Spin glass behavior in $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ ($x = 0.4, 0.5$, and 0.6)

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We studied the magnetic ground state of Co/Rh-disordered $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ ($x = 0.4, 0.5$, and 0.6) by means of powder neutron diffraction (PND), muon spin relaxation (μSR), ac susceptibility, isothermal magnetic relaxation, and heat capacity measurements. The dc magnetic susceptibility measurements exhibit a cusp around the freezing temperature T_f of all studied compounds. PND measurements show no indications of long-range magnetic ordering down to 4 K in all studied samples. μSR experiments on these compounds show a peak in the muon spin relaxation rate around T_f . However, no spontaneous muon spin precession can be observed evidencing the short-range nature of the magnetic ordering. For the $x = 0.5$ sample ac susceptibility measurements show that T_f shifts to higher temperatures with increasing frequency and becomes suppressed by a dc biasing field. All these observations indicate that the Co/Rh-disordered $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ system is a spin glass for $x = 0.4, 0.5$, and 0.6 .

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I. INTRODUCTION

The spin state of the Co^{3+} ions in LaCoO_3 has been studied extensively in the past as a function of temperature, pressure, magnetic field, and cation substitution [1–12]. For the octahedrally coordinated Co^{3+} ions in LaCoO_3 a nonmagnetic low-spin (LS) configuration ($t_{2g}^6 e_g^0$) can be observed at low temperatures (below about 100 K) due to the crystal field splitting that overcompensates the Hund's coupling. On heating, a gradual transition to a paramagnetic state with magnetic Co^{3+} ions can be observed. For higher temperatures the spin state of the Co^{3+} ions is controversially discussed in the literature [3, 10–12]. Polarized neutron scattering experiments indicate the thermal population of the high-spin (HS) configuration ($t_{2g}^4 e_g^2$) above about 100 K [6], whereas theoretical calculation proposed also the occupation of an intermediate-spin (IS) state ($t_{2g}^5 e_g^1$) [7] as supported by several subsequent experiments [8, 9]. Finally, it was shown that the thermal population of a HS state is consistent with magnetic susceptibility, ESR, neutron scattering, and x-ray absorption spectroscopy data whereas the IS state is never favorable [12].

Recently, it was reported that the substitution of Rh for Co ions induces possible magnetic ordering in $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ [13–15]. LaCoO_3 and LaRhO_3 crystallize in the rhombohedral and orthorhombic structure with the space group $R\bar{3}c$ and $Pbnm$. The substitution of Rh for Co rapidly stabilizes the $Pbnm$ structure, and for $x > 0.2$ the pure orthorhombic phase appears [13, 16]. Generally, no charge transfer between Co^{3+} and Rh^{3+} ions is expected. However, there exist proposals for a complex mixture of Co^{2+} , Co^{4+} , Rh^{2+} , and Rh^{4+} ions in this system [17]. The ionic radius of Rh^{3+} (0.665 Å) is larger than that of Co^{3+} (0.545 Å for the LS state and 0.61 Å for the HS state) [18]. Due to the different ionic sizes of Co^{3+} ions in the HS and in the LS state it can be expected that the Co^{3+} HS state can be stabilized by a lattice expansion.

An anomalous cusp was observed in magnetic susceptibility measurements below $T_{\text{cusp}} \sim 15$ K for $0.1 \leq x \leq 0.4$. T_{cusp} decreases with increasing x . A bifurcation between the zero-field-cooled (ZFC) and field-cooled (FC) data and a small hysteresis effect in the isothermal magnetization measurement was observed below T_{cusp} . It is, therefore, suggested that the system undergoes a weak ferromagnetic transition below T_{cusp} [13].

Here, we reanalyzed the magnetic ground state of $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ around $x = 0.5$. Therefore, we studied the magnetic properties of $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ ($x = 0.4, 0.5$, and 0.6) by means of dc and ac magnetic susceptibility, powder neutron diffraction (PND), and muon spin relaxation (μSR) methods. Our structural refinement indicates that the Rh and Co ions are randomly distributed in all our studied samples. In the magnetic susceptibility measurements an anomalous cusp could be observed for all studied compositions x . However, there is no indication of static long-range magnetic ordering in PND and μSR measurements. In ac susceptibility measurements T_{cusp} shifts to higher temperatures with increasing frequency and is suppressed by a biasing magnetic field. Thus, our results are indicative of a spin glass ground state in Co/Rh-disordered $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$.

II. EXPERIMENT

Polycrystalline samples of $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ with $x = 0.4, 0.5$, and 0.6 were synthesized by solid state reaction. Stoichiometric amounts of La_2O_3 , Co_3O_4 , and Rh_2O_3 were mixed and ground thoroughly in an agate mortar and sintered for 2 days at 1200°C in air with several intermediate grindings. The phase purity was confirmed by both x-ray diffraction (XRD) and PND. Powder x-ray diffraction measurements were performed on a Bruker D8 Discover A25 powder x-ray diffractometer.

The dc magnetic susceptibility, $\chi(T)$, was measured using the magnetic property measurement system (MPMS; Quantum Design) in a temperature range between 2 K and 380 K. The ac susceptibility was measured using the vibrating sample magnetometer (VSM; Quantum Design). The ac magnetic

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driven field, H_{ac} , was fixed to 4 Oe, and χ was recorded with frequencies $f = 3, 13, 57, 113, 317$, and 898 Hz. A dc biasing magnetic field, $H_{dc} = 0, 200, 1000$, and 5000 Oe, was also applied with f fixed at 57 Hz. For all ac susceptibility measurements, the sample was first zero-field cooled to the base temperature and $\chi(T)$ was recorded in the heating run. Isothermal magnetization relaxation measurements were performed using the VSM system. The samples were cooled from room temperature to the measuring temperature with a magnetic field of 1000 Oe. Then, the field was switched off and the time dependence of the magnetization was recorded. Heat capacities were measured using the physical property measurement system (PPMS; Quantum Design). The contributions from grease and sample holder were measured separately and subtracted from the total capacity.

PND was performed on the high-resolution powder diffractometer SPODI at the FRM-II in Garching, Germany (λ of 2.536 Å; 8 hours counting time for each diffraction pattern). Muon spin relaxation (μ SR) experiments were performed at the GPS spectrometer at the PSI in Villigen, Switzerland. The decay positrons from the injected muons were accumulated by the forward and backward counters located before and after the sample. The asymmetry of the muon spin polarization is defined as $A(t) = [F(t) - \alpha B(t)] / [F(t) + \alpha B(t)]$, where $F(t)$ and $B(t)$ are the number of positrons detected at the forward and backward counters at time t , respectively. The parameter α is a correction of the counting efficiency for the forward and backward counters, which was determined by a transverse (perpendicular to the initial muon spin direction) field (TF) measurement in the high-temperature paramagnetic state. A small longitudinal (parallel to the initial muon spin direction) field (LF) of 20 Oe was applied in order to decouple the muon spin from the nuclear moments during the experiments. A LF of 500 and 2000 Oe was also applied at 1.55 K in order to distinguish whether the internal field is static or dynamic. The data were analyzed with the free software package WIMDA [19].

III. RESULTS AND DISCUSSION

A. Structure and magnetization

The $x = 0.4, 0.5$, and 0.6 compounds have been measured at 4 K and 300 K by means of powder neutron diffraction. A typical diffraction pattern for $x = 0.5$ is shown in Fig. 1(a). The obtained diffraction patterns were refined by the Rietveld method using the FullProf software package. The crystal structure can be described by the orthorhombic space group $Pbnm$. The very weak (1 0 1) Bragg peak indicates that the Co and Rh ions are randomly distributed in the sample [20,21]. The Rh-doping dependence x of the lattice constants is shown in Fig. 1(e). Due to the larger Rh^{3+} ionic radius the lattice constants along three crystallographic directions all increase with increasing Rh content x [18]. Our results are consistent with previous studies [13,16]. Especially, also the crossover of the a and b lattice parameters can be observed at $x = 0.5$.

In Fig. 2(a) the dc magnetic susceptibility measurements of $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ are shown. All studied samples exhibit a cusp in the ZFC measurement at about 5 K, 4 K, and 3 K for $x = 0.4, 0.5$, and 0.6 respectively. As can be seen, T_{cusp} shifts

FIG. 1. (a) Rietveld fit of the powder neutron diffraction data measured at 300 K for the $x = 0.5$ sample. The red points are the experimental data, and black and green curves are the calculated intensity and difference between the experimental and calculated values. Blue bars indicate the Bragg peak positions. (b)–(d) Comparison of PND pattern for $x = 0.4, 0.5$, and 0.6 measured at 300 K and 4 K, respectively. (e) The doping dependence of the lattice constants. Open and solid symbols indicate the values obtained from PND and XRD, respectively.

towards lower temperature with increasing Rh content x which is consistent with a scenario where the Co ions are substituted by nonmagnetic Rh ions. The FC measurements diverge from the ZFC measurements at temperatures higher than T_{cusp} . The magnetization measurement at different temperatures are shown for the $x = 0.5$ sample in Fig. 2(b). At 2 K a weak

FIG. 2. (a) Magnetic susceptibility measurements for $x = 0.4$, 0.5 , and 0.6 . Open and solid symbols: ZFC/FC measurements. For clarity, the data sets for the $x = 0.4$ and 0.5 samples are shifted with the dashed lines indicating the shifted zero values. (b) Isothermal magnetization measurements for $x = 0.5$ at different temperatures. (c) Comparison of isothermal magnetization measurements at 2 K for $x = 0.4$, 0.5 , and 0.6 .

hysteresis effect is observable with a remanence of $0.01\ \mu_B/\text{f.u.}$ and a coercivity of 600 Oe . At 10 K , which is somewhat higher than T_{cusp} , the hysteresis effect is absent, and, finally, the magnetization curve is straight at 50 K as typical for a paramagnetic state. The magnetization per formula unit, remanence, and coercivity measured at 2 K decrease with increasing x as can be seen in Fig. 2(c).

The temperature dependence of the inverse magnetic susceptibility $\chi(T)$ is shown in Fig. 3(a). Note that previous studies [13] fit a Curie-Weiss function $\chi^{-1}(T)$ between 200 K and 300 K to the data:

$$\chi^{-1}(T) = (T - \theta_{\text{CW}})/C, \quad (1)$$

where C is the Curie constant and θ_{CW} is the Curie-Weiss temperature. We fitted our data in the same temperature range as well as in the high-temperature regime between 300 K and 380 K ; see Fig. 3(a). The obtained effective moment $\mu_{\text{eff}} = \sqrt{8C}$ and Curie-Weiss temperature θ_{CW} are plotted in Fig. 3(b). $\chi^{-1}(T)$ deviates from the fitted curve above 300 K for the $x = 0.4$ and 0.5 samples, thus indicating that the magnetic

FIG. 3. (a) Temperature dependence of $\chi^{-1}(T)$ measured in a magnetic field $\mu_0 H$ of 1 T . The red curves are fits to Eq. (1) for each data set between 200 K and 300 K and between 300 K and 380 K . The black dashed lines indicate the fitted temperature range. (b) The doping dependence of the extracted effective moment and Curie-Weiss temperature for both the low and high temperature regimes.

susceptibility is not Curie-Weiss like. This might originate from a thermal population of the HS state in $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$. While the substitution of Rh for Co might stabilize the Co^{3+} HS state due to the expansion of the lattice [see Fig. 1(e)], the remaining Co^{3+} ions in the LS state could still be thermally excited to the HS state with the increasing unit cell volume for rising temperature. Previous studies proposed that the magnetic ground state below T_{cusp} is weak ferromagnetic [13]. Although a hysteresis effect was observed below T_{cusp} , as shown in Figs. 2(b) and 2(c), the magnetization is very small compared to the effective moment. In order to unveil possible magnetic ordering, we also performed PND at 4 K for all these compounds. However, no enhancement of any Bragg peaks, or extra peaks due to magnetic ordering, could be observed; see Figs. 1(b)–1(d).

B. ZF and LF μSR

In order to get further insight in the magnetic properties of $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$, μSR experiments were performed for the samples with $x = 0.4$ and 0.5 . Since μSR is very sensitive to small magnetic moments, static long-range magnetic ordering can be easily detected. Figure 4 shows the typical time spectra measured with a tiny LF of 20 Oe in order to decouple the

FIG. 4. Typical μ SR time spectra (a) for the $x = 0.4$ and (b) for the 0.5 sample. The spectra were measured with a longitudinal field of 20 G. The red curves are fits to a two-exponential function, as described in the text. In the inset of (b) a fit with two-exponential and one with stretched-exponential function are compared.

muon spins from the nuclear moments. The spectra for the two samples show a similar line shape. At high temperatures, an exponential-like decay can be observed which is expected for a paramagnetic state. With decreasing temperature a fast relaxation component develops and coexists with the slow relaxation component. At low temperatures, e.g., at 1.55 K, it can be observed that the muon spin relaxation rate decreases. Such behavior might suggest the slowing down of magnetic fluctuations and the appearance of static magnetism. However, no spontaneous muon spin precession is observed down to 1.55 K, which is well below T_{cusp} for the samples investigated.

In order to distinguish whether magnetism at low temperatures is static or dynamic, the LF dependence of the spectra was studied at 1.55 K for $x = 0.5$. As shown in Fig. 5, muon asymmetry is recovered gradually with the increase in the LF. As a reference, the measurement in a LF of 2000 Oe at 8 K is shown in the inset of Fig. 5. The spectrum overlaps with that measured in LF = 20 Oe, thus revealing quasistatic magnetism at 1.55 K which is already dynamic at 8 K within the time scale of μ SR measurements.

The observed μ SR spectra cannot be explained by the appearance of long-range ferromagnetic or antiferromagnetic

FIG. 5. LF dependence of the spectra for $x = 0.5$ at 1.55 K. For comparison, the 8 K data are shown in the inset.

states because no spontaneous muon spin precession can be observed. Our observations are reminiscent of a spin glass state [22] with short-ranged spin correlations and T_{cusp} corresponding to the spin freezing temperature T_f . In order to extract the muon spin relaxation rate, the spectra in Fig. 4 are fitted to a two-component exponential function,

$$A(t) = A_s \exp(-\lambda_s t) + A_f \exp(-\lambda_f t), \quad (2)$$

where $A(0)$ is the initial asymmetry fixed to the value measured at high temperature, A_s and A_f are the amplitudes of the slow and fast relaxation components, and λ_s and λ_f are the muon spin relaxation rates for the slow and fast components, respectively. The fitted curves are shown in Fig. 4 in red. A two-component relaxation behavior was also observed in other spin glass systems [23,24], suggesting a distribution of the relaxation rate in the sample. We also tried to fit the spectra using the stretched exponential function, $A(t) = A(0) \exp(-\lambda t)^\beta$. As shown in the inset of Fig. 4(b), this function cannot describe the entire spectrum (especially at low temperatures in the early-time region). In addition, we also tried to fit the spectrum using a formula derived by Uemura *et al.* (Eq. (17) in Ref. [25]) for modeling a spin glass system. However, also these approaches fail to describe our spectra properly.

The temperature dependence of the extracted parameters is shown in Fig. 6. The two compounds show very similar behavior. From Figs. 6(a) and 6(b), it can be seen that the amplitude of the slow relaxation component decreases with decreasing temperature and levels off below ~ 8 K and ~ 6 K for $x = 0.4$ and 0.5, respectively, while the fast relaxation component shows opposite behavior. The ratio of A_f/A_s is almost constant below T_f and amounts to roughly 4:1 which also shows the presence of dynamic volumes in the sample since for a static specimen a ratio of 0.666/0.333 is expected. The temperature dependence of λ_s and λ_f is shown in Figs. 6(c) and 6(d). λ_s increases with decreasing temperature and shows a peak at ~ 6 K (~ 8 K) for $x = 0.5$ (0.4) which reflects the critical slowing down of the spin fluctuations in $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$. On the other hand, λ_f continuously increases with decreasing temperature, and tends to be temperature independent at low temperatures.

FIG. 6. (a), (b) Temperature dependence of the amplitude of the slow (A_s) and fast (A_f) relaxation components for the $x = 0.4$ and 0.5 samples, respectively. (c), (d) Temperature dependence of muon spin relaxation rates λ_s and λ_f for $x = 0.4$ and 0.5 , respectively.

The peak position of λ_s is very close to T_{cusp} observed in dc magnetization measurements and indicates the spin freezing temperature T_f observed by μSR . The somewhat higher value of T_f compared to T_{cusp} might arise from the faster fluctuation scale probed by μSR . Hence, the A_s component observed here corresponds to the 1/3 longitudinal relaxation component in an ideal quasistatic powder sample, and the 2/3 transverse relaxation component is included in A_f . Here, the ratio between A_f and A_s is not exactly 2:1 as expected for an ideal quasistatic case for a powder sample. This indicates that some part of the sample is still fluctuating; i.e., the sample is inhomogeneous. The increase of λ_f below T_f also suggests that the internal field distribution becomes broader at low temperatures.

C. ac susceptibility

In order to unambiguously determine the spin glass ground state in this system, we also performed ac susceptibility measurements as a function of frequency and dc biasing magnetic field. Figure 7(a) shows the temperature dependence of the in-phase component, χ' , of the ac susceptibility measured at different frequencies (no dc biasing field was applied). With increasing frequency the freezing temperature T_f shifts towards higher temperatures which is indicative for a spin glass system. The frequency dependence of T_f is estimated by the quantity $K = \Delta T_f / T_f \Delta \log_{10} f$, where Δ refers to the difference. The obtained value for K amounts to $\sim 5.3\%$ for $x = 0.5$ which resembles values for other spin glass systems [26]. The out-of-phase component χ'' also becomes nonzero below T_f as can be seen in Fig. 7(b) for the selected frequency $f = 57$ Hz, indicating a dissipative process which can be suppressed by a dc biasing field. The frequency dependence of T_f can be well described by the conventional

FIG. 7. The ac susceptibility measurement for the $x = 0.5$ sample. (a) Temperature dependence of the in-phase component χ' at different frequencies. The inset shows the plot of $\log_{10}(\tau)$ vs $\log_{10}(T_f/T_g - 1)$. Solid line is a guide to the eye according to the best-fit parameters as described in the text. (b) Temperature dependence of the out-of-phase component χ'' at different dc biasing magnetic fields.

critical slowing down behavior, and fitted by the function

$$\tau_f = \tau_0 (T_f/T_g - 1)^{-zv}, \quad (3)$$

where $\tau_f = 1/f$ corresponds to the maximum relaxation time of the system at temperature T_f , τ_0 is the intrinsic relaxation time of the spin dynamics, T_g is the freezing temperature for $f = 0$ which is fixed to T_{cusp} as obtained from ZFC dc magnetic susceptibility measurements, and zv is the dynamic exponent. A fit to Eq. (3) yields $\tau_0 = 1.6(7) \times 10^{-8}$ s and $zv = 8.3(3)$ for the $x = 0.4$ compound; $\tau_0 = 6(1) \times 10^{-8}$ s and $zv = 9.8(2)$ for the $x = 0.5$ compound; $\tau_0 = 6(1) \times 10^{-7}$ s and $zv = 9.0(4)$ for the $x = 0.6$ compound. The goodness of the fit is shown in the inset of Fig. 7(a). The intrinsic relaxation time τ_0 is found to be 5–6 orders of magnitude larger than that of typical single-ion spin glass systems which is of the order $\sim 10^{-13}$ s. This suggests that the relaxation in $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ is dominated by domains rather than by single ion effects. The dynamic exponent zv is in agreement with that of Ising spin glasses [27,28].

Spin glass behavior has been observed in several cation-doped LaCoO_3 systems such as $\text{La}_{1-x}\text{Sr}_x\text{CoO}_3$ [29] and $\text{LaCo}_{1-x}\text{Ni}_x\text{O}_3$ [30]. In the former, the competition between antiferromagnetic $\text{Co}^{3+}\text{-Co}^{3+}/\text{Co}^{4+}\text{-Co}^{4+}$ and ferromagnetic $\text{Co}^{3+}\text{-Co}^{4+}$ superexchange interaction was proposed as the origin. In the latter system, a charge transfer between the Co and Ni ions has been observed, and the competition

FIG. 8. Isothermal magnetization relaxation measurement for the $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ compounds. The red curves are fits to Eq. (4).

between ferromagnetic and antiferromagnetic interactions is responsible for the spin glass behavior in this system. For Co/Rh disordered $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ we expect no charge transfer between Co^{3+} and Rh^{3+} ions. But, the disorder induced by the random distribution Co-rich and Rh-rich clusters of different sizes might be the origin of the spin glass behavior in Co/Rh disordered $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$. The competition between the (antiferromagnetic according to Kanamori's rule [31]) nearest-neighbor and next-nearest-neighbor interactions might also be (partly) responsible for the spin glass behavior [32].

D. Isothermal relaxation

Figure 8 shows the isothermal relaxation of the three studied compounds below T_f . The data have been fitted with a stretched exponential function

$$M(t) = A \exp(-t/\tau)^\beta + B, \quad (4)$$

where A and B are constants, β the exponent, and τ the relaxation time. The resulting curves are shown as red lines in Fig. 8. Here, both τ and β are characteristic for a glassy transition. Whereas β amounts to 1 for systems with uniform energy barriers, glassy magnetic systems contain many local minima in the energy valley and β varies from 0 to 1. Our extracted parameters are listed in Table I. Interestingly, β attains a small and nearly temperature-independent value for all the $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ samples as is usually expected for typical glassy magnetic samples. On the other hand the

TABLE I. Extracted isothermal relaxation time τ and exponent β at different temperatures for the $x = 0.4, 0.5$, and 0.6 compounds.

	$x = 0.4$	$x = 0.5$	$x = 0.6$
$T = 1.8 \text{ K}$			
$\tau \text{ (s)}$	3855(38)	2964(17)	2125(10)
β	0.286(1)	0.288(1)	0.283(1)
$T = 3.0 \text{ K}$			
$\tau \text{ (s)}$	854(4)	498(2)	
β	0.302(1)	0.310(1)	
$T = 4.0 \text{ K}$			
$\tau \text{ (s)}$	410(3)		
β	0.290(1)

FIG. 9. Heat capacity measurements for the $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ compounds. The red curves are polynomial fits to the high-temperature data as described in the text.

relaxation time τ drastically falls with increasing temperature. This behavior is indicative for the presence of spin clusters in the system.

E. Heat capacity

Figure 9 shows the zero-field specific heat, C_p , measurements for the $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ compounds. There is no sharp λ -like anomaly at T_f for all the three samples, indicating no long-range magnetic ordering. In order to obtain the magnetic entropy, the data between 30 K and 100 K were fitted to a five-term polynomial function, as shown in Fig. 9, and the extrapolated low-temperature phonon contribution was then subtracted from the raw data in order to obtain the magnetic component C_M . The magnetic entropy was then calculated by $S(T) = \int_{T_0}^T C_M/T dT$, where T_0 is the base temperature. The results are shown in the inset of Fig. 9. The obtained S at 20 K for all three compounds is much smaller than the expected value for a HS Co^{3+} system. In this case S would

amount to 8.0, 6.7, and 5.3 J mol⁻¹ K⁻¹ for the $x = 0.4$, 0.5, and 0.6 compounds, respectively. Apart from a possibly lower occupation of the HS state of Co^{3+} ions at low temperatures the much lower value that we observe is indicative of substantial residual entropy in this Co/Rh-disordered system which is consistent with the glassy nature of the magnetic ground state in $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$.

IV. CONCLUSION

We have investigated the magnetic ground state of Co/Rh-disordered $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ around half doping within a comprehensive study of magnetic susceptibility, PND, μSR ,

ac susceptibility, isothermal magnetic relaxation, and heat capacity measurements. Our structural analysis confirms that the Co^{3+} and Rh^{3+} ions are randomly distributed in our studied $\text{LaCo}_{1-x}\text{Rh}_x\text{O}_3$ samples. Our PND and μSR results exclude the appearance of long-range magnetic ordered states as recently proposed for this system. Instead, we observed a short-ranged correlated spin glass state. The spin glass state in these Co/Rh-disordered samples can be characterized by the freezing of domains.

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