The Zeno Effect

The Zeno effect [202] is often considered to be a property of measurement. Consider the phrase, “A watched pot never boils.” This statement implies that act of watching or observing the pot through the measurement process, prevents it from boiling.

The Zeno effect is predicted to occur within the von Neumann framework when the same measurement is repeated. Consider a system that is initially in an eigenstate (Eigenstate 1) of the measurement observable and evolves in time via Schrödinger’s equation slowly into a superposition of Eigenstate 1 and Eigenstate 2 of the measurement observable. If a measurement is made and the result that represents Eigenstate 1 is obtained, one is obliged to apply the projection postulate to the quantum system which resets the system back to its initial state of Eigenstate 1. If the measurements are made quickly in succession with time between measurements equal to τ_r then the effect of the measurements, as seen in [202], is to delay the transition to Eigenstate 2 as τ_r is decreased.

The Zeno effect has been demonstrated in a number of experiments. In the experiment reported in [203] the quantum Zeno effect was first demonstrated using a three-level atomic system consisting of approximately 5000 Beryllium ions. The authors demonstrated a Zeno effect when the ions were subject to repeated measurement. There have been a number of experimental demonstrations of the quantum Zeno effect.

Discerning the Zeno Effect

Initially, upon publication in 1990 of [203], it was thought by many that the experiment was proof that a measurement effect was causing reduction or collapse of the wave function. Later, analysis [204] [205] showed that the use of strong pulsed lasers applied to the ions was sufficient to cause an effective loss of coherence that could also be attributable to a unitary theory. Later, it was thought that a single system was needed to show that the Zeno effect was a measurement effect. In an analysis of the Zeno effect in the paper [206], the authors recommended the use of a single system to determine if fluorescence still occurs. It is stated in [207]

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Balzer et al. later experimentally demonstrated the existence of the Zeno effect using a single system in the paper [208]. Still, a question that remained is whether or not such a demonstration is clear proof that the Zeno effect is due to measurement and not unitary evolution.

Consider the following potential method to discriminate measurement from unitary evolution in the Zeno effect. The basis of the method is to utilize different dephasing characteristics predicted under unitary interaction versus measurement. This is required at small times when the system initially couples to what is believed to cause measurement. As one can expect the latency effect of the strong optical laser to be rather fast, this would need to be done over short times. In [209] it is claimed that it is very difficult to induce and to detect experimentally the difference between unitary evolution and reduction. The authors expect that in order to accomplish such a discrimination, no interactions with the environment can take place.

These statements underscore the many subtleties that exist regarding what is required to resolve the measurement problem. Consider in Kwiat [210], using a design that appears to incorporate unitary elements, i.e., beam splitters, etc., an effect was demonstrated that is similar to the Zeno effect. The theory of interaction-free measurement is utilized in the paper because an object that can absorb the photon is either inserted within a path of an interferometer or is not inserted. If the object is inserted, the presence of the object can be completely discerned without the object absorbing the photon. The question that remains is whether or not a unitary interaction versus a bona fide measurement will change in any manner the results that were obtained in the experiment. In Exercise 4.12 in the book or kindle version of theQMP a unitary interaction is considered in place of an object that blocks the device. It can be shown by working through Exercise 4.12 in the book or kindle version of theQMP, that there is no difference between the prediction of unitary evolution and interaction-free measurement, so as long as the interaction with the device is sufficiently short that dephasing cannot be distinguished from measurement during the latency time.

In neither the Itano [203] nor the Kwiat [210] experiment does it appear that one can conclude that the Zeno effect is either a necessary or a sufficient condition for the occurrence of measurement phenomenon. In [211], this issue is further discussed and it is concluded that any mechanism that inhibits the unitary evolution (whether unitary or non-unitary) is sufficient to exhibit a Zeno effect. Hence a Zeno effect does not appear to be sufficient for measurement, and whether or not some Zeno effect is necessary for measurement is not known at present.