From Bell Inequalities to Quantum Measurements

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Abstract

In the 1970's there were two main challenges in the foundations of quantum physics:

1. Quantum non-locality, i.e. the violation of Bell inequalities, and
2. The quantum measurement problem, i.e. the Schrödinger eq. is interrupted whenever the system encounters a bunch of atoms bearing a sticker saying "measurement apparatus".

The general consensus is that the first issue has been somewhat resolved, while the second issue remains widely open and even controversial.

Here we first show that despite enormous progress on quantum non-locality, much remains to be explored. Next, we recall that naive attempts to combine relativity and quantum measurements result in signalling between space-like separated regions. In QFT, these are known as impossible measurements. We show that the same problem arises in non-relativistic quantum physics, where joint non-local measurements (i.e., between systems kept spatially separated) in general lead to signalling. However, it is possible to measure non-local variables without signalling by exploiting entanglement as a resource. This recovers the Born rule, but not the projection postulate. We use these findings to classify all joint quantum measurements from the simplest to the more complex ones, based on the amount of entanglement require to measure them. In particular, we generalize the Elegant Joint Measurements from 2 qubits to an arbitrary number of parties.

Finally, we ask what these findings teach us about the quantum measurement problem. We argue that this problem is not specific to quantum physics, but is inherent in all indeterministic models, including an alternative interpretation of classical mechanics.