

*Lecture 28**Relevant sections in text: §3.9***Spin correlations and quantum weirdness: The EPR argument**

Recall the results of adding two spin  $1/2$  angular momenta. The fact that the total spin magnitude is not compatible with the individual spin observables leads to some somewhat dramatic consequences, from a classical physics point of view. This drama was already noted by Einstein-Podolsky and Rosen (EPR) in a famous critique of the completeness of quantum mechanics. Much later, Bell showed that the basic “classical locality” assumption of EPR must be violated, implying in effect that nature is truly as weird as quantum mechanics makes it out to be. Here we give a brief discussion of some of these ideas.

The original EPR idea did not deal with spins, but with a pair of spinless particles. We shall in a moment, following Bohm, deal with a spin system. But it is worth first describing the EPR argument, which goes as follows. Consider two spinless particles characterized by positions  $x_1, x_2$  and momenta  $p_1, p_2$ . It is easy to see that the relative position

$$x = x_1 - x_2$$

and the total momentum

$$p = p_1 + p_2$$

commute, so there is a basis  $B$  of states in which one can specify these observables with arbitrary accuracy.

Suppose the system is in such a state. Suppose that an observer measures the position of particle 1. Assuming that particles 1 and 2 are well separated, there is no way this experiment on particle 1 can possibly affect particle 2. (This is essentially the EPR locality idea.) Then one has determined particle 2’s position with arbitrary accuracy – without disturbing particle two. Thus particle 2’s position is known with certainty — it is an “element of reality”. Alternatively, one could arrange to measure  $p_1$ . By locality, the value of  $p_2$  is undisturbed and is determined with arbitrary accuracy. One concludes that, given the locality principle, particle 2’s position and momentum exist with certainty as an element of reality. But, of course, quantum mechanics prohibits this situation. Thus either quantum mechanics is incomplete as a theory (unable to give all available information about things like position and momentum), or the theory is non-local in some sense because the locality idea was used to argue that a measurement on particle 1 has no effect on the outcome of measurements on particle 2. The loss of this type of locality was deemed unpalatable by EPR, and so this thought experiment was used to argue against the completeness of quantum mechanics. In fact, the correct conclusion is that quantum mechanics is, in a certain sense, non-local.