Magnetism and Superconductivity in EuFe$_2$(As$_{1-x}$P$_x$)$_2$

single crystals with $x = 0.13$, 0.19 and 0.28

studied by μSR and $^{57}$Fe Mössbauer spectroscopy

Til Gottz¹, Sirko Kamusella¹, Hirale S. Jeevan⁴, Philipp Gegenwart⁵,⁶, Hubertus Luetkens⁷, Johannes Spehl⁷, Rajib Sarkar⁵ and Hans-Henning Klaüß¹

¹ Technical University Dresden, Institute of Solid State Physics, Germany
² IFP, Physik. Institut, Georg-Auguste-Universität Göttingen, Germany
³ Experimental Physics VI, Center for Electronic correlations and magnetism, University of Augsburg, Germany
⁴ Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, Villigen, Switzerland

Introduction

The interplay of magnetism and superconductivity is one of the central topics in the contemporary studies on fermiopnictides. Of particular interest within the AFe$_2$As$_2$ compounds [1-3] is the EuFe$_2$(As$_{1-x}$P$_x$)$_2$ system because of two reasons: Firstly, the substitution of As by P is (nomially) inert but the superconductivity is not induced by charge carriers and secondly, it contains a magnetic rare earth element on the A-site. Previous studies reported that the Fe AFM ordering and the accompanying structural transition from tetragonal to orthorhombic is suppressed upon P substitution and eventually vanishes prior to the appearance of a superconducting dome [4-7]. In contrast, pressure studies demonstrated the presence of a precursor structure and Fe AFM transition above $T_{N}$, between $p = 0.4$ and 0.8 GPa [8,9] but conclude that the SDW ground state is differentially affected by x and p. Only recently, Nandi et al. [10] showed the existence of a small but finite orthorhombic splitting reminiscent of weak Fe ordering [11] below 50K in a superconducting $T_c$(x=25K) single crystal with $x = 0.15$ at ambient conditions.

Up to now, no comprehensive microscopic study of the $T$-$x$ electronic phase diagram on single crystals without any explicit symmetry-breaking forces is available. In view of this gap, this work was carried out and emphasizes further microscopic studies of single crystals EuFe$_2$(As$_{1-x}$P$_x$)$_2$ in the full temperature range to confirm our findings and improve the understanding of the superconductivity (Tc>Tc') Fe order and its possible importance for the appearance of superconductivity. Our ZF-μSR data for x=0.13 is not conclusive because of insufficient sample mass (~10mg) and therefore not shown here.

- static Fe order below 115K and 95K
- gradual increase of the magnetic volume fraction
- static ferromagnetic Eu order below 20 K
- interplay of Fe and Eu magnetic sublattices
- corexistence of AFM Fe magnetism and superconductivity
- enhanced spin dynamics

EuFe$_2$(As$_{1-x}$P$_x$)$_2$ single crystal phase diagram

Our experiments evidence (weak) Fe magnetism for all three investigated samples with x=0.13, 0.19 and 0.28. The Fe AFM magnetic volume fraction is related to the number of iron atoms which are surrounded only by As atoms, given by the proportionality factor (1-x). Our interpretation is that short range Fe order on the atomic length scale persists for x=0.13 (calculated from the percolation threshold (1-x)=0.5). Due to the gradual increase of the magnetic volume fraction as a function of temperature macroscopic probes such as resistivity or specific heat might not display pronounced anomalies. This interpretation is consistent with results of a recent muon spin relaxation study on powdered EuFe$_2$(As$_{1-x}$P$_x$)$_2$ by Gugucuha et al. [9] who showed that for x=0.20 a disordred SDW phase precedes the coherent Fe AFM order observed for x=0.12.

Compilation of main results for x=0.13 and x=0.19

Compilation of main results for x=0.28

This work was financially supported by the German Research Foundation (DFG) within priority program SPP 1488 (projects KL 1586/10-1 and Gt 1644/2-2) and the research training group GRK 1621. Rajib Sarcar thanks for funding within Grant No. SA 2426/1-1.

References and Acknowledgements