Schrödinger's Cat

In the discussion of Bohr's complementarity, Heisenberg's uncertainty principle was utilized by Bohr to show that there is always an uncontrollable uncertainty that results during measurement that broadens one variable at the expense of its conjugate, such as simultaneous measurements of position and momentum. However, there is substantially more to the measurement problem than the uncertainty principle. Understanding the entanglement predictions of Schrödinger's equation is necessary to fully comprehend the measurement problem.

Einstein was initially enthusiastic regarding the discovery of Schrödinger's equation, as he did not believe in nondeterminism. However, Schrödinger's equation can evolve product states to become entangled states which, as elaborated further in Chapter 5, Einstein similarly disliked. Einstein formulated a series of thought-experiments to illustrate that Schrödinger's equation did not appear to be the full story or that the theory was incomplete, which were sent to Schrödinger in a letter in 1935. This was originally posed as a thought-experiment in which gunpowder will spontaneously explode over a one-year period, but the time when it blows up is at an unknown random time. Furthermore, when it does blow up the explosion is so fast that one can assume the material at any time is either stable gunpowder or the state of the remnants after the explosion. Einstein was concerned that Schrödinger's equation would predict the state to be in a superposition of stable gunpowder and explosion before the one-year period. However, Einstein believed that the reality is that the actual state of the material is at any time either gunpowder or the remnants of the explosion.

Later that same year, Schrödinger published a thought-experiment similar to Einstein's in which a cat is in a box that contains a radioactive source, a Geiger counter detector, a hammer and a flask of poisonous hydrocyanic acid. When the radioactive source randomly emits a particle and the Geiger counter detects the emission, it causes a hammer to fall and break the flask, releasing the poison and killing the cat. If an observer does not open the box (assumed for times less than the mean lifetime for which the radioactive source typically takes, on average, to emit a particle), then one is forced to assume that the state of the cat inside the box is a state of a cat both alive and dead. This is further illustrated in Figure 1.15. One would have to assume by the postulates of quantum mechanics that until the box is open and the contents seen, or measured by an external observer, that the cat is in a superposition.

The issue that Einstein was most concerned with in later life is that one would not be able to predict using Schrödinger's equation when the source emits a particle that is detected by the Geiger counter, unless there are further hidden variables and a more detailed theory that exists to explain this. However, consider using the theory as proposed in the Copenhagen interpretation for which there are only the two postulates of 1) Schrödinger evolution or 2) measurement as described by Born's rule. Neither of these modes contains any such hidden variables *prima facie*, and it leads one to the conclusion that the cat is both alive and dead simultaneously. Einstein rejected this and believed the theory must therefore be incomplete.

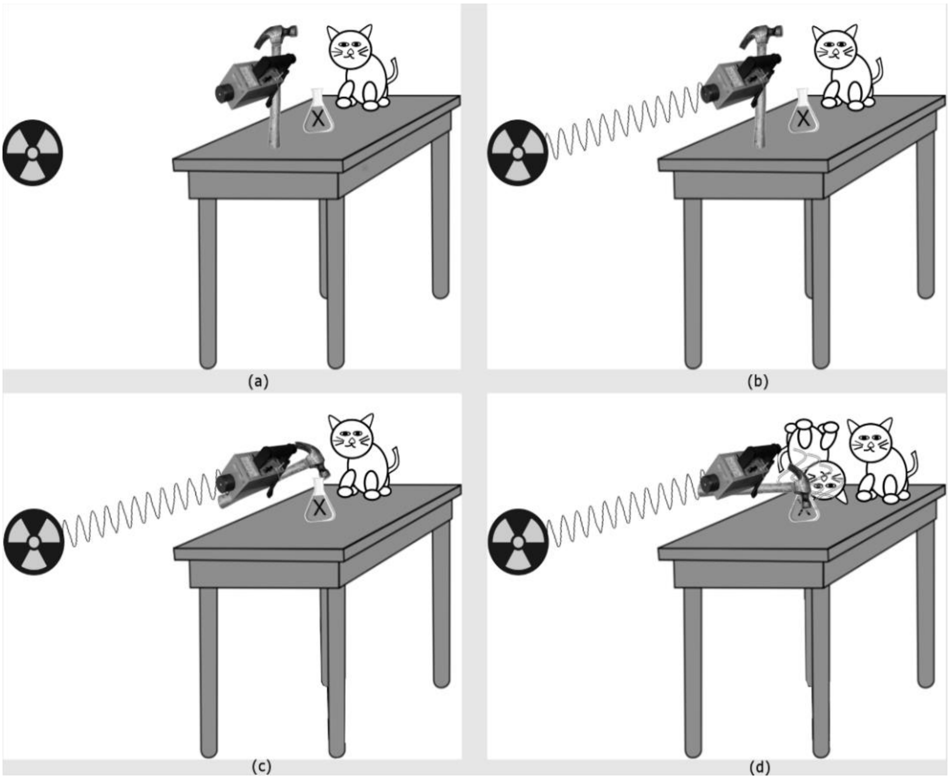

Figure 1.15: Schrödinger's cat, all times assumed less than the mean lifetime of the radioactive source (a) radioactive source off, cat alive, (b) radioactive source on, existence of quantum wave function, (c) quantum wave function evolves with the possibility that the hammer will fall and (d) the possibility that the hammer will break the flask causing a dead cat, but the possibility that the cat is still alive cannot be ruled out by Schrödinger's equation alone.

To make matters worse for Einstein, Bohr rejected the notion that such hidden variables could ever be known to an observer, and that therefore a statistical or nondeterministic accounting was all that could ever be known in the epistemological sense. This is an important issue in a thorough understanding of Bohr's complementary principle, and is further discussed in Chapter 5. The utter insistence by Bohr of the absolute necessity of the need to resort to a statistical description could be argued to have created a dilemma for Einstein and one can begin to see why. For had Bohr accepted that there might eventually be discovered a more complete model for which entangled states did not occur, rather than the *only* possibility being a nondeterministic accounting after a measurement is made, Einstein perhaps would have rested easier knowing that such a research program would continue to uncover such a full theory. But it was not to be: Bohr never wavered on the impossibility of generally being able to predict the wave function deterministically through all stages of measurement.

Schrödinger coined the term “entanglement” and this is the primary resource currently being investigated in the theory of Quantum Computing and Quantum Information. Schrödinger took Einstein’s side on the lack of completeness of quantum mechanics in disagreement with Bohr and tried in later life to develop models for which entanglement of macroscopic objects would not occur, but did not succeed.