WEEK-2 WRITEUP

EPR PAIRS

An EPR pair is a pair of qubits (or quantum bits) that are in a Bell state together. Einstein, Podolsky and Rosen proposed a gedanken experiment that uses entangled particles in a manner that seemed to violate fundamental principles of relativity. It concludes that the paradox is resolved as the symmetry shown by changing observers indicates that they cannot use their EPR pair to communicate faster than the speed of light. EPR pairs are a particular case of entangled pairs of qubits. Quantum entanglement is a physical phenomenon which occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently of the state of the other. Elementary cases of use of EPR pairs in quantum computing would be quantum teleportation and Superdense coding, and upon those pieces people have built more sophisticated applications. The Bell states, a concept in quantum information science, are specific quantum states of two qubits that represent the simplest (and maximal) examples of quantum entanglement. The Bell states are a form of entangled and normalized basis vectors. This normalization implies that the overall probability of the particle mentioned states. Entanglement is a basis-independent result of superposition.

Due to this superposition, measurement of the qubit will collapse it into one of its basis states with a given probability. Because of the entanglement, measurement of one qubit will assign one of two possible values to the other qubit instantly, where the value assigned depends on which Bell state the two qubits are in. The essence of the paradox is that particles can interact in such a way that it is possible to measure both their position and their momentum more accurately than Heisenberg's uncertainty principle allows, unless measuring one particle instantaneously affects the other to prevent this accuracy, which would involve information being transmitted faster than light as forbidden by the theory of relativity ("spooky action at a distance").

This consequence had not previously been noticed and seemed unreasonable at the time; the phenomenon involved is now known as quantum entanglement. EPR describe the principle of locality as asserting that physical processes occurring at one place should have no immediate effect on the elements of reality at another location. At first sight, this appears to be a reasonable assumption to make, as it seems to be a consequence of special relativity, which states that energy can never be transmitted faster than the speed of light without violating causality.

However, it turns out that the usual rules for combining quantum mechanical and classical descriptions violate EPR's principle of locality without violating special relativity or causality. Causality is preserved because there is no way for Alice to transmit messages (i.e., information) to Bob by manipulating her measurement axis. Whichever axis she uses, she has a 50% probability of obtaining "+" and 50% probability of obtaining "−", completely at random; according to quantum mechanics, it is fundamentally impossible for her to influence what result she gets. Furthermore, Bob is only able to perform his measurement once: there is a fundamental property of quantum mechanics, the no cloning theorem, which makes it impossible for him to make an arbitrary number of copies of the electron he receives, perform a spin measurement on each, and look at the statistical distribution of the results. Therefore, in the one measurement he is allowed to make, there is a 50% probability of getting "+" and 50% of getting "−", regardless of whether or not his axis is aligned with Alice's.

There are several ways to resolve the EPR paradox. The one suggested by EPR is that quantum mechanics, despite its success in a wide variety of experimental scenarios, is actually an incomplete theory. In other words, there is some yet undiscovered theory of nature to which quantum mechanics acts as a kind of statistical approximation (albeit an exceedingly successful one). Unlike quantum mechanics, the more complete theory contains variables corresponding to all the "elements of reality". There must be some unknown mechanism acting on these variables to give rise to the observed effects of "non-commuting quantum observables", i.e., the Heisenberg uncertainty principle. Such a theory is called a hidden variable theory.