Magnetic Order and Superconductivity in Perovskites
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Summary

This thesis presents a study of the magnetic properties of Nd_{2-x}Ce_xCuO_4 compounds and of the vortex state in the superconducting Nd_{1.85}Ce_{0.15}CuO_4-δ compound. All investigations were performed on single-crystalline samples. In addition, this thesis includes the study of crystal growth and specific heat of the YVO_3 compound.

The single-crystalline Nd_{2-x}Ce_xCuO_4 samples with various doping levels of Ce (with \(x=0, 0.08, 0.13, 0.15\) and 0.20) were grown by the travelling solvent floating zone technique using a four-mirror furnace. The characterizations of the crystallinity as well as the compositions are presented in Chapter 2. The effect of Ce doping and oxygen reduction on the Nd_{2-x}Ce_xCuO_4 structure were analyzed on the basis of X-ray powder diffraction experiments. Upon increasing Ce doping the lattice constant \(c\) is decreased in both the as-grown as well as the as-reduced samples. The effect of Ce in the as-grown samples becomes most effective in compressing the reservoir block (the layer of Nd-O-Nd) at \(x=0.15\), resulting after oxygen reduction in the highest critical temperature of 21 K (with \(\Delta T_c \sim 1\) K) for this type of compound. The temperature dependence of the crystallographic structure shows an abrupt change in structure at \(T_c\). Below \(T_c\) the lattice parameters are nearly constant.

Chapter 3 presents a study of the magnetic properties of single-crystalline Nd_{2-x}Ce_xCuO_4. In this study, the crystalline electric field (CF) is used as a probe for the intrinsic properties of the system. A description of the CF interaction of Nd^{3+} in Nd_{2-x}Ce_xCuO_4 is presented. By using the infrared experimental data, a satisfying set of CF parameters is obtained. A recent infrared transmission study of the \(^4I_J\) (with \(J=9/2, 11/2, 13/2\) and 15/2) multiplets of Nd^{3+} in antiferromagnetic Nd_2CuO_4 single crystals has revealed a splitting of the Kramers doublets due to the exchange interaction between Nd and Cu of the order of a few cm\(^{-1}\). These splittings can be described by an effective anisotropic exchange Hamiltonian for the Nd^{3+} ion expressed in terms of single-electron spherical tensor operators up to the 6\(^{th}\) order, applicable to all levels of the 4f\(^{3+}\) configuration. A least squares fit of the eight observed splittings using six parameters provides a good description of the splittings. In the Ce doping case, two inequivalent sites of Nd^{3+} are observed by the infrared experiment, and correspondingly two sets of CF parameters are obtained. One set of CF parameter is found like in the undoped compound. These sites will be referred to as the unperturbed site while the new site that is affected by the Ce doping will be referred to as the disturbed site. Furthermore, the observation
of the Kramers doublet splitting at the unperturbed site up to 15 % Ce doping level indicates the persistence of antiferromagnetism in the CuO$_2$ planes. This result has clarified that the antiferromagnetic ordering in this compound is present up to the 15 % Ce doping level. A correlation between the inequivalent sites and the transport properties has suggested a kind of phase separation in this compound.

Chapter 4 presents a study of the vortex state in Nd$_{1.85}$Ce$_{0.15}$CuO$_{4-\delta}$. The characteristic lengths of this type-II superconductor are obtained by analyzing the reversible magnetization data using the Hao-Clem model. The result of this analysis yields a constant $\kappa$ value of 80 over the temperature range between 11.25 and 19 K. Additional parameters determined in this experiment include $H_{c2}(0) = (6.47 \pm 1.27) \times 10^5$ Oe, $\xi_{ab}(0) = (22.91 \pm 2.27)$ Å, $\lambda_{ab}(0) = (1651 \pm 181)$ Å in the dirty limit and $H_{c2}(0) = (6.79 \pm 1.33) \times 10^5$ Oe, $\xi_{ab}(0) = (22.36 \pm 2.21)$ Å, $\lambda_{ab}(0) = (1788 \pm 181)$ Å in the clean limit. The vortex state of this compound is investigated by the isothermal magnetic hysteresis and by the temperature dependence of the resistivity at various temperatures and magnetic fields. The results are summarized in a $H - T$ phase diagram. In addition to that, a more comprehensive phase diagram incorporating the region of the peak effect in this compound is also presented along with the results of an analysis based on existing models. It is shown that the effective penetration of the external magnetic field in the 3D vortex regime is a prerequisite to the transition from a quasilattice to a disordered glass vortex state which transition is associated with the occurrence of the peak effect. Comparison with previous results on similar samples further indicates a certain sample-dependent nature of the data. Finally, the vortex dynamics of a Nd$_{1.85}$Ce$_{0.15}$CuO$_{4-\delta}$ single crystal were investigated in terms of a magnetic relaxation process. The measurement of the time dependent magnetization was carried out in a magnetic field of 750 Oe applied parallel to the c-axis with temperatures varying between 5 and 17 K. This temperature range covers the second-peak region and extends below as well as above this region. The relaxation rates $S$, determined from the reverse-sweep and forward-sweep data, generally exhibit asymmetrical behaviors. Both feature narrow and shallow valleys that interrupt the otherwise monotonie rise of the curve. In particular, the forward-sweep data for $S(T)$ display an additional maximum somewhat similar to those found in BSCCO and TBCCO. The data are further analyzed on the basis of a collective flux creep model. The results show a crossover from a "rigid" to a "soft" vortex glass as we move from the lower to the higher temperature regimes of the peak effect.

The last chapter of this thesis describes the preparation and characterizations of single-crystalline YVO$_3$ grown by the TSFZ technique. The thermal properties in this compound are investigated by specific heat measurements. The specific heat results reveal three transitions, around 75 K, 115 K and 200 K. All of the transition correspond to the previous studies of the magnetic properties as well as of the crystallographic structure. The transitions around 115 K and 200 K show that the phase transition is
of the second-order type, whereas around 75 K, unusual features of the specific heat are found. These unusual features are attributed to the effect of a large change in the volume around $T_g$ resulting in problem with the contact between the sample and the sample holder/plate. The specific heat data are analyzed in terms of a lattice contribution, a Schottky contribution and an excess magnetic contribution at high temperature. The magnetic contribution well above the magnetic ordering temperature is ascribed to short range interactions due to the presence of strong magnetocrystalline anisotropy. The magnetic entropy considered by using this approach is 8.38 J/mole K which is close to the theoretical estimate for the $S = 1$ system.
The vortex state of the compound is observed by the magnetic moment alignment and by the temperature dependence of the magnetic properties. The vortex state is shown in the 3D vortex state proposed to be the counterpart of a vortex state in superconducting crystals. The vortex state is consistent with the theory of the vortex structure in superconducting materials. The examination of the temperature-dependent magnetic structure in a magnetic field of 7 Tesla again reveals the presence of temperature variation between 3 and 4 K. This temperature-range covers the vortex-core region and extends below as well as above this range. The examination shows a similar magnetic structure and temperature-dependent properties in the lower and higher temperatures. The results also indicate a transition from a "rigid" to a "soft" vortex phase as the temperature drops below the lower temperature regime of the peak effect.

The next chapter of the thesis describes the magnetization and temperature-dependent magnetic properties of single-crystalline YVO₄ sample by the VSM technique. The thermal dependence of this compound are investigated by specific heat measurements. The specific heat results reveal a peak temperature around 30 K, 33 K and 300 K. All of the transition temperatures show a broader peak of the magnetic properties as well as the crystalline properties. The transition around 33 K and 300 K shows that the YVO₄ compound in