

# NMR study of the impurity effects in noncentrosymmetric superconductors $\text{Li}_2(\text{Pd,Pt})_3\text{B}$

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**Abstract.** We report  $^{11}\text{B}$  nuclear magnetic resonance (NMR) studies of the impurity effect in noncentrosymmetric superconductors  $\text{Li}_2\text{Pt}_3\text{B}$  and  $\text{Li}_2\text{Pd}_3\text{B}$ . We substitute B with Al, and find that the full width of half maximum (FWHM) of the NMR spectrum increases with increasing Al content. The superconducting transition temperature ( $T_c$ ) of  $\text{Li}_2\text{Pt}_3\text{B}_{1-x}\text{Al}_x$  decreases drastically with increasing non-magnetic impurity (Al) content, while it is hardly affected in  $\text{Li}_2\text{Pd}_3\text{B}_{1-x}\text{Al}_x$ . These results provide new evidence for superconducting gap with line nodes in  $\text{Li}_2\text{Pt}_3\text{B}$ .

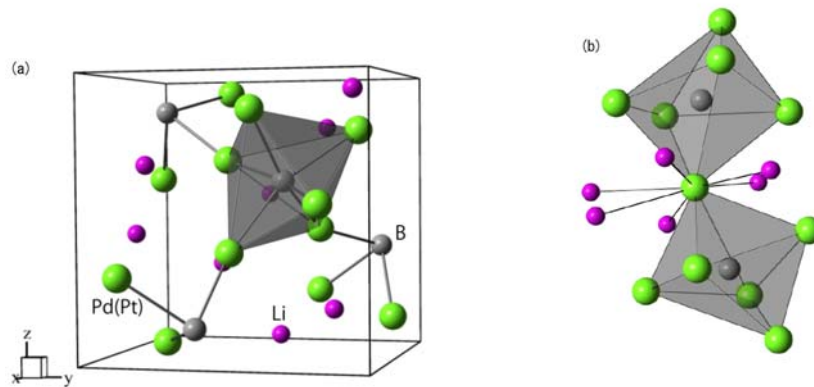
## 1. Introduction

In most superconductors, there is an inversion center in the crystal structure. In such superconductors, the Cooper pairs are either in the spin-singlet state or spin-triplet state because of parity conservation law. If a crystal lacks an inversion centre, an electric field is induced which leads to an asymmetric spin-orbit coupling (ASOC). This allows a mixing of the spin-singlet and spin-triplet superconducting states [1, 2].

$\text{Li}_2\text{Pd}_3\text{B}$  and  $\text{Li}_2\text{Pt}_3\text{B}$  are non-centrosymmetric superconductors with  $T_c = 7$  K and 2.7 K, respectively [3,4]. Fig. 1 shows the crystal structure of  $\text{Li}_2\text{M}_3\text{B}$  (space group;  $P4_332$ ). It consists of distorted octahedra of  $\text{BM}_6$ . The electron-correlation is weak in these compounds and they are most suitable for studying the effects of the inversion symmetry breaking. Previous works have found that the superconducting state is dominantly in a spin-triplet state with line nodes in the gap function in  $\text{Li}_2\text{Pt}_3\text{B}$  [5], while  $\text{Li}_2\text{Pd}_3\text{B}$  is a conventional superconductor [6]. The  $^{11}\text{B}$  spin-lattice relaxation rate ( $1/T_1$ ) in  $\text{Li}_2\text{Pd}_3\text{B}$  shows a coherence peak just below  $T_c$  and decreases exponentially with decreasing temperature, and the Knight shift changes below  $T_c$ , which indicate a spin-singlet state with an s-wave gap [6]. In the case of  $\text{Li}_2\text{Pt}_3\text{B}$ , however,  $1/T_1$  shows no coherence peak and decrease with  $T^3$ , and the Knight shift does not change across  $T_c$ . Recently, it has been found that the contrasting behaviour of the superconducting state of the two compounds stem from a difference in the local crystal structure that is responsible for the ASOC [7].

In order to shed new light on the superconducting gap, here we report a study of the impurity effect on these compounds by substituting Boron with Aluminum and characterizing with nuclear magnetic resonance (NMR). We replace B with Al as a non-magnetic impurity with concentrations up to 5%.





**Figure 1.** (a) Crystal structure of  $\text{Li}_2\text{M}_3\text{B}$  ( $\text{M}=\text{Pd}$ ,  $\text{Pt}$ ). In a unit cell, there are 8 Li, 12  $\text{M}$  and 4 B. (b) Neighbourhood near Pt atom. The octahedron of  $\text{BM}_6$  is distorted.

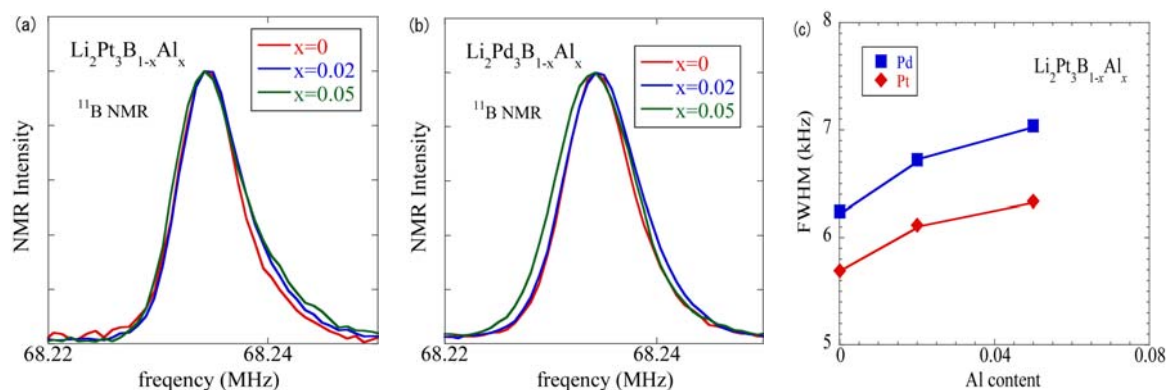
## 2. Experimental results

Poly-crystal samples of  $\text{Li}_2(\text{Pd}, \text{Pt})_3\text{B}_{1-x}\text{Al}_x$  ( $x=0, 0.02, 0.05$ ) were prepared by arc melting method with starting materials of Li (99.9% purity), Pt (99.999%), Pd (99.9%), B (99.8%), Al (99.99%). The two-step arc-melting process was used [4, 5]. For NMR measurements, the polycrystalline samples were crushed into powder. The  $T_c$  at zero magnetic field was determined by measuring the ac susceptibility using the NMR coil. The  $T_c$  of  $\text{Li}_2\text{Pd}_3\text{B}$  and  $\text{Li}_2\text{Pt}_3\text{B}$  is 7.2 K and 2.9 K, respectively. The NMR spectra were obtained by fast Fourier transform (FFT) of the spin echo taken at  $H=5$  T. The full width of half maximum (FWHM) of the  $\text{Li}_2\text{Pd}_3\text{B}$  and  $\text{Li}_2\text{Pt}_3\text{B}$  are around 6 kHz and 5.5 kHz, respectively.

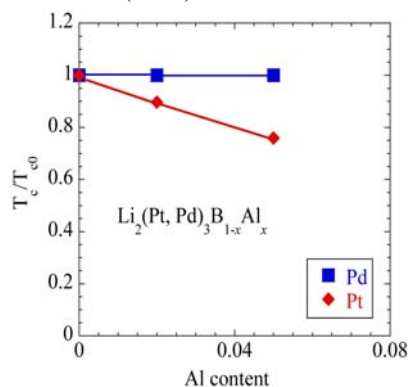
Fig. 2(a) shows the  $^{11}\text{B}$  NMR spectrum of  $\text{Li}_2\text{Pd}_3\text{B}_{1-x}\text{Al}_x$  and Fig. 2(b) shows that of  $\text{Li}_2\text{Pt}_3\text{B}_{1-x}\text{Al}_x$ . In Fig. 3(c), we plotted the FWHM of  $^{11}\text{B}$  NMR spectrum vs. Al content. One can see that the FWHM for both compounds increases with increasing Al content up to  $x=0.05$ , which indicates that Al indeed replaces B in the crystal, and act as impurity.

Fig. 3 shows the dependence of  $T_c$  on the impurity content  $x$ . The vertical axis is normalized by  $T_c$  of  $\text{Li}_2\text{Pd}_3\text{B}$  or  $\text{Li}_2\text{Pt}_3\text{B}$ . The  $T_c$  of  $\text{Li}_2\text{Pd}_3\text{B}_{1-x}\text{Al}_x$  is 7.4, 7.3 and 7.3 K for  $x=0, 0.02$  and  $0.05$ , and the  $T_c$  of  $\text{Li}_2\text{Pt}_3\text{B}_{1-x}\text{Al}_x$  is 2.9, 2.6 and 2.2 K for  $x=0, 0.02$  and  $0.05$ , respectively. In  $\text{Li}_2\text{Pd}_3\text{B}$ , the Al impurity up to  $x=0.05$  has little effect on  $T_c$ . By contrast, in  $\text{Li}_2\text{Pt}_3\text{B}$ , the Al impurity suppresses  $T_c$  drastically.

These results indicate that  $\text{Li}_2\text{Pt}_3\text{B}$  is sensitive to impurity scattering. The behavior in  $\text{Li}_2\text{Pt}_3\text{B}$  is similar to that of spin-triplet superconductor  $\text{Sr}_2\text{RuO}_4$  [8]. Generally, non-magnetic act as strong pair breakers and suppress  $T_c$  drastically in superconductors with nodes in the gap function. Thus, our results provide new evidence for nodal superconducting gap in  $\text{Li}_2\text{Pt}_3\text{B}$ .



**Figure 2.** (a), (b)  $^{11}\text{B}$  NMR spectra of  $\text{Li}_2(\text{Pd}, \text{Pt})_3\text{B}_{1-x}\text{Al}_x$  ( $x=0, 0.02, 0.05$ ) (c) the Al content dependence of the FWHM of  $^{11}\text{B}$  NMR spectra. FWHM increases with increasing Al content.



**Figure 3.** The Al impurity content dependence of  $T_c$  in  $\text{Li}_2(\text{Pd}, \text{Pt})_3\text{B}_{1-x}\text{Al}_x$ .

### 3. Conclusion

In conclusion, we have presented a study of the impurity effect on the superconducting transition temperature in noncentrosymmetric superconductors  $\text{Li}_2\text{Pt}_3\text{B}$  and  $\text{Li}_2\text{Pd}_3\text{B}$ . We found that the FWHM of  $^{11}\text{B}$  NMR spectrum increases with increasing  $x$  in both  $\text{Li}_2\text{Pt}_3\text{B}_{1-x}\text{Al}_x$  and  $\text{Li}_2\text{Pd}_3\text{B}_{1-x}\text{Al}_x$ . However, the Al impurity suppresses the  $T_c$  drastically in  $\text{Li}_2\text{Pt}_3\text{B}_{1-x}\text{Al}_x$ , while it has little effect in  $\text{Li}_2\text{Pd}_3\text{B}_{1-x}\text{Al}_x$ . Our results indicate that  $\text{Li}_2\text{Pt}_3\text{B}$  is sensitive to impurity scattering and provide new evidence for the superconducting gap with nodes in  $\text{Li}_2\text{Pt}_3\text{B}$ .

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