We elucidate the nature of the Bose-Einstein condensate observed in cold fermionic gases when fermionic atoms are strongly paired

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Fermionic condensates which were created in recent years by efforts of D. Jin (Boulder), R. Hulet (Rice), W. Ketterle (MIT) and others attracted attention as systems which could be similar to high temperature superconductors. It is believed that understanding these condensates can help understanding how high temperature superconductors of the future might work. Despite significant theoretical effort, the properties of such a condensate in the strongly paired “molecular BEC” phase (the “high-temperature” phase) became a subject of controversy. In our work, we resolve the controversy and show that a theoretical treatment exists which reconciles existing theories and predicts the behavior of strongly paired fermionic condensates.

Theoretically these systems are usually studied with the help of the Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity (1957), as augmented by A. Leggett (1980) and by P. Nozieres with S. Schmitt-Rink (1985). Most theoretical work amounts to a direct extension of the BCS theory into the regime of a strongly paired superconductor, even though such an extension was not what the creators of the BCS theory had in mind. Nevertheless, the results obtained via this approach made sense until the work of Petrov, Salomon, and Shlyapnikov (2004). These authors analyzed, without relying on the BCS theory, what would happen to a strongly paired fermionic condensate if the entire condensate consisted of merely four atoms. Their results, although definitely correct, directly contradicted the BCS theory when extended to the strongly paired regime. On the other hand, their technique crucially relied on the existence of just four atoms and could not be generalized to a larger condensate.

The approach we suggest creatively combines the BCS theory of superconductivity and the Bogoliubov-Belyaev theory of the weakly interacting Bose gas (1957). It allows us to compute all the properties of the strongly paired fermionic condensate in a controlled way, despite the presence of strong interactions. It reproduces the results of Petrov, Salomon, and Shlyapnikov when confined to four atoms, but also works when a macroscopically large number of atoms is involved. On the other hand, our results differ from what the BCS theory, in its naïve extension, would have predicted. In our work, we apply our technique to describe, in particular, how waves would propagate through such a strongly paired condensate and indicate how its critical temperature could be determined.