Muon spin rotation/relaxation measurements of the non-centrosymmetric superconductor $Mg_{10}Ir_{19}B_{16}$

A. A. Aczel,[1] T.J. Williams,[1] T. Goko,[1,2,3] J.P. Carlo,[3] W. Yu,[4] Y.J. Uemura,[3] T. Klimczuk,[5,6] J.D. Thompson,[5] R.J. Cava,[7] and G. M. Luke[1,8,9]

[1]*Department of Physics and Astronomy, McMaster University, Hamilton, Ontario, Canada, L8S 4M1*
[2]*TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada, V6T 2A3*
[3]*Department of Physics, Columbia University, New York, NY 10027, USA*
[4]*Department of Physics, Renmin University of China, Beijing 100872, China*
[5]*Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[6]*European Commission, Joint Research Center, Institute for Transuranium Elements, Post Box 2340, D-76125 Karlsruhe, Germany*
[7]*Department of Chemistry, Princeton University, Princeton, NJ 08544, USA*
[8]*Brockhouse Institute for Materials Research, McMaster University, Hamilton, Ontario, Canada, L8S 4M1*
[9]*Canadian Institute of Advanced Research, Toronto, Ontario, Canada, M5G 1Z8*

(Dated: October 29, 2018)

We have searched for time-reversal symmetry breaking fields in the non-centrosymmetric superconductor $Mg_{10}Ir_{19}B_{16}$ via muon spin relaxation in zero applied field, and we measured the temperature dependence of the superfluid density by muon spin rotation in transverse field to investigate the superconducting pairing symmetry in two polycrystalline samples of signficantly different purities. In the high purity sample, we detected no time-reversal symmetry breaking fields greater than 0.05 G. The superfluid density was also found to be exponentially-flat as T→0, and so can be fit to a single-gap BCS model. In contrast, the lower purity sample showed an increase in the zero-field μSR relaxation rate below T_c corresponding to a characteristic field strength of 0.6 G. While the temperature-dependence of the superfluid density was also found to be consistent with a single-gap BCS model, the magnitude as T→0 was found to be much lower for a given applied field than in the case of the high purity sample. These findings suggest that the dominant pairing symmetry in high quality $Mg_{10}Ir_{19}B_{16}$ samples corresponds to the spin-singlet channel, while sample quality drastically affects the superconducting properties of this system.

PACS numbers: 76.75.+i, 74.70.Dd

The spin-singlet Cooper pairs of conventional superconductors require the corresponding superconducting order parameter to exhibit time-reversal symmetry[1]. For spin-triplet pairing, time-reversal symmetry is characteristic of only some of the possible superconducting states, but Anderson originally hypothesized that these should all have spatial inversion symmetry[2]. This then suggested that a material lacking an inversion center should be an unlikely candidate for spin-triplet pairing. However, a potential exception was found recently with the discovery of superconductivity in the non-centrosymmetric, heavy fermion compound $CePt_3Si$[3] where the upper critical field was found to exceed the paramagnetic limiting field in this material, suggesting possible spin-triplet pairing. A mixed spin-singlet and triplet pairing state was proposed to resolve this controversy, and this exotic possibility has stimulated significant effort in both theoretical and experimental studies to understand superconductors lacking inversion centers.

The proposed mixed pairing state was found to be a consequence of superconductivity in a material that exhibits spin-orbit coupling (SOC) but lacks inversion symmetry. In this case, the usually doubly-degenerate electronic bands become non-degenerate almost everywhere in the Brillouin zone and the resulting superconducting states can no longer be classified according to parity. While non-centrosymmetric, heavy fermion superconductors[3–6] have been studied in more detail to-date, these materials often have magnetically-ordered states that compete or coexist with the superconducting state, and such behaviour tends to significantly complicate penetration depth measurements. For example, the heavy fermion superconductor $CePt_3Si$ first becomes magnetically-ordered at 2.2 K before superconducting below 0.75 K[3], and the two states have been shown to coexist on a microscopic level[7]. Transition-metal compounds such as Li_2M_3B (M = Pd, and Pt)[8, 9], $Mg_{10}Ir_{19}B_{16}$[10], and M_2Ga_9 (M = Rh, Ir)[11] are therefore generally more straightforward systems for exploring the effect of SOC on superconductivity in the absence of inversion symmetry.

The strength of the SOC in any material is determined by both the crystallographic structure and the elemental composition. The latter is well-illustrated through recent NMR[12] and magnetic penetration depth[13] measurements on Li_2M_3B, which found that increasing SOC by replacing Pd with Pt changes the superconducting order parameter from dominantly spin-singlet (Li_2Pd_3B) to nodal, spin-triplet (Li_2Pt_3B). Muon spin rotation measurements of the penetration depth in Li_2Pd_3B sup-