Experimental report

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Council: 10/2014

Title: Probing magnetic phase separation at a metal-insulator transition

Research area: Physics

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Main proposer: **Mark LAVER**

Experimental team: Gabrielle BEAUDIN
Stavros SAMOTHRAKITIS
Robert ARNOLD
Mark LAVER

Local contacts: Robert CUBITT

Samples: EuB_6

Instrument	Requested days	Allocated days	From	To
D22	4	0		
D11	4	4	23/07/2015	27/07/2015
D33	4	0		

Abstract:

We aim to complete previous measurements at the ILL on the semimetal EuB_6.
Our study will provide the first direct evidence of the magnetic polarons thought to underpin the colossal magnetoresistance effect in this compound. Using a magnetic field to tune the percolation transition, we will characterise the sizes and temperature-dependent behaviour of the polarons across the transition.

Evidence of Magnetic Polarons in EuB_6

M. Laver[1], R. Arnold[1], S. Samothrakitis[1], G. Beaudin[2,3], A. D. Bianchi[2,3], J. L. Gavilano[5], M. Kenzelmann[6], R. Cubitt [7], and C. Dewhurst[7]

[1]School of Metallurgy and Materials, University of Birmingham, Birmingham, B15 2TT, UK
[2]Université de Montréal, Montréal, Canada
[3]Regroupement Québécois sur les Matériaux de Pointe (RQMP)
[4]Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut, Villigen, Switzerland
[5]Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, Villigen, Switzerland
[6] Laboratory for Scientific Developments and Novel Materials, Paul Scherrer Institut, Villigen, Switzerland
[7]Large Scale Structures Group, Institut Laue Langevin, Grenoble, France

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The physics of the ferromagnetic semi-metal EuB_6 remains a subject of controversy, despite extensive experimental efforts in the last decades. Ferromagnetism emerges in this material from a semi-metal state via two phase transitions at T_M = 15.5 K and T_C = 12.6 K as the temperature is decreased [1]. The phase transitions come along with an order-of-magnitude drop in the electrical resistivity. Various experimental techniques, such as resistivity and magnetization [1,2], muon spin rotation [3], non-linear Hall effect [4] and fluctuation spectroscopy [5] support a scenario, where the state in the temperature range $T_C <$ T is understood as an electronic phase separation with randomly distributed ferromagnetic spin clusters (magnetic polarons), surrounded by a poorly conducting matrix. It is believed that the spin clusters form well above the ferromagnetic transition and grow in size as the temperature is decreased. T_M is associated with percolation of the spin clusters, before the material enters a long-range ordered ferromagnetic state.

Small-angle neutron scattering (SANS) was employed to study the ferromagnetic spin clusters in EuB_6, due to its sensitivity to the magnetization contrast in the mesoscopic range. The aim of these experiments was to determine the T-dependent correlation length of the short-range ferromagnetic fluctuations, i.e., the size of the proposed magnetic polarons in EuB_6. Anomalies in the scattered intensity I(q) as a function of transferred momentum q are expected from well-defined spin clusters. Such an approach was earlier successfully used to study polarons in manganites [6].

Measurements on D11 were carried out with a mosaic of co-aligned EuB6 single crystals, which were polished to a thickness of less than 380 μm. ^{11}B was used in the crystal synthesis to reduce the absorption of neutrons. The sample was cooled by a 7 T horizontal-field cryomagnet with $\mathbf{n}$ || [1 0 0], where $\mathbf{n}$ is the direction of the neutron beam. The magnetic field direction $\mathbf{H}$ was aligned perpendicular to $\mathbf{n}$.

At first, the instrument was set up in a medium-q configuration with a neutron wave-length of λ = 4.6 Å, 10.5 m collimation and 10.5 m sample-detector distance to reproduce the SANS-I data. However, the large neutron absorption, primarily of europium, resulted in very long counting times for the different q-ranges [multiple datasets are needed for a complete I(q)]. We continued taking data with zero field applied. We then went on to use the magnetic field. We then proceeded to apply a magnetic field, measuring the medium-q region at 0.25 T, 0.5 T and 0.9 T(Figure 1). We also tried the very low q region with an applied field of 0.5 T, but the results were not conclusive. The data were then analyzed and we were able to retrived a correlation length for the magnetic polarons.

A promising route for future SANS experiments on EuB6 may be to measure the scattering from the ferromagnetic spin clusters in the presence of calcium doping[7]. It wouldbe interesting to measure the correlation length of the magnetic polarons in this system and compare it to the undoped one.

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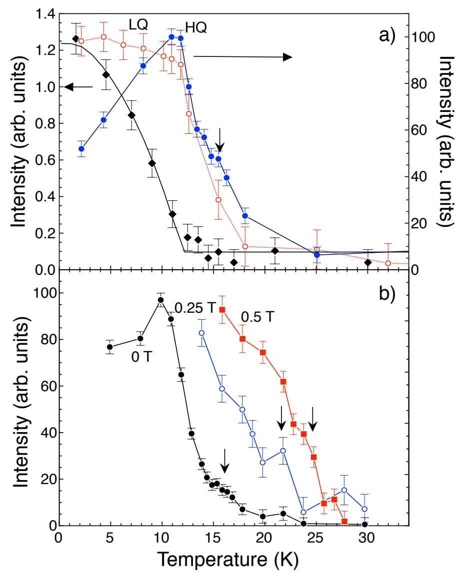

Figure 1: Integrated intensity for various ranges of wave vector q. **a)** The solid black diamonds show the integrated intensity of an anomalous featue observed in the low q region. This solid line is a fit a Brillouin function squared. The solid blue circles are the data from the high q- regime (HQ) averaged over the range from 0.050 to $0.140\,\text{Å}^{-1}$. The open red circles are the average over the low q regime (LQ) from 0.006 to $0.025\,\text{Å}^{-1}$. Data is taken in zero field. **b)** The data are averaged over the medium q- regime in the range 0.020 to $0.055\,\text{Å}^{-1}$(MQ). The full black circles show the zero field data, the open blue circles are taken with an applied field of 250 mT and the full red squares with 500 mT. The black arrows indicate the positions of T_{M}.