We discuss a model based on a field-induced mixture of two odd-parity irreducible representations to explain the unusual features of $H_{c2}(T)$ in the heavy fermion compound $\text{UBe}_{13}$. We compare its predictions with recent pressure measurements as well as with the most prominent theoretical models which have been proposed up to now.

I. INTRODUCTION

Heavy-fermion compounds are well-known candidates for a search and investigation of unconventional superconductivity. In these three-dimensional systems, the symmetry analysis of the possible superconducting state, depending on the crystalline lattice of the compound, sets the frame for the identification of the unconventional superconducting phase. This analysis gives a complete list of possible superconducting phases together with their properties determined by symmetry, including the type and order of nodes in the superconducting gap. In spite of a favorable theoretical situation and numerous experimental work, there doesn’t exist yet a firm and widely accepted identification of these superconducting phases (comparable to the results on superfluid $^3\text{He}$) in any heavy fermion superconductor.

In this paper, we examine the upper critical field $H_{c2}$ of the heavy fermion superconductor $\text{UBe}_{13}$ as a probe of the symmetry of its superconducting phase. The upper critical field is usually not very sensitive to gap nodes (see for example the quantitative studies for various scenarios in UPd$_2$Al$_3$ [Ref. 2]). But it is sensitive to the spin state of the Cooper pairs or more generally to the parity of the order parameter, because in heavy fermion systems, the orbital limitation is so large that $H_{c2}$ may be governed by the paramagnetic limitation.
UBe$_{13}$ is a cubic compound with a $T_c$ of order 1 K, and it is a non-magnetic superconductor. Since the first measurements of its upper critical field, it is known that it presents two very unusual and intriguing features. First, $H_{c2}(T)$ has a strong negative curvature close to $T_c$ which changes sign at intermediate fields. Then, taking account of a realistic value of the conduction electrons gyromagnetic $g$-factor, the paramagnetic limit at $T=0$ is exceeded several times, while the strong negative curvature close to $T_c$ shows that there exist a pronounced effect of the paramagnetic limitation.

Numerous explanations have been proposed since the first precise measurements of $H_{c2}(T)$ in this compound. Some have relied on additional hypothetic magnetic phase transitions, or on the field dependence of the normal state properties. But none of these phenomenological interpretations have found a firm basis in other measurements or theoretical developments. Another hypothesis, much closer to the point of view adopted here, relies on two different superconducting order parameters with a weak Pauli limitation. It has not been carried out quantitatively, but experimental support has been sought through the detection of a possible second phase transition already in zero field below the main superconducting transition. To our opinion, such a second phase transition is not supported by the data, which only show a weak and smeared maximum in the specific heat or minimum in the thermal expansion. The model that we propose here involves a mixture of two different irreducible representations, but does not rely on nor predict such a second phase transition.

At present, the only competing quantitative explanation relies on a simple strong-coupling model. It has been also successful in describing the evolution of both features up to pressures of 20 kbars: the complete temperature and pressure dependence of $H_{c2}$ comes out from a straightforward strong-coupling calculation with a single even parity state. The conflict with the paramagnetic limit at $T=0$ is resolved by its enhancement due both to direct strong-coupling effects (increase of the ratio $\Delta/T_c$) and to the (parameter free) inclusion of the formation of a spatially modulated superconducting state (FFLO), induced by the dominance of the paramagnetic limitation. Very good agreement with the data of Ref. 12 is provided in the whole pressure range, for $g$ being close to its free electron value, by fitting the strong coupling constant $\lambda$. The pressure dependence of $\lambda$ agrees with that of the effective masses (as indicated by the Sommerfeld coefficient or the slope of $H_{c2}$ at $T_c$), but it also turns out to be exceptionally large: $\lambda \approx 15$ at $p=0$. For all other known superconductors where the strong coupling regime due to electron–phonon interaction is well characterized, $\lambda$ does not exceed 5.

The model in this paper is based on a field-induced mixture of two odd-parity irreducible representations of the symmetry group ($O_h$) of the