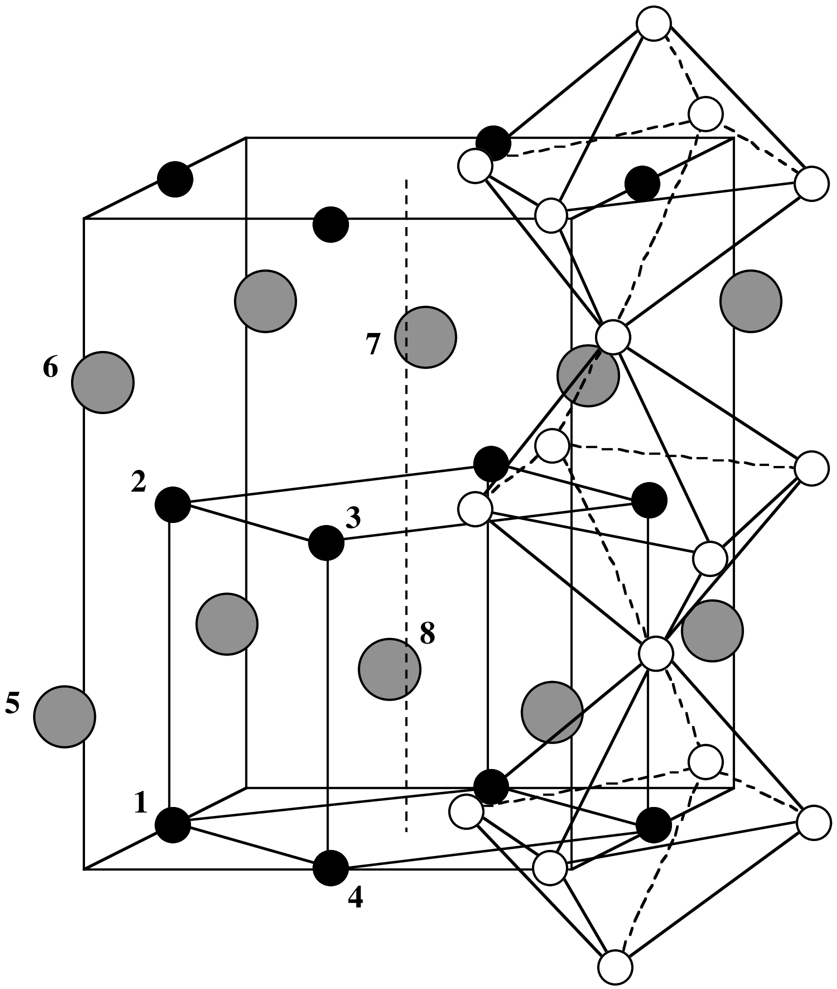
Outline



1. Introduction

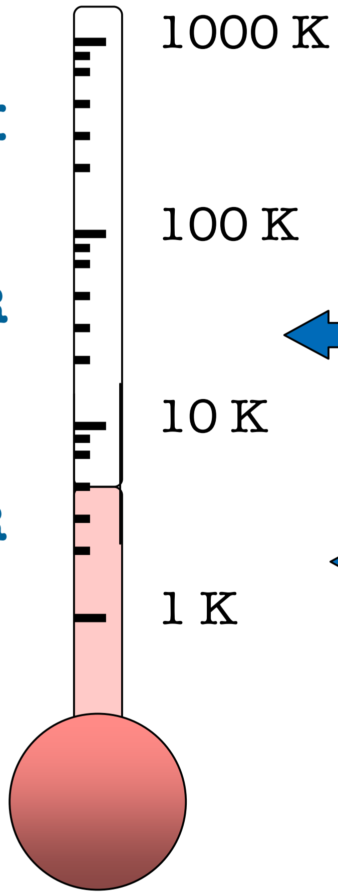
2. Low-temperature Specific Heat results in $NdFe_{1-x}Co_xO_3$ ($x \leq 0.5$)

3. Models and interpretation

4. Conclusions

RMO_3 : Model systems M-M, M-R, R-R interactions.

- **M-M**
- **M-R**
- **R-R**



M magnetic order **(Cr, Fe, Ni, ...)**

M SRT's, ...

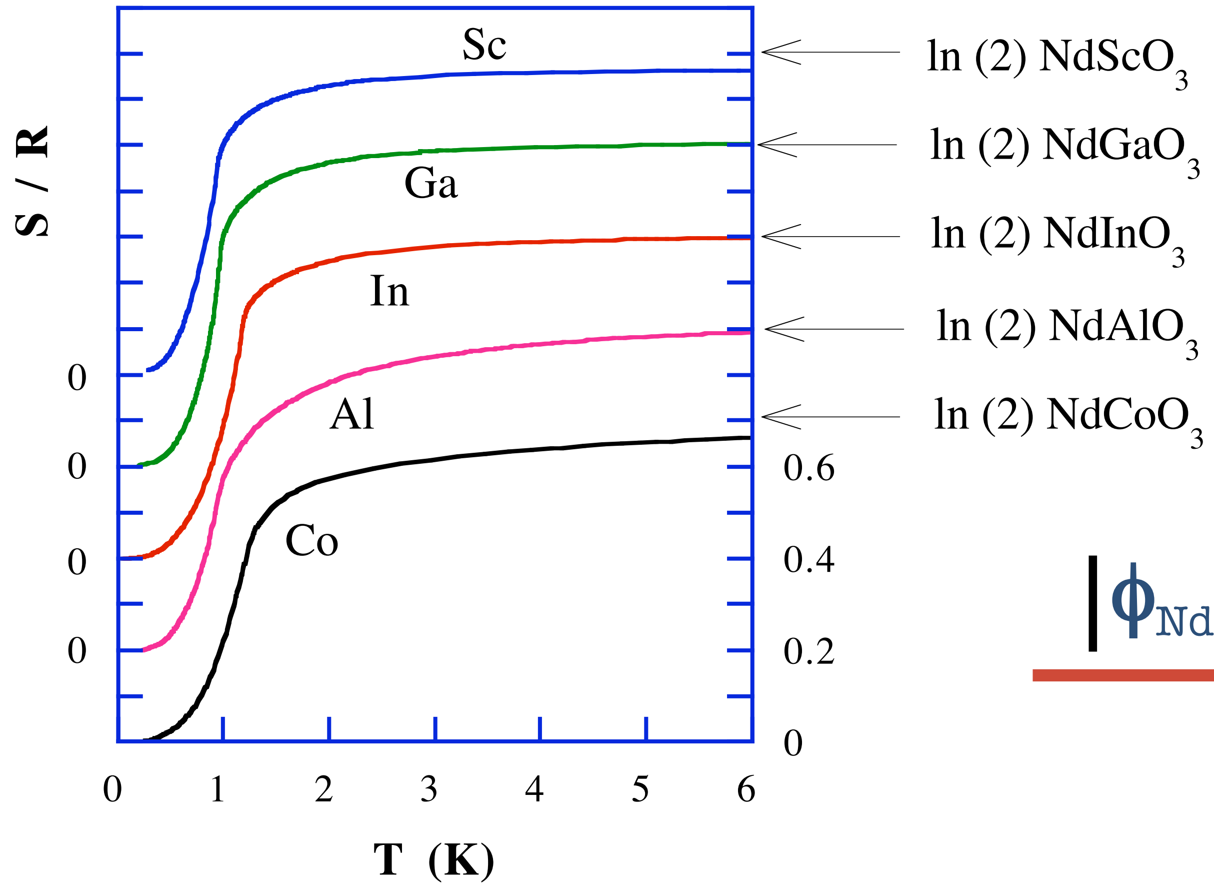
R induced order: M-R

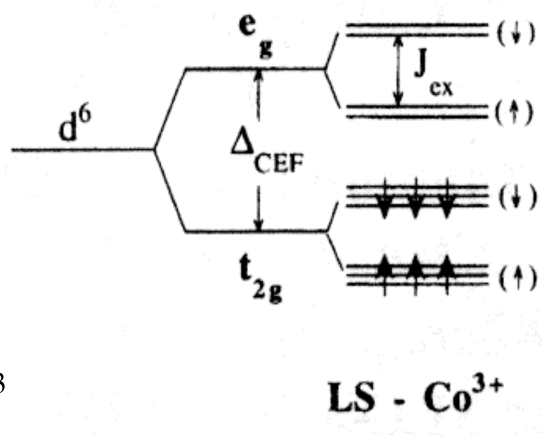
R cooperative order: R-R

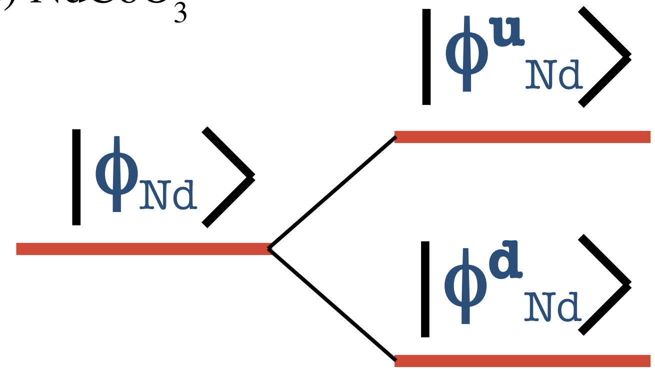
(Nd, Sm, Gd, Er, ...)

Introduction: $NdFe_{1-x}Co_xO_3$

x=1 Co *is* in LS state in $NdCoO_3$







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Magnetic susceptibility of $NdGaO_3$ at low temperatures: A quasi-two-dimensional Ising behavior

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(Received 3 February 1998)

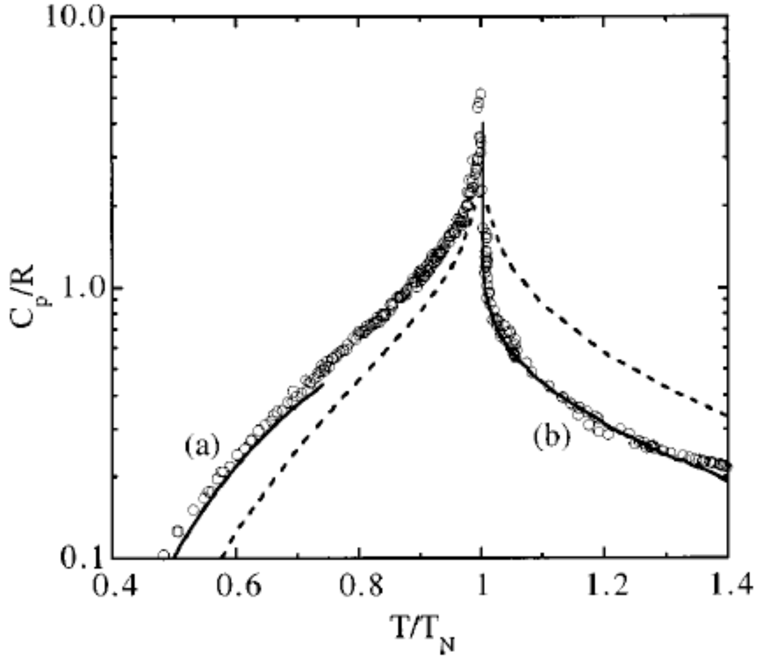

FIG. 9. Experimental heat capacity of $NdGaO_3$ vs reduced temperature (T_N=0.97 K). (—) Calculated predictions for the 2D-3D crossover case with $|r|=0.1$ from (a) spin-wave low-temperature series, (b) extrapolated high-temperature series. (--) Heat capacity for the antiferromagnetic simple quadratic $S=\frac{1}{2}$ model ($r=0$).

The heat capacity was calculated as

$$C/R=A\left(1-\frac{K}{K_c}\right)^{-\alpha}+e_0+\mathrm{PA}\left\{\sum_{n=2}^{\infty}(K/2)^n\left(\sum_{j=0}^{n}c_{nj}r^j\right)-\left[A\left(1-\frac{K}{K_c}\right)^{-\alpha}+e_0\right]\right\} \quad (14)$$

above $T_c=T_N$, as shown in Fig. 9. We observe an excellent

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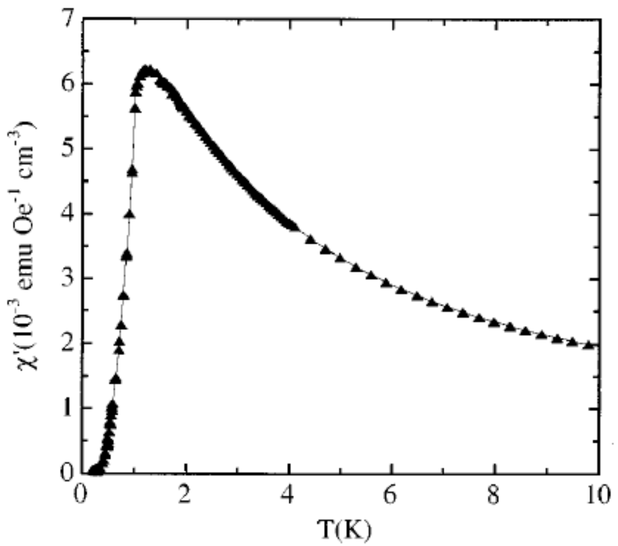

FIG. 1. Magnetic susceptibility of $NdGaO_3$ along [001].

used to measure the microwave frequency. The Nd content of the doped $LaGaO_3$ sample was determined by electron probe microanalysis to be $(2.1\pm0.3)\times10^{20}$ Nd^{3+} ions/cm^3.

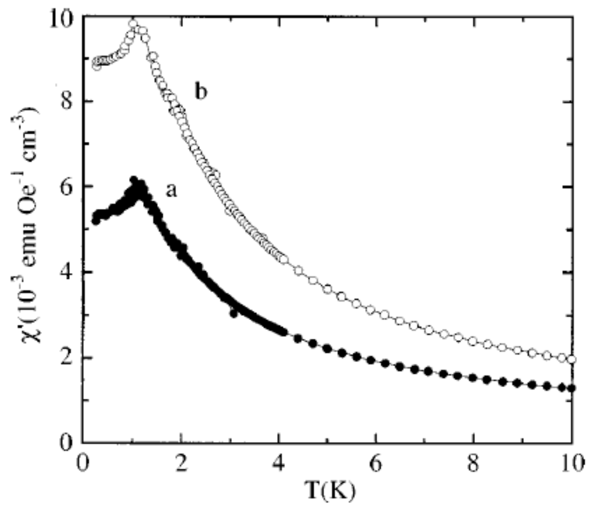

FIG. 2. Magnetic susceptibility of $NdGaO_3$ along [100] (a), and [010] (b).

TABLE II. Critical temperature, g-tensor components, and exchange parameters obtained from the analysis of the experimental data.

Expt.	T_c (K)	g_x	g_y	g_z	$J_\perp/k$(K)	r
C_p	0.97 ± 0.01				-0.70 ± 0.01	-0.10 ± 0.02
$\chi_\parallel$				2.73 ± 0.02	-0.70 ± 0.01	-0.10 ± 0.02
$\chi_{\perp,\max}$		$1.80\ \pm0.02$	$2.28\ \pm0.02$		-0.86 ± 0.05	
$\chi_\perp$ $(T=0)$		$1.84\ \pm0.02$	$2.41\ \pm0.02$			
EPR		2.025 ± 0.005	2.495 ± 0.005	2.72 ± 0.01		

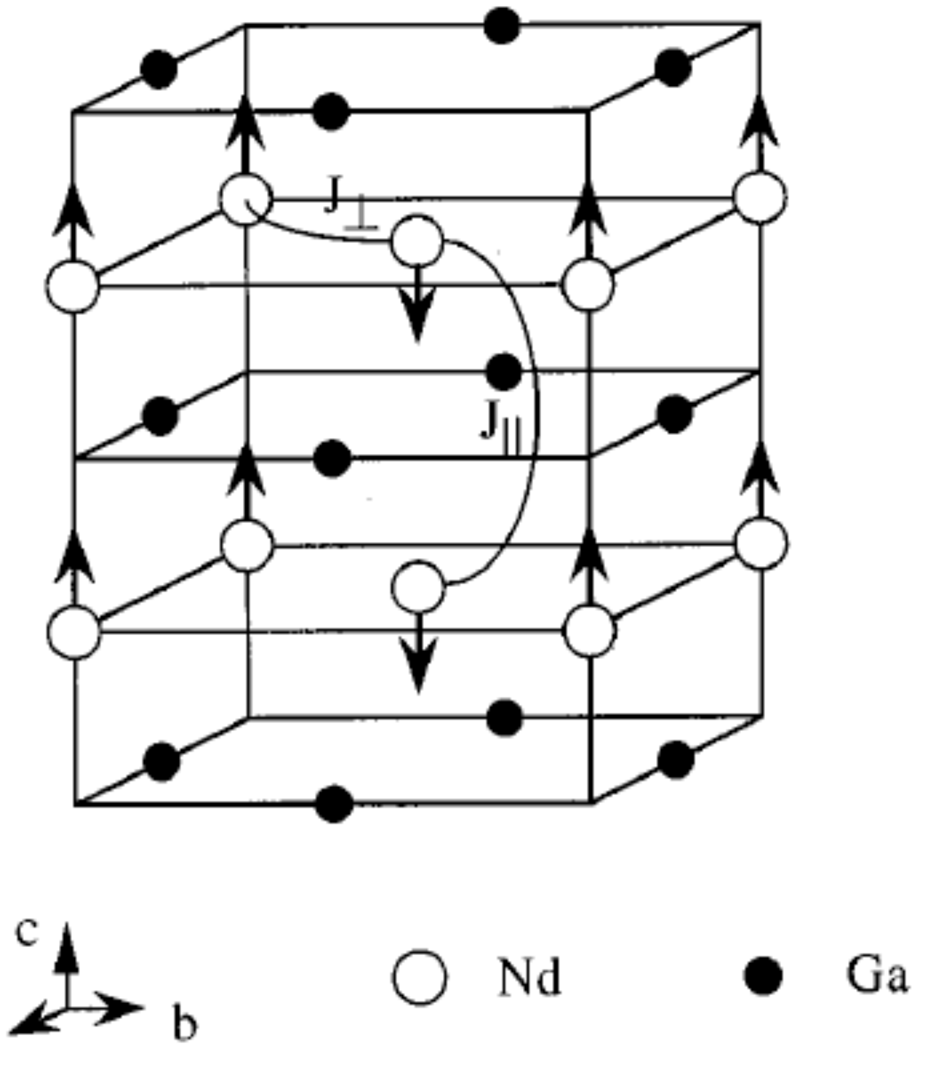

FIG. 3. Magnetic structure C_z of $NdGaO_3$ (oxygen atoms are not depicted).

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Specific heat and magnetic interactions in $NdCrO_3$

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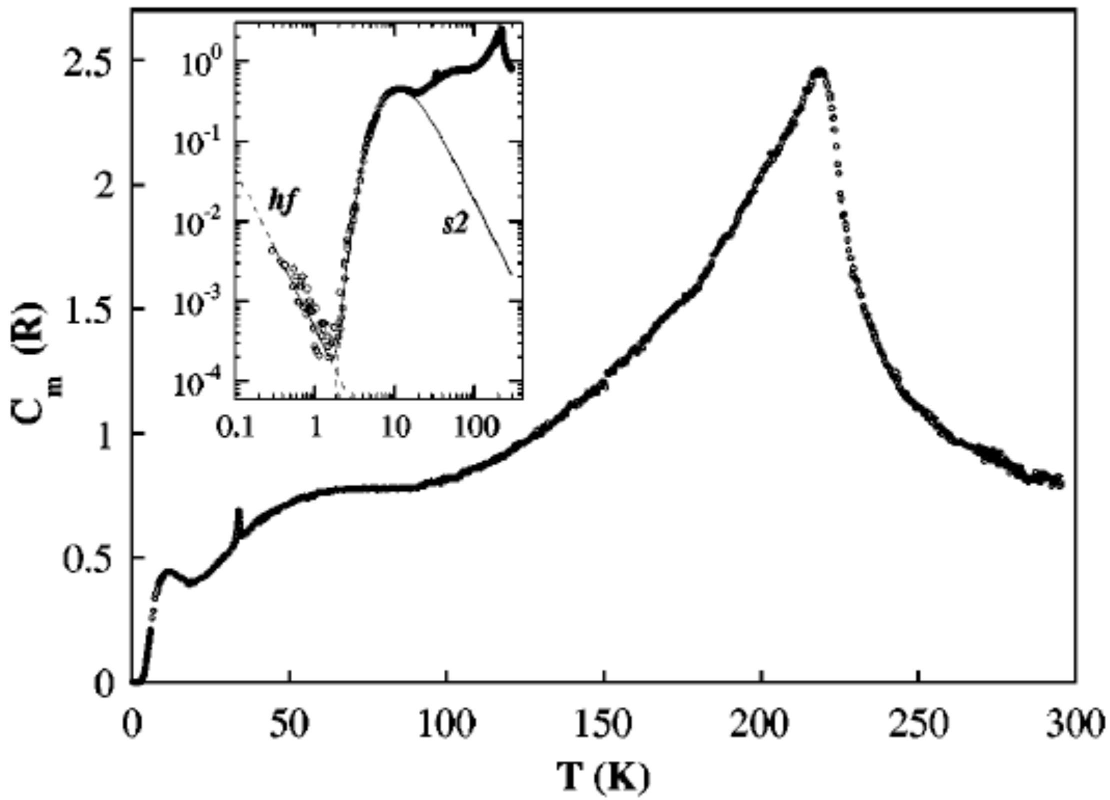

FIG. 2. Magnetic specific heat of $NdCrO_3$, C_m. The inset shows the same data on a double-log scale. The fitted hyperfine (hf) and two-level Schottky ($s2$) contributions are also shown.

$$C_{hf}/R = \frac{\overline{\mu_{eff}^2} \cdot H_{hf}^2}{3k_B^2 T^2},$$

$$C_{sw}/R = 13.7\left(\frac{k_B T}{12JS}\right)^3$$

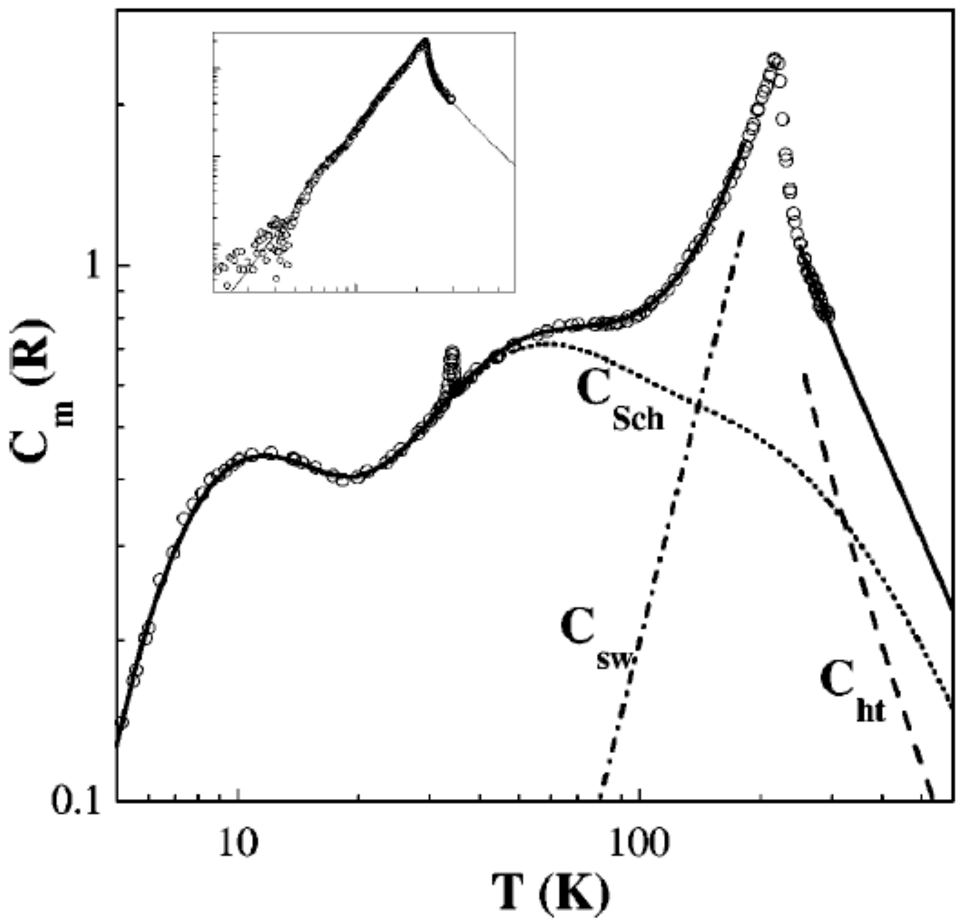

FIG. 5. Magnetic specific heat of $NdCrO_3$ (open symbols) on a double-log scale. For the sake of clarity, only a part of the data is shown. The three separate contributions to the calculated C_m (solid line) are shown; Nd $^4I_{9/2}$ Schottky, C_{Sch} (dotted line), magnonic contribution of the Cr subsystem, C_{sw} (dash-dotted line), and s.c. $S=3/2$, isotropic Heisenberg high-temperature specific heat, C_{ht} (dashed line). The inset show the data on a double-log scale, once C_{Sch} has been subtracted, isolating the Cr magnetic contributions (except for the spin reorientation transition peak at $T=34$ K).

simple cubic, $S=3/2$, isotropic Heisenberg Hamiltonian,

$$C_{ht}/R=\frac{2z(S(S+1))^2}{3\theta^2}\left(1+\sum_{n=1}^{5}\frac{c_n}{\theta^n}\right) \tag{3}$$

where z is the number of nearest neighbors (6 for the s.c. lattice), $\theta=k_BT/J$ and c_n are the expansion coefficients, given in Ref. 29 up to $n=5$. The best fit of C_m above 250 K is shown in Fig. 5, yielding the result $|J^{ht}_{Cr}|/k_B=21.6(5)$ K.

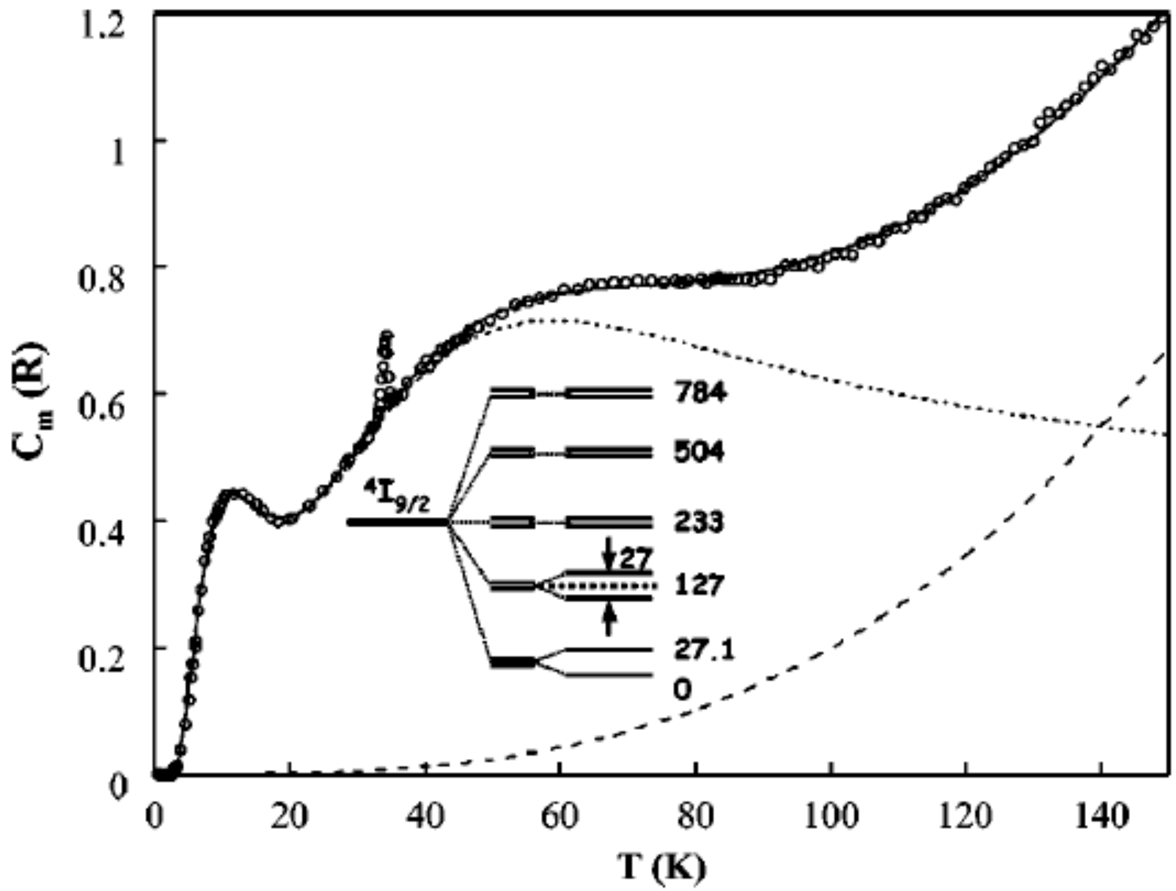

FIG. 4. Magnetic specific heat of $NdCrO_3$ below 150 K (open symbols). The fitted curve (solid line) is the sum of the Schottky curve from Nd $^4I_{9/2}$ (dotted line) and the magnonic specific heat of the Cr subsystem (dashed line). The crystal-field energies derived from the fit is shown in the scheme. For the sake of clarity, only one half of the data is shown.

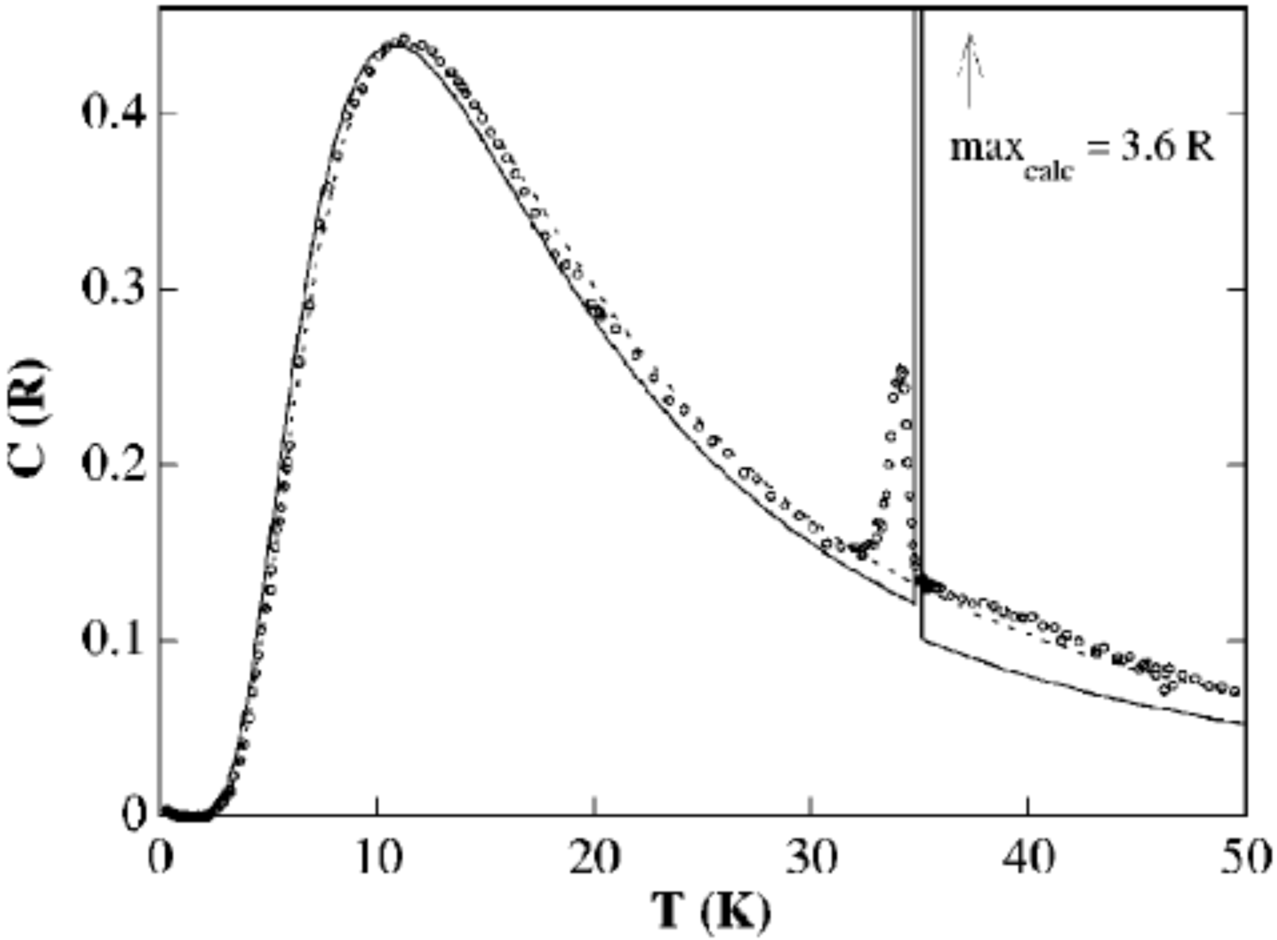

FIG. 9. Specific-heat Schottky contribution of the Nd ground doublet, compared to the Hornreich's prediction (solid line) presenting a discontinuity of $0.02R$ at T_{SRT} and a sharp anomaly characteristic of a first-order transition. The theoretical curve obtained from our fit, with $\Delta_g/k_B = 27.15$ K (dotted line), is also shown.

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Single-crystal neutron diffraction study of Nd magnetic ordering in $NdFeO_3$ at low temperature

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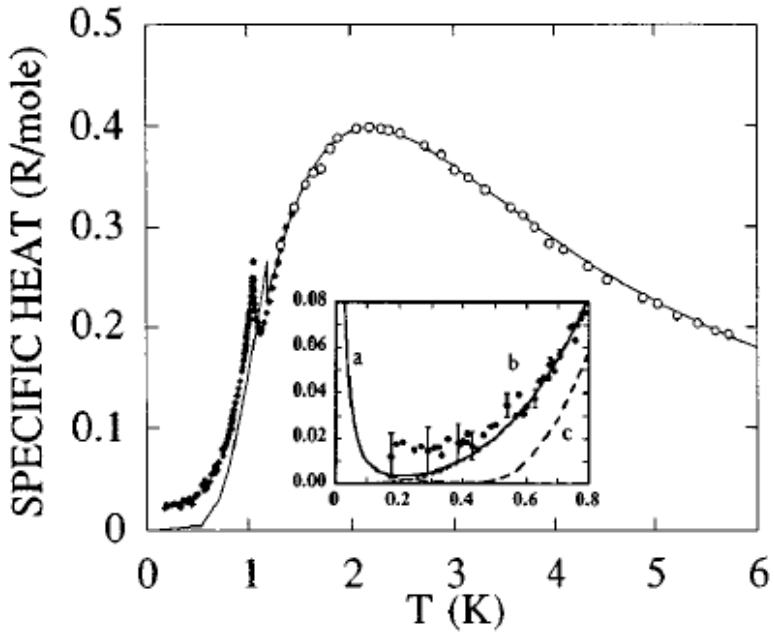
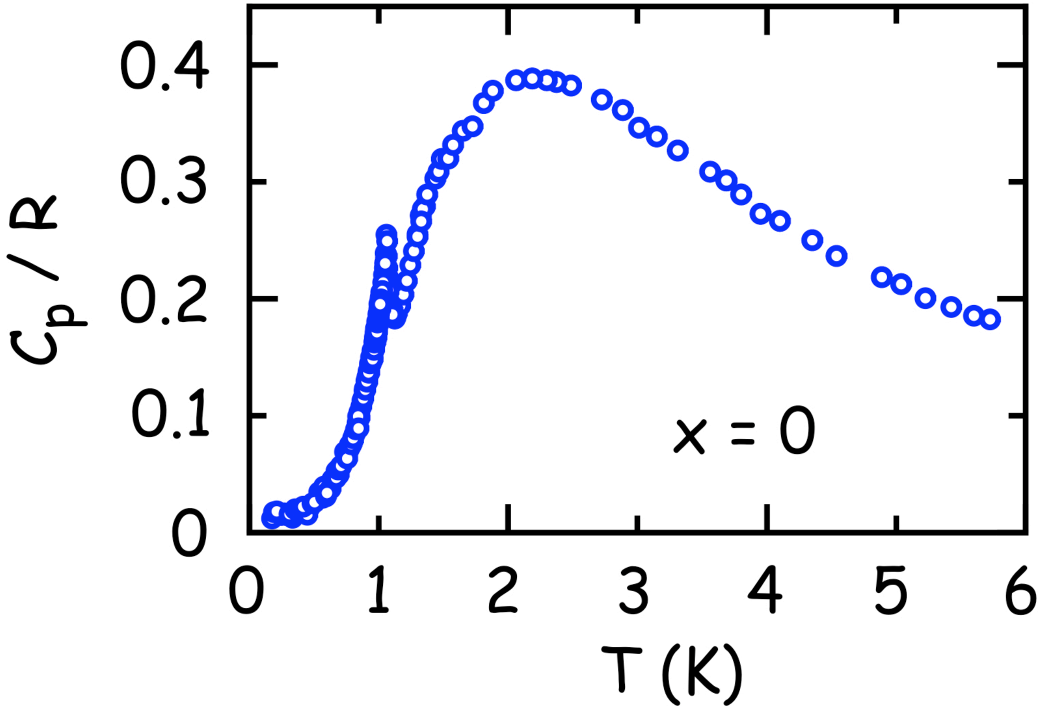


FIG. 5. Temperature dependence of the specific heat of $NdFeO_3$: ♦ experiment, Ref. 2; ○ experiment, Ref. 3; continuous curve—calculation, see the text. Inset; ● low-temperature data. (a) Hyperfine contribution calculated with H_{hf}=1 MOe, (b) spin-wave contribution, (c) mean-field model calculation.

Introduction: $NdFe_{1-x}Co_xO_3$

x=0



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Spin Hamiltonian for the Nd system

$$\mathcal{H} = -2\,\theta_c\,\gamma\,\hat{\mathbf{g}}_x \; -2\,\theta_p\,\chi\,\hat{\mathbf{c}}_y \; + g_y\,\mu_B\,H_{Fe\text{-}Nd}\hat{\mathbf{c}}_y \; -2\,\theta_c\,\gamma^2 \; -2\,\theta_p\chi^2$$

Self interaction terms

Fe-Nd Zeeman term (eff. exchange field)

Nd-Nd exchange of the polarized component

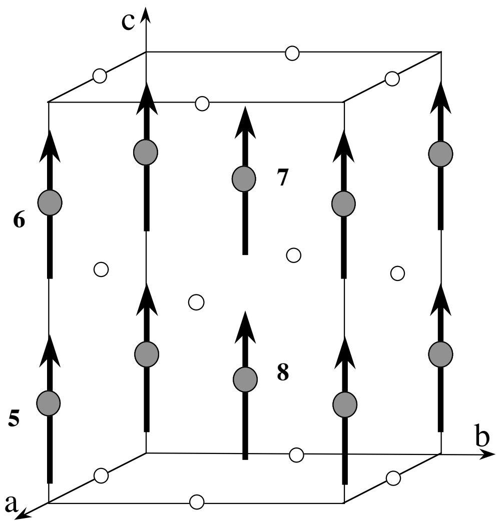
Nd-Nd exchange in cooperative mode

where...

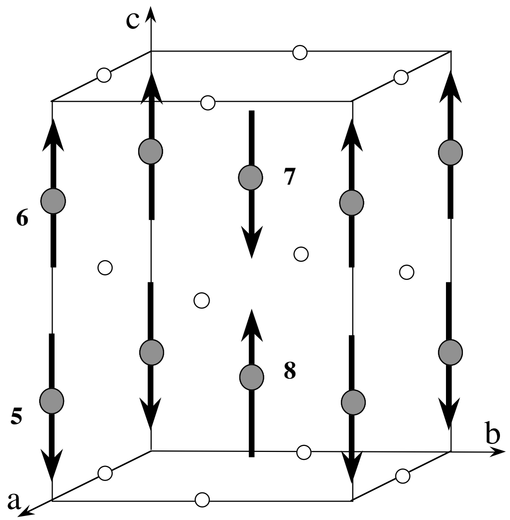
$\gamma = -\frac{1}{2}\langle\hat{\mathbf{g}}_x\rangle$ and $\chi = -\frac{1}{2}\langle\hat{\mathbf{c}}_y\rangle$ are mean field order parameters for the cooperative and induced modes

θ_c and θ_p are the Nd-Nd exchange constants in cooperative and polarized modes

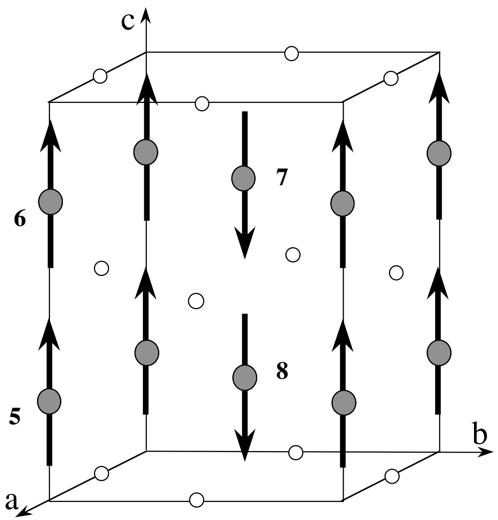
Antiferromagnetic Bertaut's modes



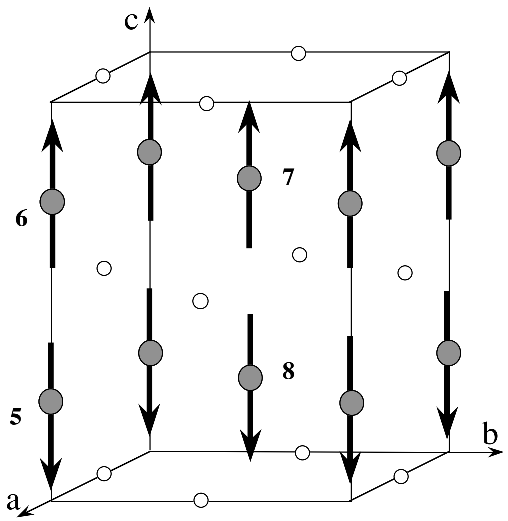
Modo f_z



Modo g_z



Modo c_z



Modo a_z

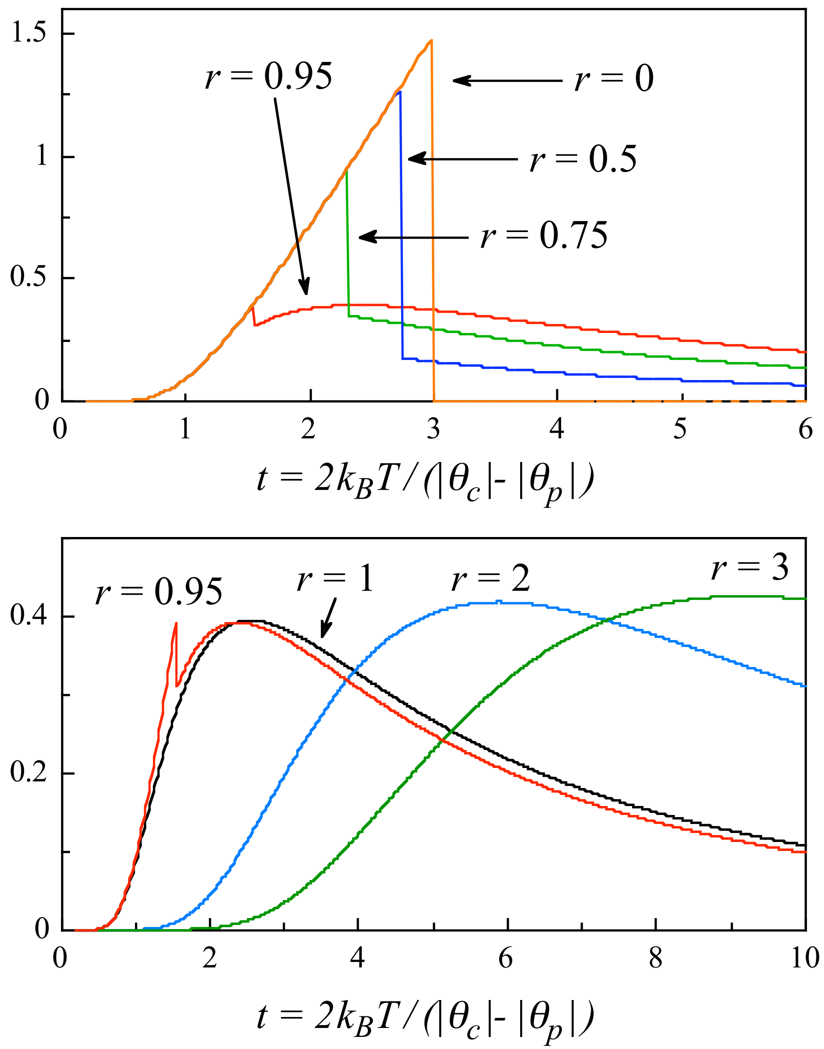
$$\hat{\mathbf{f}}_{M,R} = \hat{\mathbf{s}}_{1,5} + \hat{\mathbf{s}}_{2,6} + \hat{\mathbf{s}}_{3,7} + \hat{\mathbf{s}}_{4,8}$$

$$\hat{\mathbf{g}}_{M,R} = \hat{\mathbf{s}}_{1,5} - \hat{\mathbf{s}}_{2,6} + \hat{\mathbf{s}}_{3,7} - \hat{\mathbf{s}}_{4,8}$$

$$\hat{\mathbf{c}}_{M,R} = \hat{\mathbf{s}}_{1,5} + \hat{\mathbf{s}}_{2,6} - \hat{\mathbf{s}}_{3,7} - \hat{\mathbf{s}}_{4,8}$$

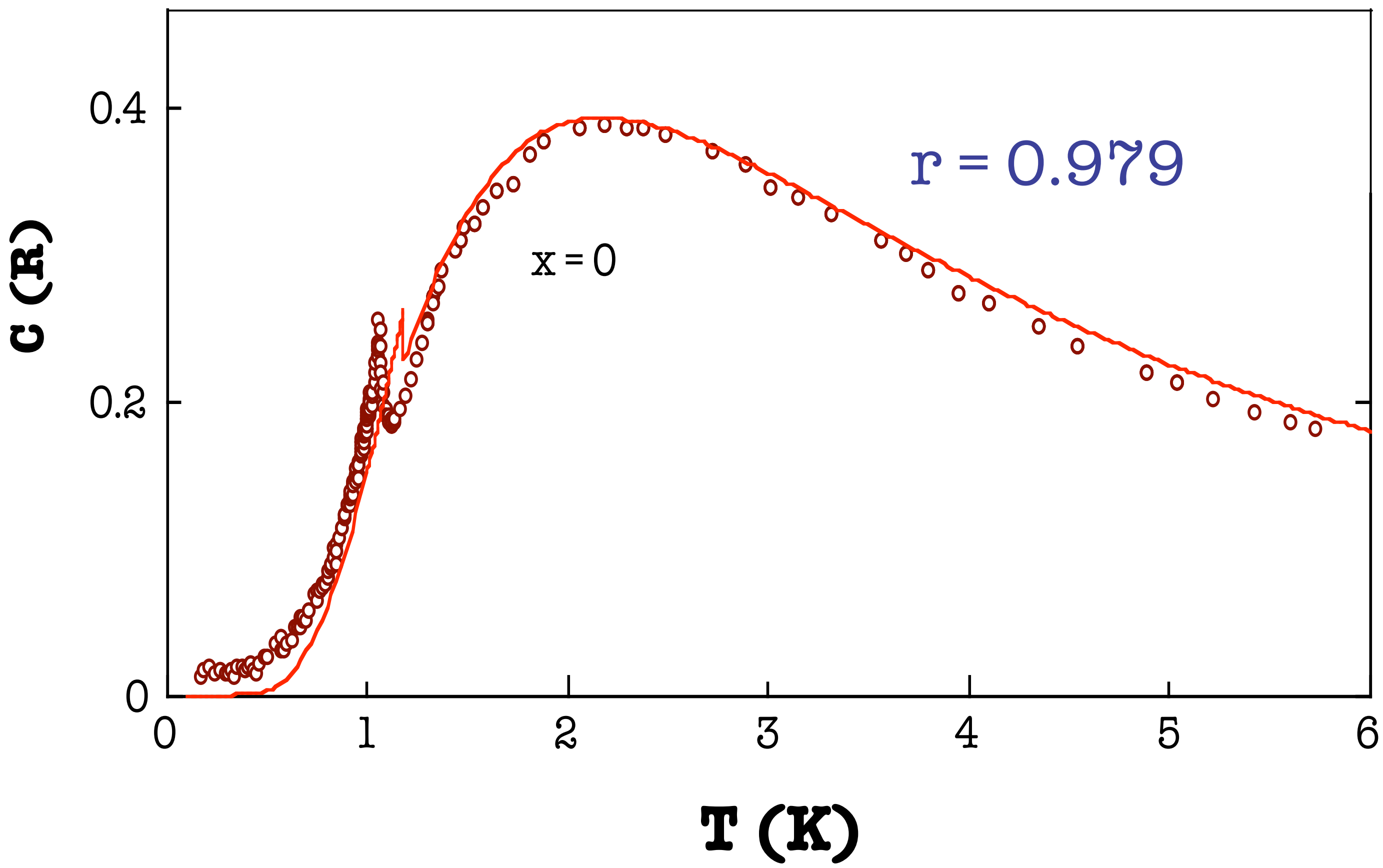
$$\hat{\mathbf{a}}_{M,R} = \hat{\mathbf{s}}_{1,5} - \hat{\mathbf{s}}_{2,6} - \hat{\mathbf{s}}_{3,7} + \hat{\mathbf{s}}_{4,8}$$

Mean-field Model results

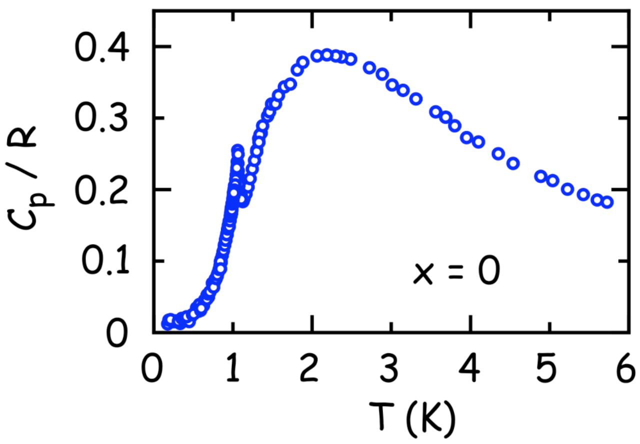


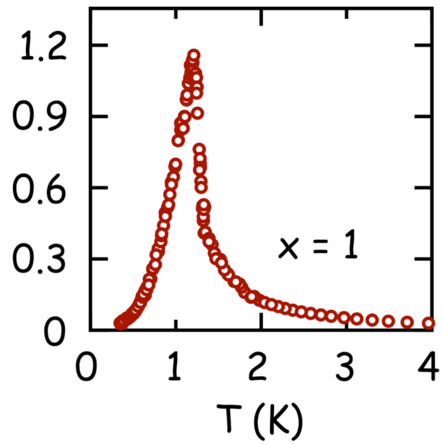
$$r = \frac{g_y \mu_B H_{Fe-Nd}}{2(|\theta_p| - |\theta_c|)}$$

x = 0, $NdFeO_3$

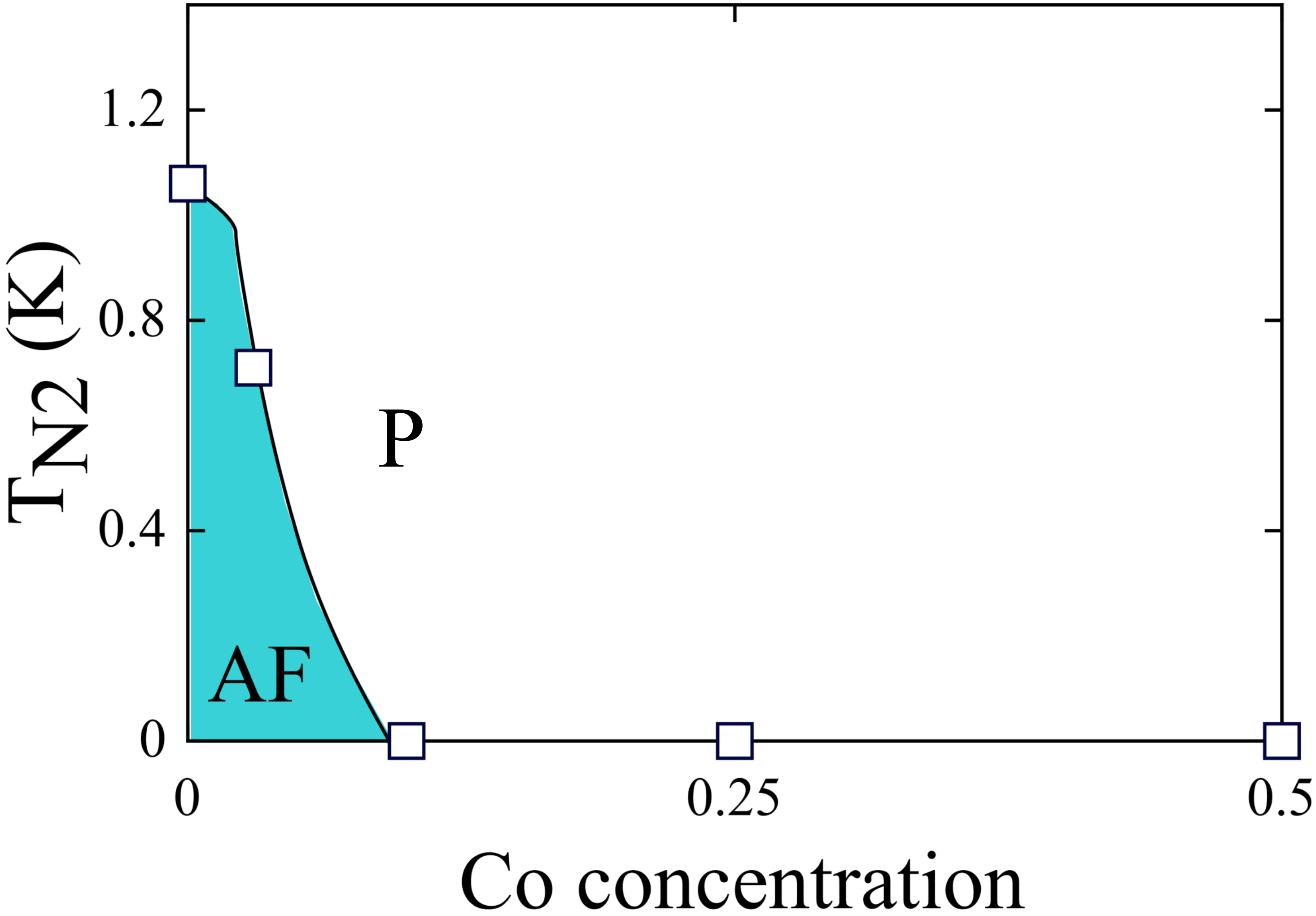


Specific heat resuts

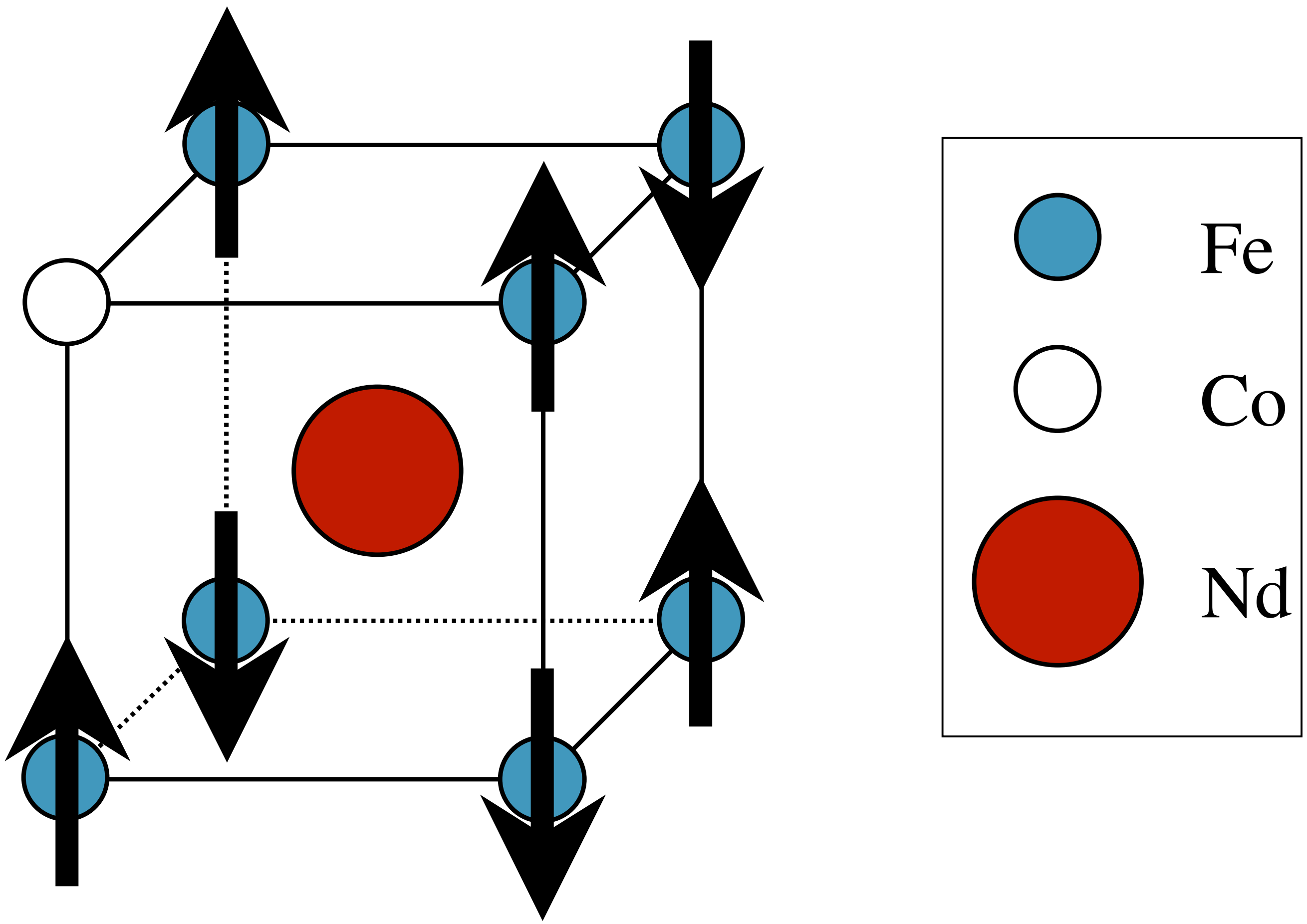




Nd Phase diagram



magnetic vacancies



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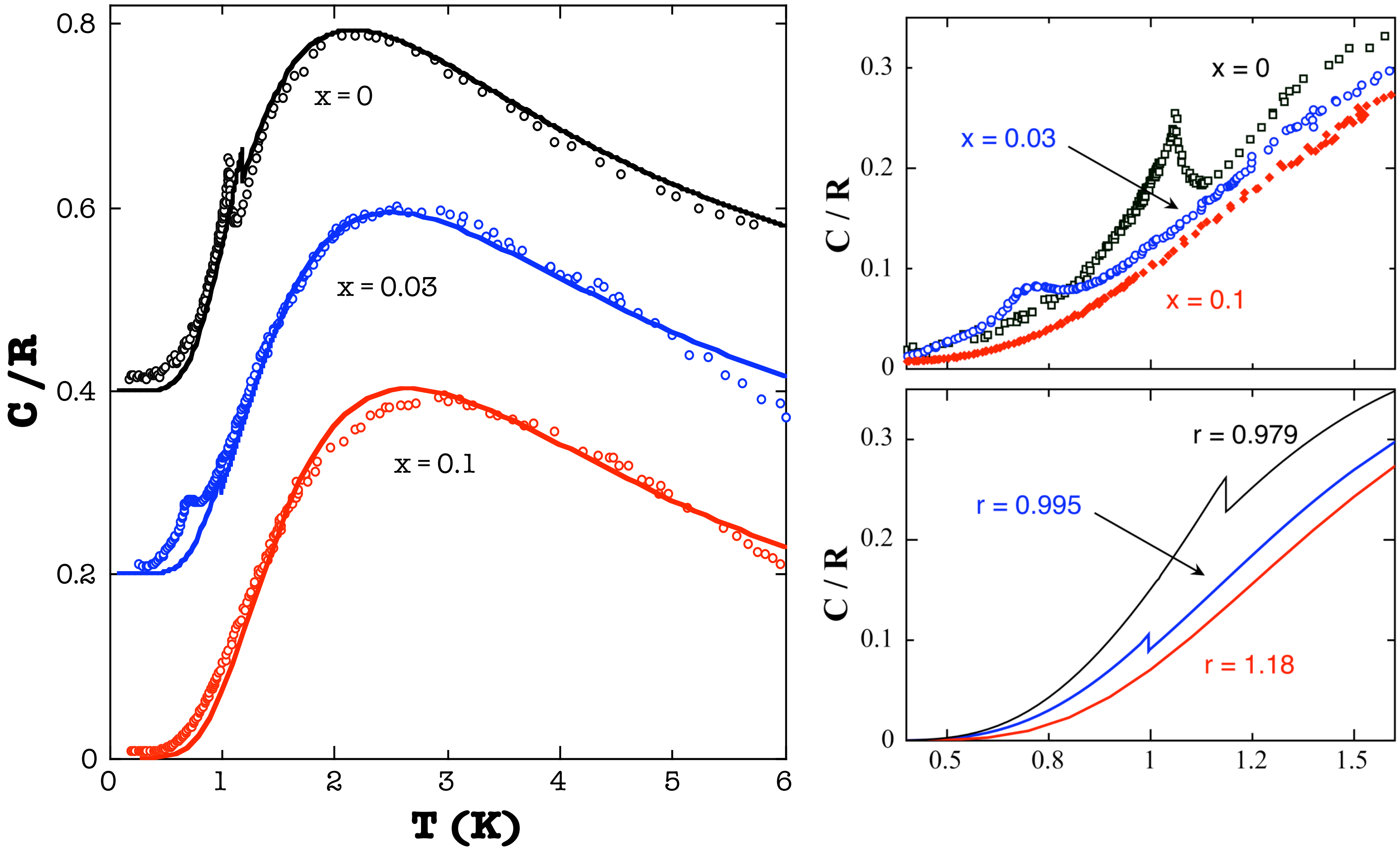
$$H_{eff} = \frac{z-2}{z}\,H_{Fe-Nd} + \eta\;H_{ex}\;c_y$$

$$\mathcal{F} = \frac{1}{2}\theta_c\gamma^2 + \frac{1}{2}\theta_p\chi^2 + (1-zx)\;T\ln\left[2\cosh\left(\frac{\Delta}{2T}\right)\right] + \frac{1}{2}\sum_{\eta=\pm1}(zx)\;T\ln\left[2\cosh\left(\frac{\Delta^{\pm}}{2T}\right)\right]$$

fits x ≤ 0



C / R
T (K)
x = 0
x = 0.03
x = 0.1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
C / R
x = 0
x = 0.03
x = 0.1
0.3
0.2
0.1
0
C / R
r = 0.979
r = 0.995
r = 1.18
0.3
0.2
0.1
0
0.5
0.8
1
1.2
1.5