Lecture 19: March 30, 2021

I. Introduction

In this lecture, we present 1) Wigner's argument and 2) the Einstein-Rosen-Podolsky argument against the Bohr interpretation of quantum mechanics.

1 Schrödinger's Cat Revisited

Many have sought to resolve the Schrödinger cat problem. The key problem here is entanglement as Schrödinger called it. Entanglement refers to the inherent inseprability of the elements of a linear superposition. Mathematically, this results from a state that cannot be written as a matrix product state. Here is Wigner's solution. What if a friend of Wigner's is in the room who runs the Schrödinger cat experiment while Wigner is out of the room. The question arises what is the state that is relevant to Wigner before he enters the room. Wigner argues that because conscious experience is discrete, that is, mutually incompatible states cannot be perceived at the same time, it is impossible for the superposed state to be the correct description. Hence, his friend must be in either a state in which he knows the cat is dead or the cat is alive. Since this argument appeals to the special status of consciousness, it is consciousness that collapses the wavefunction.

There are many counters to this. One is to appeal to possible worlds. There is no need to appeal to consciousness here because the different outcomes lie in different worlds. In this scenario, there is no collapse of the wavefunction.

2 Alternative views

We discussed last class that the problem with quantum mechanics is not the measurement problem but a reality problem. Why is it that as the wavelength of an object increases to the atomic realm, that objective reality ceases? This is the reality problem in quantum mechanics. Bohr and those in the Copenhagen school claimed that we should not really worry about this. Afterall the wavefunction is not real anyway. It is simply a computational tool. Plus we are hinged to superposition because of interference. This would seem to imply that the wavefunction is real. But if the wavefunction is an objective property of an object then why should it collapse once a measurement is made? Here are some possible ways out of this dilemma.

(Folk) somehow the state vector (TSV) collapses, don't ask how.

(Copenhagen) TSV wasn't ever real, so don't worry about how it collapses. It was just a calculating tool.

(Macro-realism) TSV does too collapse, but that involves deviations from the linear wave equation. Such non-linear terms can be found, but the theory isn't yet developed very far. (Pearle)

Local "hidden variables" were always around to determine the outcome of the experiments, so it doesn't have to collapse. (Einstein, DeBroglie, Bohm)

(Many Worlds). The wavefunction doesn't collapse; all those different branches (you seeing the live cat, you seeing the dead cat) occur but have no reason (until you understand the wave equation) to be aware of each other's existence. There's nothing but the linear wave equation, you just have to understand what it implies. (Everett, Wheeler,)

(Many Many Worlds). As above, but the linear wave equation predicts incorrect probabilities, so you need non-linear terms to give the right probabilities. (only mbw)

(quantum logic) Classical Boolean logic is empirically disproved (as a description of our world) by QM, just as Euclidean geometry was shown by G.R. not to describe our world. (Putnam,)

3 Einstein-Rosen Podolsky Experiment

Realism. "If, without in any way disturbing a system, we can predict with certainty (i.e., probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity." (Einstein, Podolsky, Rosen, 1935).

This was the basic principle EPR were trying to establish. Here's how they did it. Let's consider a two-electron atom. In a two-electron atom, the spin of the electrons must be apposed–that is, they must be antiparallel. If electron A has spin up(u) then B has spin down(d). Likewise if A is down (d) then B must be up (u). Hence, before we do any measurement on our system, quantum mechanics tells us that the total wavefunction for our system is S(whole)=S(ud)+S(du). A measurement will result in either S(ud) or S(du). Hence, knowing S(whole) does not tell us which spin is up or down. To do this we need to know either S(ud) or S(du). Hence, the individual states, S(du) and S(ud), tell us more about the state of the spin than does S(whole) itself. This is peculiar, but true. In S(whole) the spins are in a quantum entangled state. This results in the wavefunction for the whole system carrying less information than each of the entangled states. Einstein knew this fact and devised along with Rosen and Podolsky the following thought experiment to show that quantum mechanics as we know it is an incomplete description of nature.

Let's say that our two-electron atom is placed half-way between two spin detectors. The distance between the two spin detectors is L. Let's zap the atom so that one electron goes to the left and the other to the right. If we measure at one detector that one of the electrons is up, then we know immediately that the other is down. Hence, if we measure that electron 1 is up, we know immediately without measuring electron 2 that it is in a down spin state. Hence, we know that the wavefunction has collapsed to S(ud). Likewise, if we measure that electron 1 is down, then we know immediately that the state of the system is S(du). Hence, we have devised an experiment in which the spin of electron 2 can be inferred by measuring what is going on with electron 1. How is this possible? EPR said that this is nonsense. Although their original dictum on realism stated that if without disturbing a system, the system is in a definite state, then there must exist some objective reality associated with that object. Why do they reject the objective reality they have inferred about spin 2. Here's the reason why. The distance between the two dectors can be as large as possible. Further there is no force that dector 1 exerts on detector 2. Hence, we have knowledge of what is going at 2 from an event a distance L away, where L can be quite large. This is action at a distance, a concept EPR thought was not reasonable.

Now here is the second part of the experiment. EPR then argue that let's say we also measure the electron spin along some other axis. Heisenberg tells us that we cannot have two sharp values of the electron along two axes at the same time. So let's do this any way. Regardless of the axis we choose to measure the spin of electron 1 along, we will by inference know that electron 2 has a spin along that same direction that is also sharp. But the question is how does electron 2 know that it should have a definite value of the spin along the axis that we have measured the spin of 1. If we argue that it knows so instantaneously, then this will require that the signal should travel faster than the speed of light. EPR rejected this and opted for instead that the spin of 2 must have been sharp in the first place. QM tells us that the spin of 2 must be fuzzy before the measurement but EPR have just shown that the spin of 2 is in fact sharp before a measurement. So QM is not the full story. They also purport to show that Heisenberg is wrong. They have inferred that the spin along any direction must be an equally sharp value. This violates Heisenberg.

So what went wrong. The problem lies with simultaneity of measurement along the different spin axes. We cannot measure two components of the spin simultaneously. Hence, we cannot hold it as a given that in the future the spin along some unmeasured axis will also be sharp. Hence, the EPR claim that two components of the spin along two different axes is sharp is not correct. Secondly, can the collapse of the wavefunction occur at a speed faster than the speed of light. No energy is transferred when the wavefunction collapses. Signals involve the transfer of energy. Collapse of the wavefunction does not correspond to the transmission of a signal in any usual way. No energy implies no signal and hence there is no problem with causality.

But what do we do about the first conclusion that the spin of 2 must have been sharp to start with at least along some axis? If quantum mechanics is not the whole story maybe there is some hidden variable which allows for the collapse of the wavefunction and hence saves objective reality. Bohm constructed a local hidden variables theory of quantum mechanics that preserved the basic structure but introduced classical realism as an essential feature. If the hidden variables are not operative, then we recover the usual lack of objectivity. The question then arises, how can one tell the difference between local hidden variable theories and non-objective quantum mechanics. John Bell devised a set of relationships which did exactly this. He showed how in EPR-type experiments, one can tell if the outcome was a result of quantum mechanics or some local hidden variables theory. In the experiments he devised, many successive measurements are made on the spin of two electrons along two different axes so that one could determine the degree to which they were correlated. Bell experessed the experimental result of the degree to which two spins are correlated with a parameter, S. In local hidden variables theory, this number cannot exceed 2. Whereas in non-objective quantum mechanics, the number must be larger than 2. The experiments have been done and the value of S is around 2.70. Hence, the local hidden variables theories are wrong. So what remains is the possibility that non-local hidden variable theories might account for objectivity in quantum mechanics. There has been no successful proposal of this form developed thus far. Hence, it seems that we are stuck with the lack of objective reality imposed by quantum mechanics.