Neutron scattering: A unique microscopic probe to study magnetism

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1) Basic Principles and Methods

The fundamental properties of the neutron are briefly introduced and the basic concepts of neutron scattering as an energy- and momentum-dependent probe to study solids are mentioned. Focusing mainly on the magnetic interaction of neutrons with unpaired electrons the cross section for magnetic neutron scattering is presented and its characteristics are discussed. The main material-dependent factor in the cross section, the spin correlation function, makes magnetic neutron scattering a unique microscopic tool to study the static and dynamic magnetic properties of matter on an atomic scale. Here, the spin correlation function is related to the generalized susceptibility using linear-response theory. Simple examples concerning magnetic neutron diffraction and inelastic scattering are presented: paramagnetism, ferromagnetism and commensurate antiferromagnetism as well as magnetic excitations including spin waves.

2) Magnetic Order and (Critical) Spin Dynamics in Strongly Correlated Electron Systems

Strongly correlated electron systems, mostly rare-earth based intermetallic compound, display a rich variety of different ground states, such as magnetically ordered, paramagnetic or superconducting. Since their ground state can be tuned by e.g. pressure, composition or magnetic field, even a $T = 0$ magnetic instability, a quantum critical point, with exciting new properties can be reached. Elastic and inelastic neutron scattering can help to identify the magnetic order, the quantum critical spin fluctuations in these systems and can give new information on the unconventional superconductivity occurring in some of the compounds. The capabilities of neutron scattering for such studies will be given.

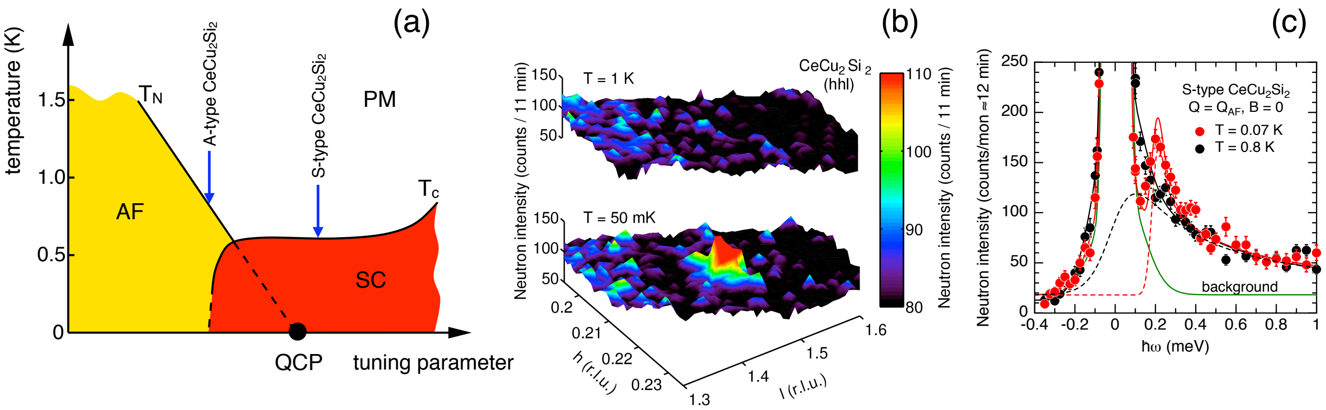

Figure 1: (a) Schematic phase diagram of a quantum critical point (QCP) showing the vicinity of $CeCu_2Si_2$ to quantum criticality with the appearance of unconventional superconductivity around the magnetic instability. (b) Intensity map of reciprocal space across the position of an antiferromagnetic superstructure peak in A-type $CeCu_2Si_2$. (c) Magnetic response in the superconducting state (at $T = 0.07\,K$) and the normal state (at $T = 0.8\,K$) of $CeCu_2Si_2$ indicating a spin excitation gap in the superconducting state (after [1, 2]).

[1] O. Stockert, E. Faulhaber, G. Zwicknagl, N. Stüßer, H. S. Jeevan, M. Deppe, R. Borth, R. Küchler, M. Loewenhaupt, C. Geibel, and F. Steglich, Phys. Rev. Lett. **92**, 136401 (2004).

[2] O. Stockert, J. Arndt, E. Faulhaber, C. Geibel, H. S. Jeevan, S. Kirchner, M. Loewenhaupt, K. Schmalzl, W. Schmidt, Q. Si, and F. Steglich, Nat. Phys. **7**, 119 (2011).