement event, consider two atoms in place of the devices in Figure 3.4. Evidence from the Haroche entanglement experiments in [173] can be directly applied to each of the two devices and would indicate that the photon absorption is unitary in this case. Hence the Chapter 3 UMDT test would be expected to yield the value $2\sqrt{2}$. On the other hand, if TI claims that a bona fide measurement can occur such that the energy of the photon has been transferred to exactly one of the two atoms with the final state of the two atoms in a product state, then this can be falsified by performing the Chapter 3 UMDT experiment. If such an experiment were performed and the proponents of TI claimed that this is only because the process is unitary and there is no need to use TI, then it is clear that TI is only being invoked as an *a posteriori* theory, with no predictive power to explain the conditions under which a device functions as a measurement device. What is missing from TI is precisely what is needed to provide a solution to the measurement problem as we define it. L. Marchildon states [174] regarding TI and the measurement problem:

> *The question now is: What distinguishes a reversible entanglement process, which gives rise to no confirmation wave and no transaction, from an irreversible one, which does give rise to a confirmation wave and, possibly, to a transaction. Of course, this question has no answer within the strict Hilbert space formalism of quantum mechanics, where all entanglement is in principle reversible. The upshot is that a transaction finds no room within the limits of that formalism. Just like the notion of a classical apparatus in the Copenhagen interpretation, or the one of wave function collapse in von Neumann's theory of measurement, the notion of a transaction must be added to the minimal quantum-mechanical formalism. In particular, the transactional interpretation cannot be considered complete unless the conditions for the possible occurrence of a transaction are spelled out in detail.*

Marchildon here has expressed, in a manner that is in-agreement with the overall theme of this book, as to why further conditions and requirements are needed in order for the TI to be considered as a potential solution to the measurement problem.

Other Interpretations

There are a large number of other interpretations that have been put forward to explain measurement. While it is beyond the scope of this book to present every interpretation, it is instructive to examine several more.