24.111: Philosophy of Quantum Mechanics, Spring 2016
Homework 5

1. Suppose you've seen a proof of Bell's theorem but haven't yet done any experiments. (So you don't know, yet, whether quantum mechanics is true, or a local hidden variables theory is true.) If you choose just one experiment (say, $(0°, 120°)$), and perform that experiment just once on a pair of particles in the singlet state, the outcome of that one experiment cannot tell you whether a local hidden variables theory is true. (That is, the local theory and quantum mechanics do not disagree about the outcome of any single experiment considered in isolation.) Explain why.

Well, if you choose an experiment where the angles are the same, it is easy for a local theory to replicate the QM predictions. If you pick an experiment where the angles are different, QM is consistent with any outcome of a single experiment, since it only makes statistical predictions. A local theory is also consistent with any outcome. So no single outcome rules out one or another of the theories.

2. Suppose (hypothetically!) that we have created a device that, as in the EPR experiment, emits two particles in opposite directions. Suppose that there are three properties we can measure on each particle: A, B, and C. And suppose that a measurement of any of these properties can have one of two outcomes: "yes" or "no" (or, if you like: $+1$ or -1). So we could choose to measure A on particle 1 and B on particle 2; or measure C on both particles; and so on.

We do a variety of measurements on pairs of particles and collect statistics. We discover the following two facts:

> Fact 1: when we measure the same property on both particles, the outcomes always agree.
>
> Fact 2: when we measure different properties on both particles, the outcomes always disagree.

A local theory of the behavior of the particles will say that a measurement of a property on particle 1 in this experimental set-up does not influence the outcome of the measurement on particle 2. Prove that, given these facts, no local theory of the behavior of the particles could be true. (Note: you should not say anything about quantum mechanics, the theory, in your answer. Facts 1 and 2 are not derived from that theory, nor can they be derived from it when considering any of the experiments we have discussed.)

Since the theory is local, the only way to respect fact 1 is to have the particles carry deterministic instruction sets when they leave the source, that tell them exactly what to do for any experiment. Furthermore, they must carry identical instruction sets. Now suppose that the left guy carries an instruction set that starts (A:1,...). Since both carry the same set, respecting fact two requires the B and C values to be opposite the A value. So the instruction set must be (A:1,B:-1,C:-1). But in fact this instruction set does not satisfy fact 2: the outcomes will agree if we measure B on the left and C on the right. A similar argument shows that there is no possible instruction set that starts with (A:-1,...).

3. Read the excerpt from the Mermin paper "A Bolt from the Blue" (available on the readings page). In that paper Mermin makes a false statement about the relationship between the EPR argument and Bell's theorem. What is the false statement? Why is it wrong? Explain your answer fully.

It's where he says that the experiment "establishes that the EPR reality criterion is not valid." Bell's theorem says that QM, and any local theory, must differ in some of their statistical predictions. The experiments showed that it was the QM predictions that were observed. So what the experiment shows is that no local theory is true. The EPR criterion of reality is not the same as the claim that there is no non-local causation; the EPR criterion could be right even if locality were false. (Some people said: the experiment showed that the EPR conclusion was false, but since the criterion was only one of its premises, the experiment doesn't show that the that particular premise is false. That's not right. The EPR conclusion was the the orthodox interpretation is false (or more generally, that the wavefunction is not complete). The Aspect experiments do NOT show that the orthodox interpretation is false (or, more generally, that the wavefunction is incomplete).)