Quantum Phase Transitions in CoCl$_2$ salts, and the Nature of the Co-existance of Magnetism and Superconductivity in Y$_9$Co$_7$ and La$_{2-x}$Sr$_x$CuO$_{4+y}$ - DTU Orbit (15/05/2019)

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In this thesis I present two studies of magnetism. First, I present a study of a transverse field quantum phase transition in the quasi-Ising antiferromagnetic CoCl$_2$ salts. Second, I present various studies of phase separation between magnetic and superconducting regions, in the low temperature superconductor Y$_9$Co$_7$ and in high temperature superconductors with chemical formula La$_{2-x}$Sr$_x$CuO$_{4+y}$.

In the first part of this thesis Neutron scattering is used to study the quasi-Ising antiferromagnet CoCl$_2$·2D$_2$O. As a consequence of crystal field and spin-orbit effects in the monoclinic crystal structure of CoCl$_2$·2D$_2$O, its low-temperature magnetic properties can be considered to approximate an effective $S=1/2$ model with anisotropic, primarily Ising-like, exchange interactions and anisotropic $g$-factors. The dominant interactions are ferromagnetic and couple nearest neighbor spins forming chains. Weaker interchain interactions give rise to commensurate antiferromagnetic order below $T_N = 17.2$K. Theory predicts that the spin wave excitation spectrum of Ising magnets softens as a magnetic field is applied transverse to the preferred spin direction. This has been observed in the three-dimensional dipolar coupled ferromagnet LiHoF$_4$ and in CoNb$_2$O$_6$, which like CoCl$_2$·2D$_2$O consists of weakly coupled ferromagnetic Ising-like chains. Comparing CoCl$_2$·2D$_2$O to CoNb$_2$O$_6$ one might expect some similarities in the excitation spectra. However, different ratios of interchain to intrachain interactions and different degrees of deviation from the ideal Ising spin Hamiltonian, can also be expected to modify the spin waves.

We provide evidence that the spin wave mode indeed softens at $\mu_0H_c$, and spin excitations reappear at field larger than $\mu_0H_c$. Our findings are compared with RPA theory that reaches excellent agreement with our data. These studies indicate that CoCl$_2$: 2D$_2$O shares more characteristics with an anisotropic Heisenberg magnet in transverse field than the pure Ising model. We have also addressed the possibility to lower the critical field by chemically substitute NH$_3$ for H$_2$O in CoCl$_2$ salts, in order to search for optimal experimental conditions within a certain class of materials using density functional theory.

The second part of this thesis is subdivided into three separate studies, all focusing on phase separation in superconductors. In the first part I present a muon spin rotation study of the magnetic properties of Y$_9$Co$_7$ - an example of a system displaying evidence for weak itinerant ferromagnetism and low temperature i.e. phonon driven superconductivity. With the highest quality sample available, our results provide evidence that the sample phase separates on a length scale of more than 30 $\text{Å}$. Phase separation on this length scale or larger is also observed in the superoxygenated Lanthanum based hightemperature superconductor La$_2$-xSr$_x$CuO$_{4+y}$ which separates into an incommensurate magnetic phase similar to the so-called '1/8' stripe phase observed in other Lanthanumbased cuprate compounds such as La$_{1.88}$Sr$_{0.12}$CuO$_4$ and La$_{1.48}$Nd$_{0.4}$Sr$_{0.12}$CuO$_4$, and a superconducting phase similar to optimally doped La$_2$-xSr$_x$CuO$_4$. We are able to extract the magnetic transition temperature, the superconducting transitions temperature and respective volume fraction of the magnetic and superconducting regions. Using transverse field muon spin rotation, we present an analysis which is consistent with previously published results but in addition, we extract the penetration depth which allows for a direct comparison of the superconducting phase in these samples and with other superconductors. We find very similar values regardless of Strontium doping in La$_2$-xSr$_x$CuO$_{4+y}$. Finally, we have combined zero field and transverse field muon spin rotation with neutron spin echo spectroscopy to study the spin freezing process in oxygen-stoichiometric La$_{1.88}$Sr$_{0.12}$CuO$_4$ which does not phase separate on a length scale visible to the muon spin rotation technique. In this compound the onset temperature of incommensurate magnetic order is dependent on the time scale of the experimental technique used to probe it. Using the ultra-high resolution of the spin echo technique, we present measurements of the quasi-elastic energy width of an incommensurate Bragg peak in La$_{1.88}$Sr$_{0.12}$CuO$_4$. Our results on La$_{1.88}$Sr$_{0.12}$CuO$_4$ illustrate the complementary aspects of the local probe of muon spin rotation and neutron scattering.

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