Irreversibility and Entropy

The concepts of irreversibility and entropy were presented in Boltzmann's theory, however, whether or not such irreversibility was a consequence of a large number of reversible interactions that are for all practical purposes not distinguishable from the existence of actual elementary non-reversible operations, was not known at the time of Boltzmann. Von Neumann in [13, p. 365] examined the reversibility of the two processes and states:

> *The simplest process would be to refer to the time dependent Schrödinger differential equation, i.e., our process 2. The process is also reversible.*

In regards to the measurement process, Process 1 [13, p. 380]:

> *... each measurement on a state is irreversible, unless the eigenvalue of the measured quantity has a sharp value, in which case the measurement does not change the state at all. As we see, the non-causal behavior is thus unambiguously related to a certain concomitant thermodynamical phenomena.*

Later [13, p. 388]

> *Therefore, if only interventions 1., 2., are taken into consideration, then each process 1., which effects a change at all, is irreversible*.
>
> .

Again, the property of irreversibility as present in the formalism of quantum mechanics is understood by Bohr and in the mathematics of von Neumann's Process 1. Irreversibility is consistent with Bohr's viewpoint of the non-causal or statistical nature of observation.

Von Neumann also considered in [13] the theory of entropy which is related to the theory of information change. Von Neumann introduced a measure of entropy (often referred to as the von Neumann entropy) and showed that under unitary evolution such entropy remains unchanged. Von Neumann also showed, under projective measurement, that the von Neumann entropy of the system increases except when the system is already in an eigenstate of the measurement observable.

On the other hand, we have already made mention of two types of measurement: a measurement whereby a device detects the presence of a particle such as a photon, and another type termed interaction-free measurement (IFM) whereby the detector does not undergo a change that indicates the presence of the particle.

In the case of IFM it cannot be said that measurement is a necessary condition for irreversibility. In the paper [199] by Elitzur and Dolev, it is shown that IFM's can sometimes be reversed. The interested reader should read the original paper, as a detailed exposé of their work is beyond the scope of this book; a synopsis will be given here. The authors consider a photon that is in a superposition of polarization and consider using detectors to create a partial measurement on the polarization superposition state. They show when the detector does not detect and partly disrupts the state, it is sometimes possible to completely reverse the effect and re-establish the original superposition. The authors state that in the case of partial measurement that in comparison to the case of positive measurement, the case of negative or IFM can sometimes be reversed.

Discerning Irreversibility and Entropy

Irreversibility and entropy increase are predicted to accompany certain acts of measurement as shown by von Neumann. And as reversibility is intrinsically linked to unitary evolution, the question arises as to whether or not irreversibility and entropy change are properties that can be used to distinguish measurement from unitary evolution. As has been discussed, irreversibility does not appear to be a sufficient condition for all cases of measurement, due to the possibility of reversing certain interaction-free measurements.

Now, supposing that one can demonstrate that a system has truly undergone an irreversible time evolution, one can ask if this is a sufficient condition for measurement. This appears to be a reasonable hypothesis at this time. A Category 1 theory that includes irreversible evolution under certain conditions would require augmenting the orthodox theory. Such augmentation could very well also include an entropy change that is associated with an informational change.

A Category 2 theory of measurement has already been proposed as one for which the very conditions under which measurement occur prevent to some extent the experimental verification of the theory. Consider the possibility of a Category 2 theory for which there exist certain configurations of particles for which unitary evolution can never be reversed. Furthermore, that all measurement configurations necessarily belong to such configurations. Then a logical possibility is that it is no longer possible to experimentally falsify an improper mixture that resulted from unitary evolution, in which case the improper mixture might be interpreted as a proper mixture. If such a theory were proven correct, then the property of irreversibility could still logically follow from certain configurations of unitary evolution. However, in a Category 2 theory it does not appear that von Neumann entropy of a system plus apparatus can change.