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A NEUTRON DIFFRACTION STUDY OF THE MAGNETIC ORDER IN THE $ThCr_2Si_2$ TYPE PHOSPHIDES $PrCo_2P_2$ AND $NdCo_2P_2$

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Abstract—The magnetic structures of the compounds $LnCo_2P_2$ (Ln = Pr and Nd) were investigated at different temperatures by neutron powder diffractometry and refined by the Rietveld technique. In agreement with the previously determined magnetic susceptibility data the magnetic moments of both the Pr^{3+} ions and the cobalt atoms of $PrCo_2P_2$ were found to order antiferromagentically with different, well-defined Néel temperatures. The magnetic lattices of the two magnetic species have different propagation vectors of $\mathbf{k} = (0, 0, 1)$ and $\mathbf{k} = (0, 0, \frac{1}{2})$ for the Pr^{3+} ions and the cobalt atoms, respectively. In contrast, in $NdCo_2P_2$ only the magnetic moments of the cobalt atoms order at a well-defined Néel temperature with a propagation vector again of $\mathbf{k} = (0, 0, \frac{1}{2})$, while the magnetic order of the Nd^{3+} moments is induced gradually at a lower temperature with the same propagation vector through the magnetic order of the cobalt atoms. The magnetic moments of the cobalt atoms of both compounds are ordered ferromagnetically within the basal planes of the tetragonal magnetic structures and parallel to the c-axis with the stacking sequence $+ + - -, + + - -$ along this direction. For the moments of the Pr^{3+} ions the order is again ferromagnetic within the basal planes and the stacking sequence is $+ - + -, + - + -$. In the magnetic structure of the Nd^{3+} sublattice no magnetic order (0) was found for every other basal plane; the stacking is of the type $0 - 0 +, 0 - 0 +$. At low temperatures the magnetic moments of the cobalt atoms were found to be about $\mu_{exp} = 0.8\,\mu_B$ in both compounds. The experimental moments of the Ln^{3+} ions were $3.08(2)\,\mu_B$ for Pr^{3+} and $2.78(6)\,\mu_B$ for Nd^{3+}, somewhat smaller than the theoretical values of $\mu_S = 3.20\,\mu_B$ and $3.27\,\mu_B$, respectively, expected for the Ln^{3+} ions.

Keywords: Magnetic structure, $PrCo_2P_2$, $NdCo_2P_2$, neutron diffraction.

1. INTRODUCTION

The magnetic properties of the $ThCr_2Si_2$ type lanthanoid (Ln) transition metal (T) silicides are well known [1]. The study of the magnetic order in the corresponding phosphides started much later. In the series $LnNi_2P_2$ and $LnFe_2P_2$ the transition metal atoms carry no magnetic moments, whereas ferromagnetic or antiferromagnetic order is observed for the moments of the cobalt atoms in the $LnCo_2P_2$ compounds [2–5]. We have recently reported a single-crystal neutron diffraction study of $EuCo_2P_2$ [6], in which the moments of the divalent europium atoms order with an incommensurable antiferromagnetic spiral structure, while no magnetic order was observed for the Co atoms. Here we report our results for the corresponding Pr and Nd phosphides, where magnetic order is found for the (trivalent) rare earth atoms as well as for the cobalt atoms.

2. SAMPLE PREPARATION AND NEUTRON DIFFRACTION

$PrCo_2P_2$ and $NdCo_2P_2$ were prepared from the elemental components in a tin flux as described earlier [7, 8]. The metals (with stated purities all >99.9%) were in the form of powders or filings. The filings of praseodymium and neodymium were stored under oil, which was washed away with dried n-hexane before use. The reactions were carried out in evacuated, sealed silicia tubes. The "ultrapure" red phosphorus (Hoechst AG, Werk Knapsack) was in the form of small pieces. The samples were annealed for 7 days at 900°C and subsequently quenched in water. The tin-rich matrix was dissolved in slightly diluted (1:1) hydrochloric acid. With the optimized starting ratio Ln:Co:P:Sn = 1.2:2:2:20 single-phase products were obtained. They were identified by their Guinier powder diagrams. The lattice constants were refined by least-squares fits using α-quartz ($a = 491.30$ pm, $c = 540.46$ pm) as standard.

The neutron powder diffraction measurements were made at the Institut Laue-Langevin. The $PrCo_2P_2$ data were collected with the D2B instrument and the $NdCo_2P_2$ data with the D1A set-up. Both instruments use germanium single crystals as monochromators with the 335 ($\lambda = 159.4$ pm) and 115 ($\lambda = 191.1$ pm) reflections, respectively. Further details of these instruments are described elsewhere [9]. The $PrCo_2P_2$ patterns were recorded at 1.6 K and 30 K, the $NdCo_2P_2$ patterns at 2 K and 60 K; both between diffraction angles of $2\theta = 8°$ and $2\theta = 150°$.

The Rietveld refinements of the neutron powder diffraction data were carried out with the program FULLPROF [10]. The nuclear scattering lengths used were: $b(\mathrm{Pr}) = 4.45$ fm, $b(\mathrm{Nd}) = 7.69$ fm, $b(\mathrm{Co}) = 2.50$ fm and $b(\mathrm{P}) = 5.13$ fm [11]. The magnetic form factors were of the form $f = \langle j_o \rangle + c_2\langle j_2 \rangle$, where the values of $\langle j_o \rangle$ and $\langle j_2 \rangle$ for Pr^{3+} (obtained by linear interpolation of the corresponding values for Ce^{3+} and Nd^{3+}) and Nd^{3+} were taken from Freeman and Desclaux [12]. The coefficients $c_2(Pr^{3+}) = 1.50$ and $c_2(Nd^{3+}) = 1.75$ were used [13].

The powder data of $NdCo_2P_2$ were also recorded at 0.134 K and 2.0 K up to $2\theta = 100°$ using a dilution fridge with instrument D20, a graphite monochromator and a wavelength of $\lambda = 241$ pm. The temperature dependence of the magnetic peaks $(1, 0, 0)_M$ of $PrCo_2P_2$ and $(1, 0, \frac{1}{2})_M$ of $NdCo_2P_2$ were also recorded with this high flux instrument.

3. RESULTS AND DISCUSSION

Magnetic susceptibility measurements carried out earlier with a Faraday balance [4] indicated antiferromagnetic order of the cobalt moments at $T_N = 304$ K and $T_N = 309$ K for the praseodymium and neodymium compounds, respectively (Fig. 1). A second antiferromagnetic upturn in the reciprocal susceptibility curve was observed at a temperature $T_N = 19$ K in the praseodymium compound, which could be ascribed to the magnetic order of the praseodymium moments. The magnetic susceptibilities of this compound were independent of the magnetic field strength above 19 K and decreased with increasing field strength below that temperature. For the neodymium compound the magnetic susceptibilities were found to behave anomalously at low temperature. It was thought [4] that the neodymium moments order antiferromagnetically at about 20 K, followed by a ferromagnetic coupling at lower temperatures. The field dependence of the magnetic susceptibility of that compound observed more recently below about 15 K seemed to be in agreement with this conclusion. With the present neutron diffraction data the antiferromagnetic order of the praseodymium moments was confirmed and the magnetic moments of the neodymium atoms were found to align antiferromagnetically with no sharp order–disorder transition. No ferromagnetic coupling of the neodymium moments could be observed without an applied field, but may be assumed in a magnetic field as discussed below. In addition, the careful evaluation of the data resulted in a model for the antiferromagnetic order of the weak magnetic moments of the cobalt atoms, which successfully was refined for both, $PrCo_2P_2$ and $NdCo_2P_2$.

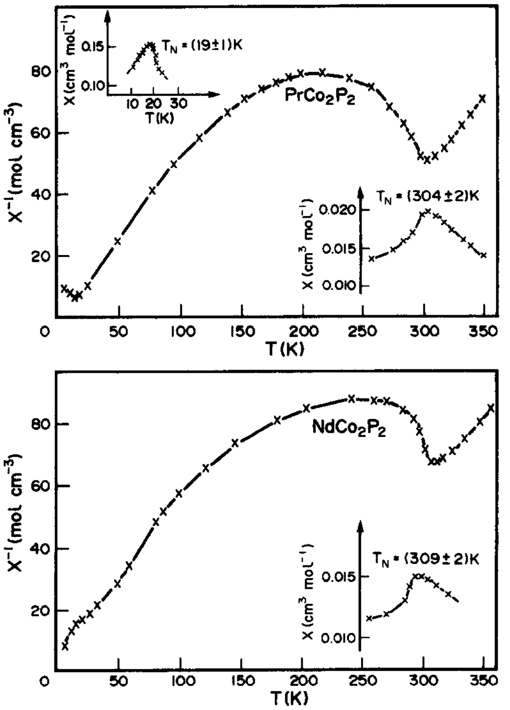

Fig. 1. Reciprocal magnetic susceptibilities of $PrCo_2P_2$ and $NdCo_2P_2$ [4] measured with a magnetic field strength of 1 T. The inserts show the susceptibilities around the Néel temperatures.

Trial structures

The nuclear $ThCr_2Si_2$-type structure was confirmed for both compounds. It was refined from the neutron diffraction patterns taken at 30 and 60 K for the praseodymium and neodymium compound, respectively (Figs 2 and 3). The data recorded at 1.6 K for $PrCo_2P_2$ and 2 K for $NdCo_2P_2$ showed additional peaks which could be ascribed to the ordered structure of the magnetic moments of the Ln^{3+} ions. In the pattern of $PrCo_2P_2$ the magnetic reflections (1, 0, 0), (1, 1, 1), (1, 1, 3), (1, 0, 4), (2, 0, 1), (2, 1, 0) etc. could be observed. In general these reflections are generated by the rule $(hk\ell)_M = (hk\ell)_N \pm \mathbf{k}$ where the propagation vector **k** corresponds to $\mathbf{k} = (0, 0, 1)$. Thus, the magnetic structure violates the body centering. The absence of the reflections (0, 0, 1), (0, 0, 3), etc. indicated that the magnetic moments are parallel to the tetragonal *c*-axis. The simplest structure corresponding to these requirements has already been observed previously in silicides with $ThCr_2Si_2$ structure [1] and has been designated AF I. In this magnetic structure the moments are parallel in the basal plane of the tetragonal cell with antiferromag-

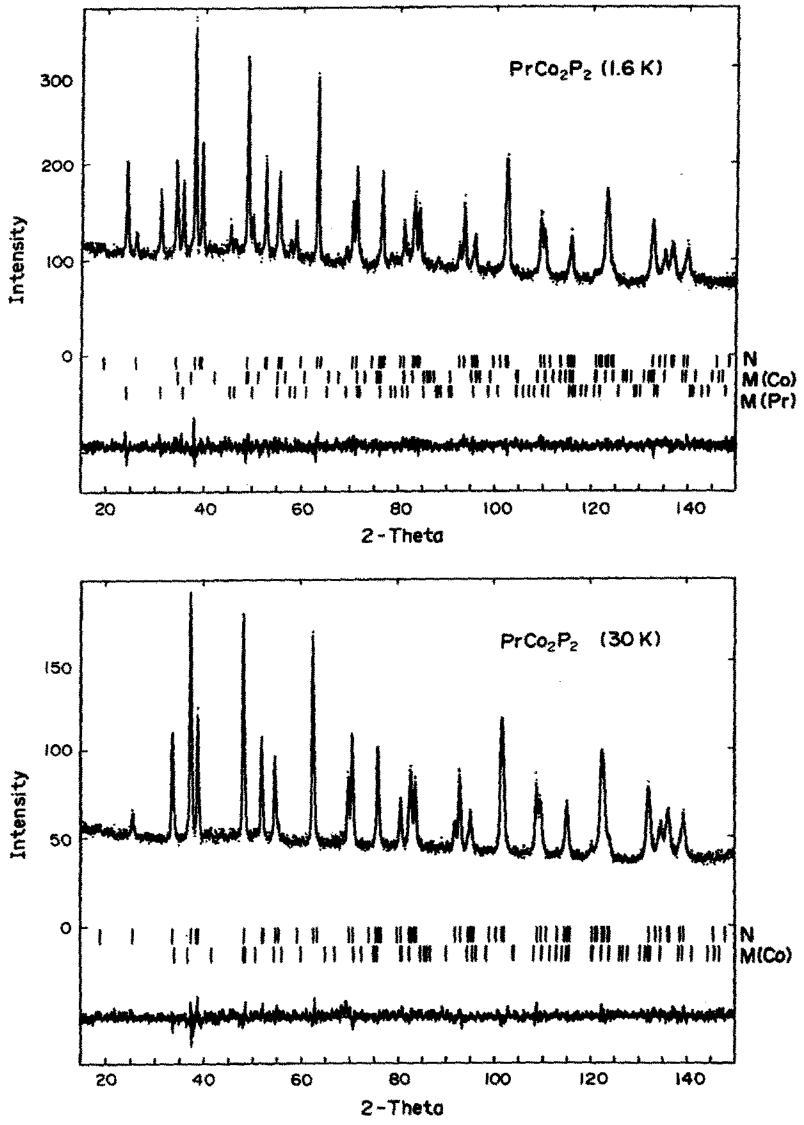

Fig. 2. Neutron diffraction patterns of $PrCo_2P_2$. The peak positions of the nuclear (N) and the magnetic (M) structures as well as the differences between the observed and calculated patterns are shown. The data measured at 30 K were refined for the nuclear structure and for the magnetic structure of the cobalt moments. In addition, the magnetic structure of the Pr^{3+} moments was refined from the spectra taken at 1.6 K.

netic coupling between adjacent planes (Fig. 4). This structure was successfully refined for $PrCo_2P_2$.

In the 2 K pattern of $NdCo_2P_2$ the magnetic reflections, e.g. $(1, 0, \frac{1}{2})$, $(1, 0, 1\frac{1}{2})$, $(1, 0, 2\frac{1}{2})$, $(2, 1, \frac{1}{2})$, $(2, 1, 1\frac{1}{2})$ etc. obey the rule $(hk\ell)_M = (hk\ell)_N \pm \mathbf{k}$ with the propagation vector $\mathbf{k} = (0, 0, \frac{1}{2})$. Thus, the magnetic structure requires a doubling of the tetragonal c-axis. The absence of the reflections $(0, 0, \frac{1}{2})$, $(0, 0, 1\frac{1}{2})$, etc. again suggested that the magnetic moments of the Nd^{3+} ions are parallel to this axis. The simplest structure for these conditions is the AF II structure [1], where the neodymium moments are ferromagnetically ordered within the basal planes and the order along the c-axis is antiferromagnetic with the sequence $+ + - -$, $+ + - -$. Without considering the magnetic order of the cobalt moments it was possible to refine this magnetic structure, however, the resulting magnetic moments for the Nd^{3+} ions were rather small: $\mu_{exp} = 2.05(5)\,\mu_B$ compared to the theoretical value of $\mu_S = 3.27\,\mu_B$ calculated from the equation $\mu_S = g \cdot J\,\mu_B$. Even though a reasonable residual ($R_{M(Nd)} = 0.126$ for 11 magnetic structure factors) was obtained, this model had to be abandoned when the magnetic structure of the cobalt atoms was determined.

From the magnetic susceptibility data [4] it could be expected that the magnetic moments of the cobalt atoms are also ordered. For that reason the neutron

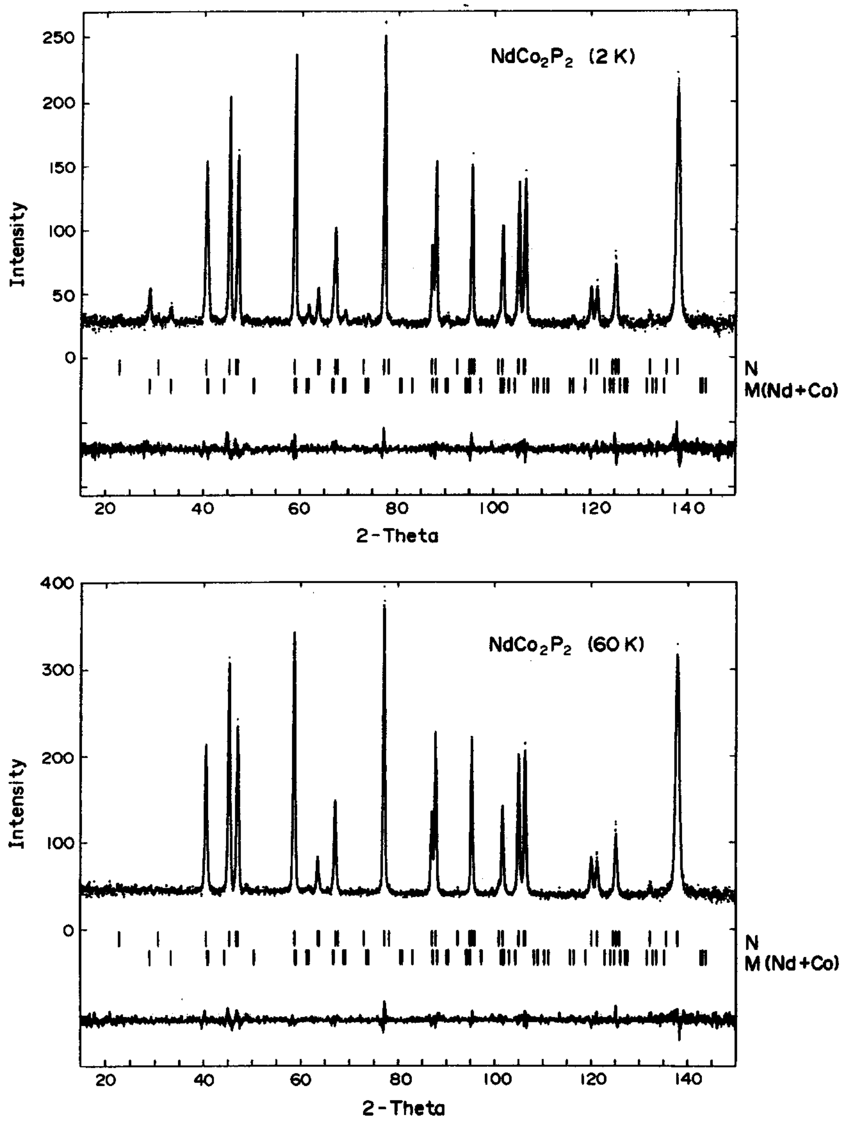

Fig. 3. Neutron diffraction patterns of $NdCo_2P_2$ measured at 2 K and at 60 K. The nuclear (N) and the magnetic structure (M) were refined from both spectra.

diffraction spectra of both compounds recorded at 30 and 60 K, respectively, were carefully inspected. In addition to the peaks of the nuclear structure very weak intensities were observed at the positions $(1, 1, \frac{1}{2})$, $(1, 1, 1\frac{1}{2})$ and $(1, 1, 2\frac{1}{2})$, corresponding to the propagation vector $\mathbf{k} = (0, 0, \frac{1}{2})$. A magnetic structure for the cobalt moments compatible with these observations has again ferromagnetic order within the basal planes and the antiferromagnetic sequence $+ + - -$, $+ + - -$ for the coupling between neighbouring planes (Fig. 4).

The structure of $PrCo_2P_2$

With these models for the magnetic structures the neutron diffractions patterns of $PrCo_2P_2$ were successfully refined. For the determination of the nuclear structure the full data sets with the 2θ values between 15° and 150° were used. A total of 14 variable parameters was refined (an overall scale factor, five profile function parameters, one preferred orientation parameter, the zeropoint and two lattice constants, the positional parameter z of the phosphorus atoms, three isotropic thermal parameters) and the following residuals (defined as $R = \Sigma(\|F_o|-|F_c\|)/\Sigma|F_o|)$ were obtained: $R = 0.030$ (30 K) and $R = 0.032$ (1.6 K). The results are summarized in Table 1. The standard deviations of the positional parameters z in these powder data refinements seem to be rather small, when compared to the standard deviations obtained in the single-crystal X-ray data refinement [8]. It seems to be generally the case that the standard deviations are underestimated in Rietveld programmes.

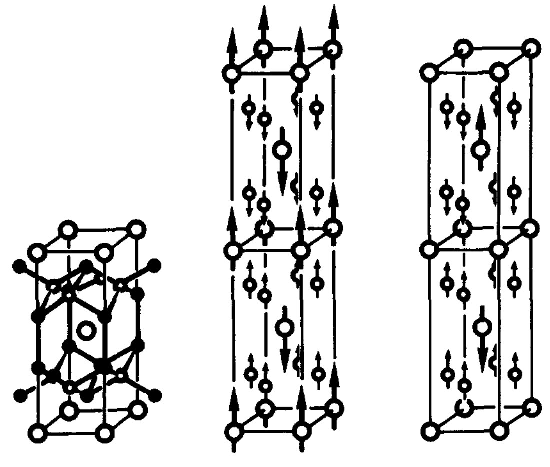

Fig. 4. $PrCo_2P_2$ and $NdCo_2P_2$ with the tetragonal $ThCr_2Si_2$ structure and their magnetic structures. The magnetic moments of the cobalt atoms and Pr^{3+} ions are always ordered ferromagnetically within the basal planes. In both compounds the order of the cobalt moments along the c-axis is the same with the sequence $++--$, $++--$. The order of the Pr^{3+} moments is $+-+-$, $+-+-$. In $NdCo_2P_2$ every other Nd layer has disordered moments and the sequence is $0-0+$, $0-0+$.

The residuals for the magnetic reflections of these refinements were rather high, because the intensities of these reflections are low at high angles. Therefore additional refinements were carried out with the data sets limited to $2\theta = 75°$. In these refinements the variable parameters of the nuclear structure were fixed at the previously obtained values and the magnetic moments of the lanthanoid atoms were varied as additional parameters. For the magnetic structure of the Pr^{3+} moments a residual of $R_{M(Pr)} = 0.057$ was obtained for the data set collected at 1.6 K. The residual for the cobalt moments of $R_{M(Co)} = 0.19$ seems to be high. However, one has to keep in mind, that the magnetic moments of the cobalt atoms are rather low ($\mu_{exp}(Co) = 0.90(5)\ \mu_B$) and the magnetic structure of the cobalt moments proposed here is the simplest one compatible with the data. This structure was also refined for the 30 K data (Table 1). Here the magnetic moment of the cobalt atoms of $\mu_{exp} = 0.74(6)\ \mu_B$ is even smaller, as expected. At this temperature the moments of the Pr^{3+} ions are not ordered in agreement with the susceptibility data.

The magnetic moment of these ions of $\mu_{exp} = 3.08(\pm 0.02)\ \mu_B$ resulting from the 1.6 K data is only slightly smaller than the theoretical saturated moment (calculated from $\mu_S = g \cdot J\,\mu_B$) of $\mu_S = 3.20\ \mu_B$. This small difference is frequently observed and is usually attributed to crystal field effects. In concluding this discussion of the $PrCo_2P_2$ structure we want to emphasize that three different lattices can be distinguished for this structure: the body centered tetragonal nuclear cell, the corresponding primitive cell for the magnetic structure of the Pr^{3+} moments, and the primitive tetragonal cell of the cobalt moments with the doubled c-axis. Therefore each lattice has its own set of reflections in the neutron diffraction pattern.

Table 1. Results of the Rietveld refinements of the neutron powder data of the tetragonal phosphides $PrCo_2P_2$ and $NdCo_2P_2$

	$PrCo_2P_2$			$NdCo_2P_2$			
	300 K†	30 K	1.6 K	300 K†	60 K	48 K	2 K
a [pm]	390.0(2)	390.0(2)	390.1(2)	389.1(1)	389.3(2)	389.3(2)	389.3(2)
c [pm]	976.6(8)	968.8(6)	968.6(6)	986.7(3)	963.0(5)	962.8(5)	962.8(5)
c/a	2.504	2.484	2.483	2.490	2.474	2.473	2.473
V [nm^3]	0.1485(3)	0.1474(3)	0.1474(3)	0.1467(1)	0.1459(3)	0.1459(3)	0.1459(3)
z	0.3684(3)	0.3697(2)	0.3697(2)	—	0.3702(2)	0.3702(2)	0.3706(2)
P–P dist. [pm]	257.0(3)	252.5(2)	252.4(2)	—	249.9(2)	249.9(2)	249.2(2)
B(Ln)	0.332(5)	0.42(4)	0.46(4)	—	0.20(3)	0.17(4)	0.12(3)
B(Co)	0.47(1)	0.59(4)	0.59(3)	—	0.35(5)	0.45(6)	0.30(6)
B(P)	0.49(2)	0.54(2)	0.65(3)	—	0.51(3)	0.45(4)	0.33(4)
R_N (no. of F s)	0.044(441)	0.030(59)	0.032(59)	—	0.017(35)	0.023(35)	0.026(35)
‡μ_{exp} (Ln^{3+}) [μ_B]	—	—	3.08(2)	—	0.40(5)	0.74(7)	2.78(6)
μ_{exp} (Co) [μ_B]	—	0.74(6)	0.90(5)	—	0.52(8)	0.64(7)	0.79(4)
$R_{M(Pr)}$ (no. of F s)	—	—	0.057(14)	—	—	—	—
$R_{M(Co)}$ (no. of F s)	—	0.31(14)	0.19(13)	—	—	—	—
$R_{M(Nd+Co)}$ (no. of F s)	—	—	—	—	0.17(11)	0.21(11)	0.10(11)

The residuals for the nuclear structure R_N (with the number of structure factors in parentheses) were obtained in refinements of the diffraction data between 2θ from 15° to 150°. The residuals for the magnetic structure factors R_M (again with the number of the F-values in parentheses) were obtained from smaller data sets (2θ between 15° and 75° for $PrCo_2P_2$ amd between 15° and 64° for $NdCo_2P_2$). The parameters of the nuclear structure were held contant during these refinements and only the magnetic moments μ_{exp} were allowed to vary.

†The lattice constants at 300 K of both compounds are taken from the X-ray data of [4]. The atomic parameters at 300 K of $PrCo_2P_2$ are from the X-ray data of [8].

‡The magnetic moment per Nd atom in $NdCo_2P_2$ at 60 K was calculated from the intensity on the (1, 0, $\frac{1}{2}$) magnetic peak measured with the D20 instrument.

The structure of $NdCo_2P_2$

In contrast to the susceptibility data of $PrCo_2P_2$, where two Néel temperatures are discernible, the reciprocal susceptibilities of $NdCo_2P_2$ show only one minimum. One rationalization for this observation is that the magnetic order of the neodymium moments is induced by the order of the cobalt moments. In agreement with this assumption the magnetic structure of the cobalt and Nd^{3+} moments should have the same propagation vector. The neutron diffraction data of $NdCo_2P_2$ recorded at 2 K, 48 K and 60 K were in qualitative agreement and suggested a propagation vector of $\mathbf{k} = (0, 0, \frac{1}{2})$, which is the same as for the magnetic structure of the cobalt moments of the praseodymium compound. Therefore it was reasonable to assume that the magnetic structure of the cobalt moments is the same for both compounds. For the order of the Nd^{3+} moments two magnetic structures seemed to be compatible with the data. One, where the moments of the basal planes are stacked along the c-axis in the sequence $++--$, $++--$. This model was already mentioned above; it resulted in the rather low magnetic moment of $\mu_{exp}(Nd^{3+}) = 2.05(5)\,\mu_B$. In refining this model together with the magnetic order of the cobalt moments the resulting magnetic moments of the Nd^{3+} ions would have become even smaller. Therefore the other possibility for the stacking of the Nd^{3+} moments in adjacent planes was considered. It has the sequence $0-0+$, $0-0+$; i.e. in every second basal plane the Nd^{3+} moments are randomly distributed. It makes sense physically to assume that these disordered planes are located between two cobalt layers of opposite magnetic orientation, as shown in Fig. 4. These structures were successfully refined. For the least-squares refinement of the nuclear structure the large data set with 2θ values up to 150° was used. The magnetic structures were again refined from a smaller data set (2θ up to 64°), again with fixed nuclear parameters (Table 1). The magnetic moment of the Nd^{3+} ions at 2 K of $\mu_{exp} = 2.78(6)\,\mu_B$ is now closer to the theoretical moment (from $\mu_S = g \cdot J\,\mu_B$) of $\mu_S = 3.27\,\mu_B$. However, the difference between the theoretical and the experimental moment is somewhat larger than in the case of the praseodymium compound, where it was attributed to crystal field effects. It can be assumed that the magnetic moments of the Nd atoms are not fully aligned parallel to the c-axis, because their order seems to be primarily induced by the magnetic order of the cobalt moments. At still lower temperature a higher degree of order can be expected. The refinements of the data recorded at 48 and 60 K resulted in Nd^{3+} moments of $\mu_{exp} = 0.98(11)\,\mu_B$ and $\mu_{exp} = 0.89(12)\,\mu_B$, respectively. The values listed in Table 1 are from a different experiment (see below), they are believed to be more reliable. The magnetic moments of the cobalt atoms decrease as expected from $\mu_{exp} = 0.79\,\mu_B$ at 2 K, to $\mu_{exp} = 0.64\,\mu_B$ (48 K) and $\mu_{exp} = 0.52\,\mu_B$ (60 K).

The magnetic structure of $NdCo_2P_2$ just described was obtained at a rather late stage of our investigation. Because the magnetic susceptibility data of this compound showed only one ordering temperature, we considered the possibility of an additional ordering phenomenon below 2 K. For this reason we examined the $NdCo_2P_2$ sample in the high flux D20 instrument. The whole neutron diffraction pattern was recorded at 0.134 K and 2.0 K up to 100° with a neutron diffraction length of $\lambda = 241$ pm. Special attention was given to the low angle range starting at $2\theta = 4°$. No superstructure reflections were observed. The difference pattern calculated from the two data sets of 0.134 K and 2.0 K gave no indication of (additional) superstructure reflections in the low temperature diagram. The difference pattern was completely flat and thus there is no change in the magnetic structure between these two temperatures. Regarding the magnetic susceptibility measurements (Fig. 1) it had been suggested that the antiferromagnetic order may change to a ferromagnetic one at lower temperatures [4]. This can be ruled out now for the case with zero magnetic field. Nevertheless such a transition may occur at finite applied magnetic fields as indicated by the field dependence observed below 15 K. Several such transitions were observed with increasing magnetic fields at low temperatures in $PrCo_2Si_2$ (metamagnetism, "devil's staircase") [14]. This may also be the case for $PrCo_2P_2$, which also has a field dependent magnetic susceptibiity below the Néel temperture, as already mentioned above.

The temperature dependence of the magnetic structure of $NdCo_2P_2$ was further investigated by measuring the intensities of the magnetic reflections $(1, 0, \frac{1}{2})_M$ and $(1, 0, 1\frac{1}{2})_M$ at temperatures between 2 and 100 K. Both peaks behaved in the same way. The data for the $(1, 0, \frac{1}{2})_M$ reflections are shown in Fig. 5. The temperature dependence of this peak is anomalous. Instead of a disappearance at a definite Néel temperature, the intensity decreases slowly on heating and only seems to have vanished completely about 100 K. This anomalous behaviour accords with the magnetic susceptibility data (Fig. 1). This curve also shows no Néel temperature for the magnetic order of the Nd^{3+} moments. On the other hand the Néel temperature at 309 K could be attributed already at that time to the order of the cobalt moments on the basis of a comparison with the data for $LaCo_2P_2$ [4]. The present investigation strongly suggests that the magnetic order of the Nd^{3+} moments is gradually induced by

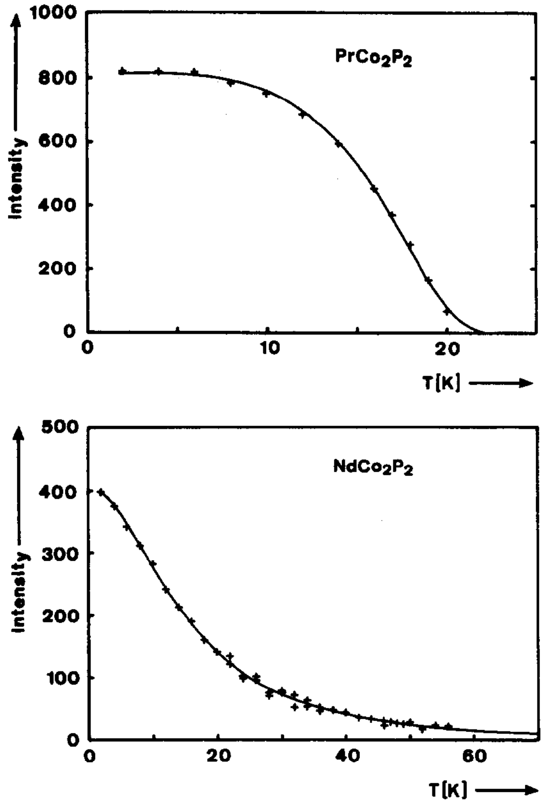

Fig. 5. Temperature dependence of the intensities of the magnetic reflections $(1, 0, 0)_M$ and $(1, 0, \frac{1}{2})_M$ of $PrCo_2P_2$ and $NdCo_2P_2$, respectively. The solid line in the case of the $PrCo_2P_2$ peak represents a fit to the data according to the Brillouin function for $J = 9/2$. The solid line in the diagram of the $NdCo_2P_2$ peak is only a guide for the eye.

the order of the cobalt moments. According to the magnetic structure of $NdCo_2P_2$ described above the magnetic peak $(1, 0, \frac{1}{2})_M$ owes its intensity to the magnetic scattering of the Nd^{3+} ions and has no contribution from the cobalt moments. The magnetic moments of the Nd^{3+} ions obtained at various temperatures for this reflection, measured on the D20 instrument (Fig. 5) increase from $\mu_{exp} = 0.40(5)$ μ_B (60 K) to 0.74(7) μ_B (48 K) to 2.78(6) μ_B at 2 K. The latter value is taken from the structure refinement with the D1A data. It was also used to obtain the scale factor for the evaluation of the D20 data.

In contrast, the temperature dependence of the strong magnetic peaks of the antiferromagnetic structure of $PrCo_2P_2$ is normal. These strong peaks with the propagation vector $\mathbf{k} = (0, 0, 1)$ owe their intensity to the order of the magnetic moments of the Pr^{3+} ions. The intensity of the strongest of these magnetic peaks, the $(1, 0, 0)_M$ reflection, can be fitted well with a Brillouin function with $J = 9/2$ [15] (Fig. 5). The Néel temperature of $T_N = 20(\pm 1)$ K obtained with this fit agrees well with that of $T_N = 19(\pm 1)$ K observed from the magnetic susceptibility data (Fig. 1).

The magnetic ordering behaviour found in the present investigation of the phosphides $LnCo_2P_2$ is parallelled by the behaviour of several lanthanoid cuprates Ln_2CuO_4 [16, and references therein]. In $PrCo_2P_2$ as well as in Sm_2CuO_4 and Gd_2CuO_4, both the magnetic moments of the Ln^{3+} ions as well as the magnetic moments of the transition metal atoms order with different, well-defined ordering temperatures and the magnetic lattices of the two magnetic species have different propagation vectors. In $NdCo_2P_2$ as well as in Pr_2CuO_4 and Nd_2CuO_4, on the other hand, only the magnetic moments of the transition metal atoms have a well-defined Néel temperature and the magnetic order of the Ln^{3+} moments is induced gradually at lower temperatures through the magnetic order of the transition metal atoms. In this case the propagation vectors of the Ln^{3+} and transition metal atom moments are the same.

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