Fock states, quantum effects, non-locality; a macroscopic version of the EPR argument.

Fock states (number states) are becoming more and more accessible experimentally. For instance, Bose-Einstein condensation in dilute gases at very low temperatures creates condensates that are, to a good approximation, represented by Fock states. Moreover, repulsive interactions between the atoms tend to stabilize the occupation of a single quantum state, because the effects of exchange occur only it the atoms occupy different individual states. Another example is given by photons in a cavity: Haroche and coworkers have shown that quantum non-destructive measurements can be used to project the state of the field contained in a cavity onto Fock states; in this case, it is the very act of quantum measurement that creates the Fock state.

Such states posses many interesting quantum properties. A first example is given by a situation where two Fock states fall on the two input ports of a beam splitter: even in such a simple situation, interesting quantum effects are visible in the number of particles contained in the output beams; they combine the spontaneous appearance of a relative phase under the effect of measurement with a generalization of the Hong-Ou-Mandel effect.

If the two Fock states fall on two beam splitters in remote locations, quantum non-local effects are predicted, signalled by strong violations of the BCHSH inequalities. The violations do not tend to zero when the number of particles tends to infinity. With three Fock states and three beam splitters, quantum violations of the GHZ equalities are also obtained.

When transposed to spin condensates, these thought experiments become especially interesting. In this case Alice and Bob observe interference effects by measuring the transverse components of spins in their laboratories. The first spin measurement provides a completely random result since the relative phase of two Fock states is completely undetermined; but, when more and more results are obtained, the relative phase of the two spins states becomes better and better determined under the effect of the quantum measurement process. After a while, one reaches a quasi-classical situation where the transverse direction of all spins is almost fixed. In Bob's laboratory, a spin orientation parallel to Alice's appears, whatever the distance between the laboratories, and with no delay proportional to this distance. One can then revisit the Einstein-Podolsky-Rosen in a context where the measurements are made on many particles so that the EPR "elements of reality" become macroscopic quantities; this raises interesting conceptual questions that were not relevant in the historical argument, dealing only with two microscopic particles.

Moreover, violations of the BCHSH inequalities are also predicted in this case. The usual reasoning with two microscopic spins in a singlet state is now transposed to quantities that can be macroscopic, but the final result remains the same: not all predictions of quantum mechanics can be explained by a classical local model.