Muon Spin Relaxation Study on Superconducting Gap Structure of Pr₃Cr_{10-x}N₁₁

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Motivation

- Cr-based superconductors are rare and all exhibit unconventional properties.
- Recent discovered Pr₃Cr_{10-x}N₁₁¹ shows interesting properties, high H_{c2} exceeds the Pauli paramagnetic limit, large electronic specific heat coefficient 170 mJ*K⁻² *mol ⁻¹ which may correlated with quantum fluctuations.
- Further study on superconducting paring symmetry of Pr₃Cr_{10-x}N₁₁ is necessary and the previous-reported novel properties can be crrossed-verified.

ZF/LF µSR experiment

ZF (zero-field) μ SR experiments were performed on polycrystals of Pr₃Cr_{10-x}N₁₁ down to 0.027 K.



Group-Free-Fit-function:

$$A(t) = A_{S} \left[\frac{1}{3} + \frac{2}{3} (1 - \Lambda_{ZF} t) e^{-\Lambda_{ZF} t} \right] e^{-\lambda_{d} t} + A_{Bt}$$

Fig.1: (a): Small difference of μ SR asymmetry spectra above and below $T_{\rm c}$.

(b): Temperature dependence of muon spin relaxation rate λ_d due to dynamic magnetic field. Straight line represents λ_d can be fixed at 0.22 µs⁻¹.

(c): Temperature dependence of Kubo-Toyabe rate Λ_{ZF} . Inset of (c): the increased Λ_{SC} in the superconducting state, fitted with an empirical expression: $\Lambda_{SC}(T) =$

 $\Lambda_{sc}(0) \tanh[b\sqrt{\frac{Tc}{T}}-1].$

LF (longitudinal-field) µSR experiments were performed at 0.4 K and 7.5 K with different fields.



Group-Free-Fit-function:

$$A(t) = A_S P_Z^{LF, LKT} e^{-\lambda_d t} + A_B$$

Fig.2: (a)-(b): LF asymmetry spectra at 0.4 K and 6 K, respectively. Static field contribution can be easily decoupled by small magnetic field. The depolarization rates exist till 500 Oe are originated from dynamic fields, which may correlated with the enhanced electronic specific heat coefficient¹.

(c): Field dependence of dynamic relaxation rate at 0.4 K and 7.5 K, which also do not change with temperature.

Gap Structure Exploration

TF (transverse-field) μ SR experiments were measured down to 0.35 K with applied field μ_0 H = 500 Oe.



Fig.3: Left: (a) μSR asymmetry spectra at 8 K (red circles) and 0.3 K (black triangles) (b): The relaxation rate fitted by *s*, *d*, *p*, wave model, while *p* wave model claims a better fit since its gap value is same with the value from specific heat data.

Right: (a): Specific heat data measured under applied fields from 0°9T. The electronic part of C_e can be well described by BCS model. (b): $H_{c2}(0)$ obtained from specific heat data which is quite larger than Pauli paramagnetic limit.

(c) The field dependence of residual sommerfield coefficient can be described by an exponential formula², which indicates the anisotropy of gap structure is enhanced by magnetic field. H* may be correlated with thermaldynamic critical field.



Conclusions

- ZF experiments indicate a spontaneous static magnetic field appearing below T_c, support TRSB in the superconducting state of Pr₃Cr_{10-x}N₁₁.
- > LF experiments indicate temperature-independent fluctuations exist, which can be related to the enhanced γ_n .
- > TF and specific heat measurements tend to support the *p* wave parity. The unusual field dependence of γ_0 also indicates a non-BCS mechanism².

References

1. W Wu, *et al.* "Superconductivity in chromium nitrides $Pr_3Cr_{10,*}N_{11}$ with strong electron correlations." National Science Review 7.1 (2020): 21-26.

2. V K Anand, et al. "Specific heat and µSR study on the noncentrosymmetric superconductor LaRhSi₃." Physical Review B 83.6 (2011): 064522.