Pairing of weakly correlated electrons in the platinum-based centrosymmetric superconductor SrPt₃P

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We report a study of the normal- and superconducting-state electronic properties of the centrosymmetric compound SrPt₃P via ³¹P nuclear-magnetic-resonance (NMR) and magnetometry investigations. Essential features such as a sharp drop of the Knight shift at \( T < T_c \), and an exponential decrease of the NMR spin-lattice relaxation ratio \( 1/(T_1T) \) below \( T_c \) are consistent with an \( s \)-wave electron pairing in SrPt₃P, although a direct confirmation in the form of a Hebel-Slichter-type peak is lacking. Normal-state NMR data at \( T < 50 \) K indicate conventional features of the conduction electrons, typical of simple metals such as lithium or silver. Our data are finally compared with available NMR results for the noncentrosymmetric superconductors LaPt₃Si and CePt₃Si, which adopt similar crystal structures.

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I. INTRODUCTION

The continuing search for new superconductors has recently resulted in the identification of a new family of superconducting phosphide compounds with the chemical composition \( \text{APt}_3 \) (\( A = \text{Sr, Ca, or La} \)) [1]. These materials, whose superconductivity has been claimed to be driven by conventional electron-phonon interactions, adopt a distorted antiperovskite structure, resembling the structure of several noncentrosymmetric superconductors, such as \( \text{LaPt}_3\text{Si} \) or \( \text{CePt}_3\text{Si} \) [2]. Contrary to the latter, however, SrPt₃P exhibits an inversion center due to the staggered arrangement of Pt octahedra. Noncentrosymmetric superconductors, characterized by antisymmetric spin-orbit couplings, are currently the subject of intense research [3–6]. Therefore, a comparative study of their centrosymmetric counterparts is of particular interest. Indeed, the Sr-based compound of the new family, with a critical temperature \( T_c = 8.4 \) K, has already been investigated in some detail. The first study included measurements of the specific heat \( C(T) \) and Hall resistivity \( \rho_H(T) \) [1]. The specific-heat data were interpreted as indicating a strong electron-phonon coupling with a relatively large ratio \( \Delta_0/k_B T_c \sim 5 \), and a fully gapped excitation spectrum below \( T_c \) with a zero-temperature gap value \( \Delta_0 = 1.85 \) meV. The nonlinear magnetic field dependence of Hall resistivity was attributed to the presence of multiple Fermi-surface pockets. Less details are known on \( \text{LaPt}_3\text{Si} \), whose critical temperature \( T_c \) is distinctly lower than that of the Sr compound, the difference being most likely due to the different valencies of the cations.

There exist several theoretical interpretations of the \( \text{SrPt}_3\text{P} \) data, which differ in their conclusions. In Ref. [7], the proximity to a dynamical charge-density wave instability is claimed to favor the occurrence of superconductivity in \( \text{SrPt}_3\text{P} \). In another approach, based on a Migdal-Eliashberg-type analysis, it is argued that a conventional phonon-mediated superconductivity is observed [8]. Density-functional-theory calculations [9] suggest that the onset of superconductivity is due to a strong coupling between the \( pd\pi \)-hybridized hands with low-energy phonon modes confined in the \( ab \) plane of the crystal lattice. The two-dimensional character of these modes seems essential to preserve the antipolar arrangement of the distorted Pt octahedra in \( \text{SrPt}_3\text{P} \), thus enhancing both the electron-phonon coupling constant \( \lambda_{ep} \) and, consequently, the critical temperature \( T_c \).

The only experimental investigation at a microscopic level cited in the literature focused on muon-spin rotation (\( \mu\text{SR} \)) measurements [10]. The established temperature dependence of the penetration depth in the form \( \lambda^{-2}(T) \) again indicated a single gap with a value of \( \Delta_0 = 1.55 \) meV. However, an upward curvature of the upper critical field \( H_{c2}(T) \) just below \( T_c \) was interpreted as reflecting two-band superconductivity with equal gaps but differing values of the coherence lengths.

In this work we report on the microscopic physical properties of \( \text{SrPt}_3\text{P} \), investigated by means of nuclear magnetic resonance [11,12]. The measurements described below are based on \( 31\text{P} \) nuclear magnetic resonance (NMR), and probe both static (linewidths and line shifts), as well as dynamic (spin-lattice relaxation) properties of the material. Overall, the data indicate that \( \text{SrPt}_3\text{P} \) is a rather simple metal and that the pairing configuration is most likely of spherically symmetric \( (s\text{-wave}) \) character. A comparison with the noncentrosymmetric superconductors \( \text{LaPt}_3\text{Si} \) and \( \text{CePt}_3\text{Si} \) is intended to clarify the peculiarities of the latter. The lack of inversion symmetry of the crystal lattice may partly account for the much lower \( T_c \) of \( \text{LaPt}_3\text{Si} \), while the rare-earth cations seem responsible for the unusual electronic properties of \( \text{CePt}_3\text{Si} \) [3,5].

II. EXPERIMENTAL DETAILS

Polycrystalline samples of \( \text{SrPt}_3\text{P} \) were synthesized under conditions of high pressure and high temperature. High-purity (99.99%) coarse powders of Sr, Pt, and P were mixed in the stoichiometric 1:3:1 ratio, then thoroughly ground, and finally enclosed in a boron-nitride container. To avoid a possible degradation of the material due to air exposure, all the preparatory steps were done in a glovebox under argon atmosphere. For the heat treatment, the BN crucible
ions give rise to alternating electric polarization vectors (blue arrows), (adapted from Ref. [9]). The asymmetric positions of the apical Pt(II) typical for the onset of superconductivity [13].

At temperatures, we observe a significant diamagnetic response, state in the same temperature regime were made in a field cooled (ZFC) and field-cooled (FC) dc magnetization measured at

A. NMR line shapes and shifts

In Fig. 2 we show the evolution of the $^{31}$P lines with varying temperature at $\mu_0 H = 2.0$ T, both above and below $T_c$. Similar results with respect to the linewidths and line shifts were obtained for $\mu_0 H = 7.0$ T (see Fig. 8).

We focus first on the normal phase. As can be seen in Fig. 3, the linewidth, of the order of 7 kHz at room temperature, increases gradually by approximately 50% down to

In order to achieve an acceptable signal-to-noise (S/N) ratio, the sample was powdered to a grain size of the order of 10 $\mu$m and kept in the form of a loose powder, hence reducing the electrical contact between the grains. NMR measurements at

The magnetic field was calibrated via $^{27}$Al NMR of elemental aluminum, whose gyromagnetic ratio and Knight shift are known to high precision. This data was subsequently used to calculate the $^{31}$P NMR shifts.

III. EXPERIMENTAL RESULTS AND ANALYSIS

A. NMR line shapes and shifts

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mostly linear down to approximately 50 K, below which the line shift remains constant down to \( T_c \) (see inset of Fig. 8). The constancy of the shift above the superconducting transition is a feature often observed in simple metals with an only weakly varying electronic susceptibility \( \chi_p(T) \). The relative shift, of the order of 0.12%, is close to that observed in simple metals such as Ag and Na and is the same for the 2- and 7-T external fields, respectively (see Fig. 8). The linewidths measured in a field of 7 T, instead, are approximately twice as large as those recorded at \( \mu_0 H = 2 \) T, which, in turn, are three times larger than those at 0.6 T. Thus the linewidth scales almost linearly with the applied field.

The most interesting results are obtained below \( T_c \), where the inhomogeneous field distribution in the mixed state of a type-II superconductor significantly broadens the NMR line. Figure 3 shows the steep increase of the linewidth, from 10 to \( \sim 18 \) kHz, between \( T_c \) and 3.5 K and from 3.2 to 8 kHz at 0.6 T—data not shown. Upon a further reduction of \( T_c \), the width remains constant down to the lowest reached temperatures. At the same time the \(^{31}\)P Knight shift exhibits a sudden decrease below \( T_c \), a strong indication of spin-singlet superconductivity, since the pairing of electrons with opposite spins occurring in type s- (or d-) wave superconductors implies a significant decrease of the local spin susceptibility, as detected by the probe nuclei. Of the two possibilities, the experimental data rule out the occurrence of a d-wave pairing, since in that case, the drop of the Knight shift would be less abrupt and the line broadening would reach its asymptotic \( T = 0 \) K value only gradually [11]. From these static NMR results, an s-type pairing seems to be the most plausible configuration adopted by electrons in the superconducting state of \( \text{SrPt}_3\text{P} \).

**B. NMR relaxation rates and nature of superconductivity**

The conclusion about the s-wave pairing configuration is also supported by the \(^{31}\)P spin-lattice \( 1/T_1 \) relaxation-rate data displayed in Fig. 5. The \( 1/(T_1 T) \) vs \( T \) plot exhibits what is considered to be a typical signature of conventional BCS superconductivity, an exponential decrease with decreasing \( T \) well within the superconducting phase, but no clear indication of a Hebel-Slichter-type coherence peak, which is masked by a distinct increase of \( 1/(T_1 T) \) in a narrow regime just above \( T_c \).

The spin-lattice relaxation times \( T_1 \) were evaluated from magnetization-recovery curves such as those shown in Fig. 4. The nuclear magnetization data \( M_z(t) \) were fitted by using the single-exponential equation valid for spin-1/2 nuclei:

\[
M_z(t) = M_z^0 [1 - f \exp(-t/T_1)]^\beta.
\]

![FIG. 3. (Color online) \(^{31}\)P NMR shift (left scale) and linewidth (right scale) vs temperature, as measured at an applied field of 2 T. The drop in shift and the increase in width below \( T_c \) are followed by a constant behavior at intermediate temperatures and by a final decrease at higher \( T \) (see text for details). The increase of data scattering below \( T_c \) reflects the decreased S/N ratio in the superconducting phase.](image1)

![FIG. 4. (Color online) \(^{31}\)P NMR spin-lattice relaxation data of \( \text{SrPt}_3\text{P} \) at selected temperatures measured at 2 T. All fit curves exhibit a simple exponential (\( \beta = 1 \)) recovery of the magnetization (see text).](image2)

![FIG. 5. (Color online) Temperature dependence of \( (T_1 T)^{-1} \) measured in a magnetic field of 2 T. A similar cusplike feature at \( T_c \) is seen also at 0.6 T. The decrease below the maximum occurring at \( T_c \) is compatible with a fully gapped superconductor (see text). Inset: \( (T_1 T)^{-1} \) data over the full temperature range show a broad maximum at \( T^* = 45 \) K (see also Fig. 7).](image3)
Here $M_n^0$ represents the saturation value of magnetization at thermal equilibrium, $f$ is the inversion factor (exactly 2 for a complete inversion), and $\beta$ is a stretching exponent which accounts for possible distributions of relaxation rates [14]. Except at the lowest temperatures, the $\beta$ values were always found to be close to 1, with no difference in fit quality whether $\beta$ was fixed or set free. Considering the purely magnetic relaxation of $I = 1/2$ nuclear probes, this implies the same local environment for all the $^{31}\text{P}$ nuclei, i.e., disorder of either structural or magnetic nature is insignificant in our case.

Up to $T^* = 45$ K, the normal-state spin-lattice relaxation rate varies approximately linearly with temperature (see inset in Fig. 5), as is usually observed in conventional simple metals. The progressive deviation from the linear-in-$T$ behavior above $T^*$ reflects a decrease in the dynamical spin susceptibility, as discussed in Secs. III C and III D.

Focusing back on the superconducting state, just below $T_c$ we do not observe a distinct Hebel-Slichter (coherence) peak, but only a cusplike feature peaking at $T_c$. Analogous data taken in a 0.6-T field showed essentially the same type of feature in the vicinity of $T_c$. We recall that the Hebel-Slichter anomaly is due to pair coherence and to a quasiparticle density-of-states anomaly at the gap edge and is more pronounced at lower fields, where the pair-breaking effect of the field is less important [15]. Both these effects can be weakened by different causes, including interaction anisotropies and the broadening of the quasiparticle states due to strong-coupling effects. Indeed, while weakly coupled conventional $s$-wave superconductors typically exhibit a Hebel-Slichter peak, it is not the case in the strong-coupling limit, where the enhanced electron-phonon coupling implies reduced quasiparticle lifetimes [16].

Since the lack of a coherence peak cannot rule out the possibility of an $s$-type electron pairing [17], further analysis is required. The temperature dependence of $T_1$ at $T < T_c$ can provide information about the symmetry of the superconducting gap. In the case of an anisotropic gap with nodes, a power-law dependence, $1/T_1 \sim T^\beta$, is expected since very low-energy electronic excitations around gap nodes can still contribute to relaxation. On the other hand, for standard fully gapped superconductors with no or a weak gap anisotropy, the relaxation rate depends exponentially on temperature, $1/T_1 \sim \exp(-\Delta_0/T)$, with $\Delta_0$ the superconducting gap at $T = 0$. In either case, non-negligible $1/(T_1T)$ residual values may be observed at the lowest temperatures [18]. Most likely these are due to the presence of vortex-core or of thermally excited vortex-motion relaxation mechanisms [19,20], which can be accounted for by an additional constant term. While both models provide reasonable fits to the data, the power-law expression shows a somehow poorer fit quality and, most importantly, the resulting exponent varies significantly (from 3.6 for the 2-T dataset to 2.7 for the data collected at 0.6 T). On the other hand, as shown in Fig. 5, an exponential curve with $\Delta_0 = 1.47(4)$ meV fits the SrPt$_3$P relaxation data satisfactorily well. Also the data taken at 0.6 T can be consistently fitted with a similar gap value, $\Delta_0 = 1.51(4)$ meV, thus providing a good indication that the superconducting gap of SrPt$_3$P is nodeless. The value of the gap parameter, although slightly modified by the presence of the constant term, is in fair agreement with the 1.55 meV value reported in Ref. [10], but distinctly lower than $\Delta_0 = 1.85$ meV reported in Ref. [1]. In any case, since the gap value from our analysis is clearly higher than 1.27 meV (the gap expected from the BCS formula $2\Delta_0 = 3.52k_BT_c$), it is compatible with a strong-coupling scenario.

Besides the vortex-core relaxation mechanism mentioned above, the almost constant value of $1/(T_1T)$ well below $T_c$ might also reflect a certain degree of superconducting-gap anisotropy, but we consider this as a less likely possibility.

C. Korringa relation and the degree of electronic correlation

Some insight into the degree of electronic correlations in the normal state of a material can be gained by considering the so-called Korringa relation [21] (Fig. 6)

$$T_1T K_s^2 = S_0, \quad \text{with} \quad S_0 = \frac{\gamma_e^2}{\gamma_n^2} \frac{\hbar}{4\pi k_B}. \quad (2)$$

Here $\gamma_e$ and $\gamma_n$ are the electronic and the nuclear gyromagnetic ratios, respectively, while $K_s$ is the line shift due to the polarized conduction electrons. Equation (2) reflects the fact that both the readily accessible experimental parameters, the Knight shift $K_s$ and the spin-lattice relaxation time $T_1$, depend on the same electron-nucleus hyperfine interaction (assumed to be mostly of Fermi-contact character). However, while for a simple (Fermi-gas) metal the parameter $S_0$ is a constant (depending only on $\gamma_n$ of the probe nucleus), for real materials the generalized relation [22] $T_1T K_s^2 = \alpha S_0$, with $\alpha$ a measure of the strength of the (Fermi-liquid) quasiparticle interactions [23], is more appropriate. Since $1/(T_1T)$ probes the dynamical susceptibility averaged over the Brillouin zone, either ferromagnetic (FM) or antiferromagnetic spin correlations will enhance it, but only FM correlations can significantly enhance also the shift. Thus, $\alpha > 1$ ($< 1$) indicates the presence of ferro- (antiferro-) magnetic electronic correlations.

From the almost constant value of $S_0/(T_1T K_s^2)$ vs $T$ (see inset in Fig. 5) and considering the negligible orbital shift contribution (see below), we find $1/\alpha \simeq 0.55$ and, hence, $\alpha = 1.8$ in our case. The resulting value, slightly larger than unity, seems to suggest the presence of ferromagnetic correlations in the normal state. However, the ratio $1/\alpha \simeq 0.55$ is similar to 0.58, 053, and 0.50 observed in typical metals such as lithium, cesium, and silver, respectively [11].
In these nearly-free-electron metals the Moriya theory of exchange enhancement, whereby the exchange fluctuations also enhance the rate of the $T_1$ process [11,24], explains the experimental data satisfactorily. Consequently, we conclude that also in SrPt$_3$P the conduction electrons experience rather weak correlation effects, in good agreement with the results reported in Ref. [1].

D. Magnetic susceptibility and NMR

The magnetization $M(T)$ was measured in an applied magnetic field of 2 T in specimens from the same batch as that used for NMR experiments. The resulting values of the susceptibility, $\chi = M/H$, for temperatures above 10 K are shown in the main panel of Fig. 7. The measured net susceptibility seems unusually small for a metal, because the contribution from the conduction electrons is almost exactly canceled by the large core diamagnetism mainly from Pt ($1.8 \times 10^{-4} \text{ emu/mol per formula unit}$, according to standard tables). This compensation effect makes it possible to measure even subtle variations of the electronic contribution with $T$.

In order to relate $\chi(T)$ with the NMR data, the relative $^{31}$P NMR shifts in the two chosen magnetic fields (2 and 7 T, respectively) are shown in Fig. 8. As expected for simple metals, the shifts are independent of the applied field and hence coincide perfectly. Below $T_c$ the high-field (7-T) data reflect the normal phase: both the line shift and linewidth remain practically constant upon decreasing temperature.

From the $\chi(T)$ data (shown in Fig. 7) and the NMR shifts (see inset of Fig. 8), one recognizes immediately very similar features. In either case, a practically linear increase upon lowering the temperature, from 300 K down to approximately $T' = 45$ K, is followed by a $T$-independent part. This clear break in the temperature dependence of both $K_s(T)$ and $\chi(T)$ coincides with a maximum of the Hall constant $R_H$ reported in Ref. [1]. The reason for this might be that the trend to $R_H = -1/ne$ starts to dominate the $R_H > 0$ contribution.

Such a comparison of microscopic (NMR) vs macroscopic (magnetometry) results provides further information about the normal-state electronic properties of SrPt$_3$P. In our case, given the relative insensitivity to the applied field (see Fig. 8), it makes sense to compare the NMR shifts with the susceptibility data, as shown in the Clogston-Jaccarino [25] (or $K - \chi$) plot in the inset of Fig. 7. Here both datasets refer to the same (2-T) field, with the temperature as an implicit parameter. From the slope $dK/d\chi$ of the $K - \chi$ plot for $T > 50$ K, and by assuming a standard electronic $g$ factor of 2.0, the relation $K = gA_{hf}\chi + K_{orb}$ gives the hyperfine coupling constant, $A_{hf} = 4.4 T/\mu_B$, while the zero intercept with the $K$ axis gives the orbital shift, $K_{orb} = -0.003\%$. The latter is perfectly compatible with known orbital-shift values for a light nucleus such as $^{31}$P. Clearly, the orbital shift is negligible in comparison with the dominant magnetic shift. We recall that hyperfine coupling constants are known to be strongly material dependent, so it is not unusual that our value is an order of magnitude higher than, e.g., $A_{hf} \sim 0.2 T/\mu_B$ found in another phosphorus-based compound, Pb$_2$(VO)(PO$_4$)$_2$ [26].

IV. DISCUSSION

Below we discuss in more detail some aspects of the results presented in the previous sections.  

Line shapes. For all the applied magnetic fields the normal-state $^{31}$P lines show a slight asymmetry, usually attributed to the crystalline surfaces or to minor impurities. However, the persistence of the line asymmetry even in samples of different quality, most likely indicates a (uniaxial) anisotropy of the hyperfine coupling tensor (whose study is beyond the scope of this work), which can be observed also in powdered samples [27]. The uniaxial nature of the hf tensor is to be expected, if the symmetry of the distorted Pt octahedra probed by the phosphorus nuclei is considered (see structural unit in the inset of Fig. 1).
The line shapes, in either the normal or the superconducting phase, indicate also the structural and chemical homogeneity of the sample. An essentially single line with a relatively narrow width of only ~7 kHz (see Fig. 2) is typical of defect-free crystalline structures, especially when considering the random polycrystalline nature of the sample. Similarly, the line asymmetry observed below \( T_c \), again reflects the high quality of the sample, since in a powdered superconductor with a significant degree of disorder the lines would appear symmetric.

**Residual shift.** A key prediction of the BCS theory for superconductors with singlet s-wave pairing is the vanishing of the Knight shift for \( T \ll T_c \), reflecting the vanishing susceptibility due to the pairing of quasiparticles with antiparallel spins. Yet, even for elemental superconductors (as, e.g., Sn or Hg), a residual shift is observed even close to \( T = 0 \) [19].

The presence of a significant orbital Knight shift and/or of spin-orbit scattering (known as Ferrell-Anderson effect) have been identified as responsible for its occurrence. The SrPt\(_3\)P case, however, is a bit more complex, since here \(^{31}\)P is a low-Z nucleus which interacts with superconducting carriers arising mostly from in-plane \( pd\pi \)-hybridized states between Pt and P ions [9]. Since orbital shifts are negligible for the light probe nuclei, the presence of a low-temperature nonzero Knight shift in SrPt\(_3\)P is, therefore, most likely due to spin-orbit scattering effects.

**Core-polarization effects and \( T^* \) anomaly.** Another contribution to the nonvanishing shift at \( T = 0 \) can arise from core-polarization effects [19,28], whereby the exchange interaction of localized core electrons with field-polarized conduction band electrons (partially of \( d \) character in our case), implies an additional nonzero contact interaction in the \(^{31}\)P nuclei. The observation of large negative \(^{195}\)Pt-NMR Knight shifts (data not shown) seems to confirm the presence of core-polarization effects in SrPt\(_3\)P [25]. While this contribution to the Knight shift would disappear entirely if purely \( d \)-band electrons were coupled into Cooper pairs, a residual shift would still arise considering the hybridized (i.e., not exclusively \( d \)) character of the conduction band quasiparticles.

The consequences of core-polarization effects are more important, however, in the normal state. The electronic contribution to the magnetic susceptibility of a \( d \)-type band is generally temperature dependent, thus implying a temperature-dependent Knight shift, as actually observed (for an ideal metal one would have expected a constant shift). While core-polarization effects might explain the similar \( T \) dependence of \( K \) and \( \chi_r \), the abrupt change in slope observed at \( T^* \), as well as the value of \( T^* \) itself, remain to be investigated.

**Weak electron correlation.** Our NMR data of SrPt\(_3\)P, indicate a fairly simple metallic behavior in the normal state, followed by standard BCS features in the superconducting state. These results are in remarkable agreement with the transport and magnetometry measurements reported in Ref. [1] in two important aspects. First, both NMR (via the Korringa product) and the macroscopic measurements (via the Sommerfeld-Wilson ratio [29]) demonstrate the absence of significant electron correlations. Secondly, there is a distinct feature at \( T^* = 45 \) K in the \(^{31}\)P Knight shift and in the \( 1/(T/T) \) relaxation behavior, respectively, both of which change from a constant-in-\( T \) to a linear-in-\( T \) decrease as the temperature changes across \( T^* \). This temperature coincides with the above-mentioned maximum in \( R_H(T) \), the latter reflecting anisotropies of the electron mean free path across different parts of the Fermi surface. The latter fact is consistent with conclusions drawn in Ref. [10]. The coincidence of \( T^* \) values, derived from results of very different types of experiments, is unclear at present.

As for the Korringa relation, we recall that the absolute value of \( a \) might also be influenced by extraneous factors, such as the presence of strong disorder [30], or effects related to the hyperfine form factor (i.e., \( q \)-space filtering). Nevertheless, as mentioned above, these can be excluded in our case and the observation of a constant Korringa ratio vs temperature represents a valid proof of Fermi-liquid behavior in SrPt\(_3\)P, where \( 1/\alpha \simeq 0.55 \) is constant over a fairly wide temperature range.

**Centro- vs noncentro-symmetric superconductors.** We conclude with a comparison of SrPt\(_3\)P with two noncentrosymmetric superconductors, the nonmagnetic LaPt\(_3\)Si (\( T_c = 0.6 \) K) and the magnetic CePt\(_3\)Si (\( T_c = 0.75 \) K), both of which were studied via NMR, as well [3–5]. The latter not only share the same structure, but show also similar antisymmetric spin-orbit couplings. Hence, a comparison of the three is relevant to understand whether it is the lack of inversion symmetry, or the presence of rare-earth ions to account for the unusual properties of noncentrosymmetric superconductors.

While SrPt\(_3\)P and LaPt\(_3\)Si both follow a perfect Korringa law down to \( T_c \), in CePt\(_3\)Si the \( 1/(T/T) \) ratio is enhanced upon cooling due to the development of \( 4f \)-derived magnetic fluctuations. Most importantly, unlike in SrPt\(_3\)P and LaPt\(_3\)Si, where the superconducting transition is of conventional type and not dominated by correlation effects, in CePt\(_3\)Si, the superconductivity emerges from a unique heavy-electron state which coexists with antiferromagnetic order.

From these facts, we conclude that the key differences between the considered centrosymmetric and noncentrosymmetric superconductors, are most likely related to the presence of Ce\(^{3+}\) ions and the ensuing heavy-fermion phenomena, while the parity mixing alone (common to both LaPt\(_3\)Si and CePt\(_3\)Si) cannot explain the peculiar behavior of the latter. Despite the many similarities between SrPt\(_3\)P and LaPt\(_3\)Si, their belonging to different classes of crystal symmetry may possibly explain their distinctly different critical temperatures. Incidentally, from the available data in literature, also the centrosymmetric LaPt\(_3\)P compound seems most likely to be a conventional BCS type-I superconductor.

**V. CONCLUSIONS**

We presented the results of \(^{31}\)P NMR measurements in the recently discovered SrPt\(_3\)P superconducting compound. In the normal state, the nuclear spin-relaxation rate obeys a Korringa-type relation \( (T/T)^{-1} = 0.522 \) (sK)\(^{-1} \) and the line shift is independent of temperature. In the superconducting state, the lack of a clear coherence peak in \( T_1^{-1} \) just below \( T_c \), most likely due to a strong electron-phonon coupling, is followed by an exponential, thermally activated decrease upon further cooling. A similar behavior is shown also by the line shift. The overall results of our NMR investigation make us conclude that SrPt\(_3\)P, which behaves as a standard metal in the normal state, is characterized by singlet pairing of the electrons...
Since the magnetic response of a superconductor is influenced by many factors, such as the sample granularity, its compactness, flux pinning, the demagnetization factor, the remanent field, etc., the proximity to the ideal diamagnetic response is rather coincidental in our case.

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