Comment on “Texture in the Superconducting Order Parameter of CeCoIn₅ Revealed by Nuclear Magnetic Resonance”

The study of the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state [1] has been of considerable recent interest. Below the temperature $T^*$ which is believed to be the transition temperature ($T$) to the FFLO phase in CeCoIn₅, K. Kakuyanagi et al. [2] reported a composite NMR spectrum with a tiny component observed at frequencies corresponding to the normal state signal. The results were interpreted as evidence for the emergence of an FFLO state. This result is inconsistent with two other NMR studies [3, 4]. Mainly, the relative shift difference between the low $T$ superconducting (SC) and normal state reported in [2] is much smaller than that in [3, 4]. Furthermore, the complex composite lineshape observed close to $T^*$ is not seen in our experiment. Finally, in the FFLO state we did not observe any signal at frequencies corresponding to the normal state signal. In this comment we show that the findings in Ref. [2] do not reflect the true nature of the FFLO state but result from excess RF excitation power used in that experiment.

In Fig. 1 NMR spectra at $T \approx 70$ mK at $H_0 = 9.55$ T, in the SC state, and at $H_0 = 11.12$ T, in the FFLO state, are shown. The spectra were recorded using different RF pulse powers while keeping all other parameters fixed. The signals at the lower frequency (blue) part of the spectra, i.e. having low shift, are as those reported in [3]. The signals at higher frequencies (in red) are at relative shift comparable to those in [2]. Evidently, signals with distinct shift can be obtained depending on the excitation power. The higher frequency signal corresponds to the main line in [2]. The exact spectral shape and position of this line is dependent on $\tau$, the time interval between the excitation and detection RF pulses, and on the pulse power. This is in contrast to the signal at lower frequencies. It is clear that the application of the RF power in a certain range can lead to the double peak structure solely in the FFLO state, as in [2]. Consequently, we deduce that the data reported in [2] do not reflect the true nature of neither the SC nor the FFLO state. Moreover, in a singlet superconductor the absolute value of the shift can only decrease with decreasing $T$. Thus, the lower shift attests to the correctness of our results in [3].

The most likely origin of the higher frequency signal is the RF heating of the electronic system. This signal is detected at frequencies comparable to those of the normal state at $T \sim 1$ K. Furthermore, only this signal displays some sample dependence. In fact, we found that this dependence stems solely from the exact size of the NMR coil, that is the power density of the delivered RF. Lower frequency signal obtained with low RF power did not show any sample dependence.

As stated above, when the appropriate RF power is applied we did not observe any NMR signal at low $T$ that corresponds to a normal state signal as in [2]. This is not surprising, since a signal from the spatial regions of vanishing order parameter should not necessarily appear at the normal state frequency [3]. Furthermore, calculations show that even if such a signal is to appear, it should be located within the line corresponding to the vortex lattice lineshape [4]. Obviously, this is not what is observed in [2]. Rather, the weak signal that appears at the frequency of the normal state in [2] is well separated from the main NMR line in disagreement with the theoretical predictions for the FFLO vortex state [3].

V. F. Mitrović, G. Koutroulakis, M. Klariček, M. Horvatić, C. Berthier, G. Lapertot, J. Flouquet

1 Brown University, Providence, RI 02912, U.S.A.
2 GHMFL, CNRS, 38042 Grenoble, France.
3 DRFMC, SPSMS, CEA Grenoble, France.

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