INVESTIGATION OF MAGNETIC STRUCTURE IN R_2CuO_4 (R=La,Sr,Nd,Ce,Eu,Sm) BY POLARIZED NEUTRONS

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The magnetic properties of the R_2CuO_4 (with R = La,Nd,Ce,Th,Eu,Sm,Gd) system are of particular interest because of a possibility to clarify the potential role of magnetism as a mechanism for superconductivity [1—3]. In the present work we report the results of the polarized neutrons investigations of $La(Sr)_2CuO_4$, $Nd(Ce)_2CuO_4$, Eu_2CuO_4 and Sm_2CuO_4 single crystals.

All the measurements were carried out in the polarized neutron spectrometer of the inverse scattering geometry. The technique of full polarization analysis was used in the experiment. Spin-flip (SF) as well as non-spin-flip (NSF) intensities were measured for all three directions of polarization of incident neutrons $\vec{P}_\beta$ ($\beta = x,y,z$, where $\vec{z}$ is vertical axis, $\vec{x}$ is horizontal axis parallel to elastic scattering vector $\vec{q} = \vec{k} - \vec{k}'$, $\vec{y}$ is horizontal axis perpendicular to $\vec{x}$).

$La(Sr)_2CuO_4$

It is known that $La_2CuO_{4-\delta}$ undergoes an antiferromagnetic phase transition with the Neel temperature T_N depending strongly on the oxygen deficiency δ [1]. However, the existence of magnetic correlations in the doped La_2CuO_4 exhibiting superconducting properties is still under discussion.

The scan through the (100) Bragg point at 4.2 K in $La_2CuO_{4-\delta}$ confirms the existence of 3D antiferromagnetic order at which Cu spins are parallel to the $\vec{b}$ axis. The temperature dependence of this reflection gives the Neel temperature $T_N = 210\ K$.

According to ref. [1], the two dimensional magnetic order exists well above the Neel temperature. We have done the (h,0 —0.625) scan at room temperature. In the inverse scattering geometry it corresponds to

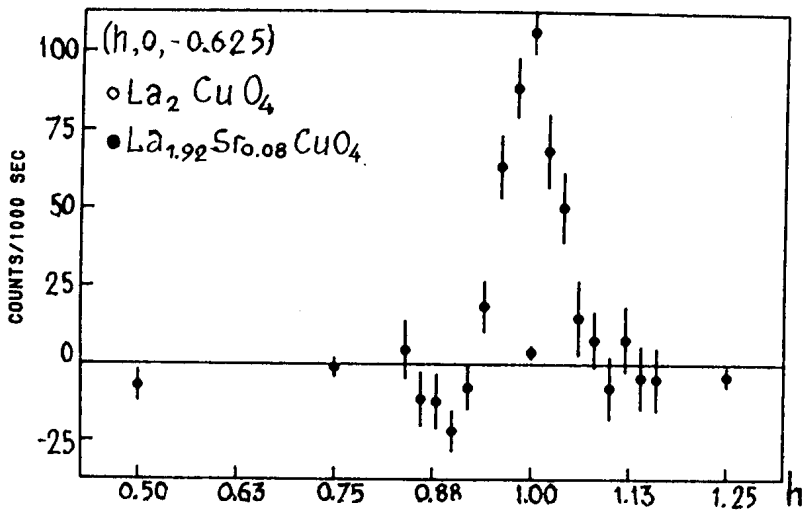

Fig.1. Pure magnetic scattering intensity in La_2CuO_4 at room temperature (open circles) and in $La_{1.92}Sr_{0.08}CuO_4$ at 4.2 *K* (closed circles)

the "focusing scan" (h,0,0.625), used in [1]. In our case $\vec{k}_0$ is parallel to the two-dimensional magnetic rod thus allowing to perform integration over energy from $-E_f$ to $(E_0 - E_f)$ while holding the 2D wave vector $\vec{Q}_{2D}$ constant. The magnetic origin of this scattering is also seen from fig.1, where pure magnetic part of intensity

$$I_m = I_x^{SF} + I_y^{SF} - 2I_z^{SF} = 2I_z^{NSF} - I_x^{NSF} - I_y^{NSF}$$

is shown.

The $La_{1.92}Sr_{0.08}CuO_4$ single crystal used in the experiment has the superconducting phase transition at $T_c = 9$ *K*. We have not found any evidence for 3D long range order by measuring neutron scattering around superlattice reflection (100) down to 4.2 *K*. Therefore we concentrated our efforts on the focusing (1, 0,—0.62) scans at 4.2 *K* and at room temperature for this crystal. Six nuclear reflections with different structure factors have been used to exclude the extinction effects and to reduce the results for La_2CuO_4 and $La_{1.92}Sr_{0.08}CuO_4$ to the same scale. The final results for the $La_{1.92}Sr_{0.08}CuO_4$ are shown in fig.1. It is seen that the magnetic intensity measured at 4.2 *K* was less than experimental errors. Similar results were obtained at room temperature.

Thus, the doping by Sr destroys 2D magnetic ordering of Cu drastically in superconducting $La_{1.92}Sr_{0.08}CuO_4$ single crystal.

$Nd(Ce)_2CuO_4$

In recent publications the existence of three successive magnetic phase transitions at $T_1 = 245(250)$ *K*, $T_2 = 75(80)$ *K*, and $T_3 = 30(40)$ *K* in Nd_2CuO_4 has been reported [2,3]. According to [2] the magnetic structures in phases 1.3 are similar to the structure of La_2NiO_4 and in phase 2 — to the structure of La_2CuO_4. These are the collinear structures which differ by the orientation of magnetic moments only. The moments are parallel to the $\vec{b}$ axis for the La_2CuO_4 and to the $\vec{a}$ one for the La_2NiO_4. (We use the orthorhombic unit cell $a < b < c$ for all R_2CuO_4 for convenience). However, since no distortion from tetragonal symmetry has been observed, another (non-collinear) magnetic structure has been proposed for Nd_2CuO_4 which may be constructed by superimposing the two collinear domains along c-axis [3]. We present some results of the polarized neutrons investigation of the magnetic structure and phase transitions in pure and doped Nd_2CuO_4.

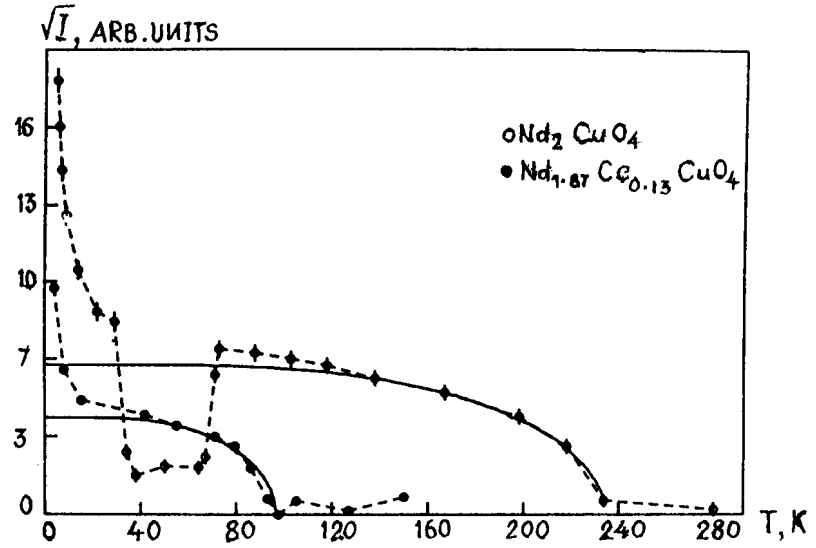

Fig.2. Temperature dependences of (103) reflections in Nd_2CuO_4 and $Nd_{1.87}Ce_{0.13}CuO_4$ (*b*). Solid curves represent fits to 1/2 Brillouin function

The samples used in the experiment were nonsuperconducting single crystals of Nd_2CuO_4 and $Nd_{1.87}Ce_{0.13}CuO_4$. The temperature dependences of the (101) reflection for these crystals were measured for all $\vec{P}_\beta$ [4]. The existence of successive phase transitions in Nd_2CuO_4 is clearly seen from fig.1. The changes of SF and NSF intensities show that the phase transitions at 75 *K* and 35 *K* are due to the spin-reorientation of the Cu magnetic moments. Polarization analysis shows that the rations of I_β^{SF} and I_β^{NSF} in the phases 1.3 are consistent with those for the La_2NiO_4 and for La_2CuO_4 in the phase 2 (in the case of balanced domain population). However the noncollinear model [3] also does not contradict to these ratios. Thus even polarized neutrons are unable to distinguish between the collinear and the noncollinear models. Comparison of the results for pure and doped samples shows (see fig.2) that the magnetic structure of the $Nd_{1.87}Ce_{0.13}CuO_4$ is the same as that of a Nd_2CuO_4 in the phase 1. It is also seen that Ce doping decreases the temperature of 3D ordering (to 90 *K*), the magnitude of the 3D magnetic moment of Cu ions and totally suppresses the spin reorientation transitions in $Nd_{1.87}Ce_{0.13}CuO_4$.

Eu_2CuO_4 and Sm_2CuO_4

Neutron scattering investigations of Eu and Ce compounds are rather difficult because of a high neutron absorption of Eu and Sm. Therefore the isotope substituting single crystals of $^{153}Eu_2CuO_4$ and $^{154}Sm_4CuO_4$ has been grown. The temperature dependencies of (10l)-type reflections were mesured. They give the Neel temperature $T_N \approx 250\ K$ for $^{153}Eu_2CuO_4$ and $T_N \approx 275\ K$ for $^{154}Sm_2CuO_4$. The ratio of the l-odd reflections to the even ones for both compounds, is similar and is typical for the La_2CuO structure. Thus the polarization analysis shows that the Cu moments order in Eu_2CuO_4 and Sm_2CuO_4 in the same way as in La_2CuO_4.However, as in the case of Nd_2CuO_4, we can't exclude as a possible magnetic structure of Eu_2CuO_4 and Sm_2CuO_4 a noncollinear one obtained by superimposing two collinear domains (of La_2CuO_4 type) along the c-axis, since no orthorhombic distortions have been found in Eu_2CuO_4 as well as in Sm_2CuO_4.

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