Experimental report

02/02/2016

Proposal:	**7-02-162**	**Council:**	4/2015
Title:	Low-energy fluctuations on approaching the structural quantum critical point in Lu(Pt_(1-x)Pd_x)_2In		
Research area:	Physics		

This proposal is a continuation of 7-02-148

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Samples: Lu(Pt,Pd)2In

Instrument	Requested days	Allocated days	From	To
IN6	5	5	28/10/2015	02/11/2015

Abstract:

Quantum critical points (QCPs) are second order phase transitions that occur at T=0; they involve unusual critical fluctuations, which give rise to interesting phenomena such as unconventional superconductivity and non Fermi-liquid behaviour. So far QCPs have mostly been studied for magnetic phase transitions.

Recently, we have discovered that the phase diagram of the substitution series Lu(PtPd)2In shows a QCP of a structural phase transition, from a cubic Heusler to a cubic superstructure phase. We observe superconductivity with the highest transition temperature at the QCP, suggesting a link between the unusual critical fluctuations and the appearance of superconductivity.

We have previously measured inelastic neutron scattering at IN4 and IN6, where we observed enhanced fluctuations at the transition temperature in LuPt2In. They appear below 1-2 meV at the superstructure Bragg peak, while other energy and momentum transfers are unaffected by both Pd substitution and temperature. Now we propose to study these unusual fluctuations for other samples of the substitution series, closer to the QCP, using the cold neutron spectrometer IN6.

Low-energy fluctuations on approaching the structural quantum critical point in $Lu(Pt_{1-x}Pd_x)_2In$ (Proposal 7-02-162)

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Quantum critical phenomena are still intensively investigated in condensed matter physics. The low-energy fluctuations occurring in the vicinity of a quantum critical point (QCP), i.e. a continuous phase transition at absolute zero temperature, are thought to be the origin of exotic phases showing up close to the QCP. Phenomena like superconductivity, metamagnetism or non-Fermi-liquid behavior are often observed in the quantum critical regime. Up to now, these effects were theoretically described and experimentally investigated mainly in magnetic systems. Since there are not many materials known, which exhibit a structural quantum phase transition, the related quantum critical effects are not well known. A promising material to study the effect of low-energy quantum fluctuations in the vicinity of a structural QCP is the substitution series $Lu(Pt_{1-x}Pd_x)_2In$. Thermodynamic measurements revealed a continuous suppression of the structural phase transition from $T_s = 490\,K$ in pure $LuPt_2In$ to $T_s = 0$ at a critical Pd concentration of about 55 %. Thereby the system undergoes a Peierls transition from a cubic Heusler structure above T_s towards a cubic superstructure below T_s. Furthermore the system becomes superconducting below $T_c \approx 1\,K$ and shows a clear enhancement of T_c just in the vicinity of the QCP. Thermodynamic measurements like resistivity or specific heat indicate an enhanced electron-phonon coupling around the QCP, which might support the evolution of superconductivity.

In a previous experiment performed at IN4 and IN6 (see experimental report of proposal 7-02-148) powder samples of $LuPt_2In$, $LuPd_2In$ and $Lu(Pt_{0.45}Pd_{0.55})_2In$ had been investigated. In $LuPt_2In$ a clear enhancement of low-energy fluctuations around the structural phase transition at $T_s = 490\,K$ were observed compared to the spectra at $T = 430\,K$ and $T = 550\,K$. For the sample with the critical Pd concentration of 55 %, where critical fluctuations were expected close to $T = 0$, none could be observed. The previous experiment was hampered by a strong background signal at positive energy transfers and no signal on negative energy transfers due to the Bose factor, which avoided the observation of possible fluctuations.

In this experiment we avoided scattering from the orange cryostat by attaching cadmium also on the backside of the sample holder, which clearly reduced the background signal. We used the same experimental setup on IN6 as for the previous experiment, i.e. we measured at a neutron wave length of 4.14 Å in reflection mode. To study the evolution of critical fluctuations towards the QCP, we prepared powder samples with 40, 50 and 52 % Pd content. To find out the correct transition temperature (T_s was roughly estimated from resistivity measurements before) and to see, how the intensity of the superstructure peak at $Q = 2.45\,\text{Å}^{-1}$ develops, each sample has been measured during the cooling process down to 1.5 K for about 15 hours. For Pd concentrations of 50 and 52 % the evolution of a superstructure peak was hardly visible. Even at lowest temperatures of 1.5 K the superstructure peak was only very weak and it was impossible to find out a precise transition temperature, which was important for the further study of the evolution of fluctuations. That's why we concentrated on the sample with 40 % Pd content to investigate the inelastic response because there the intensity of the superstructure peak was large enough for a good estimation of the transition temperature. In Fig. 1 the temperature dependence of the elastic intensity of $Lu(Pt_{0.6}Pd_{0.4})_2In$ is shown. The intensity increases linearly below $T_s \approx 145\,K$, which yields a critical exponent $\beta \approx 0.5$ in this case, describing a mean-field like phase transition. In contrast to that, we observed a value of $\beta \approx 0.25$ in $LuPt_2In$ in our previous experiment. The reason for this change is not clear. In general the superstructure intensity does not seem to saturate in $Lu(Pt_{0.6}Pd_{0.4})_2In$ at lowest temperatures and its width is roughly twice as large as in $LuPt_2In$. This might indicate, that the formation of the superstructure is more on a dynamic level closer to the QCP than on a static level.

To investigate the evolution of critical fluctuations around the phase transition, we measured spectra in steps of 10 K around T_s, most of them for 6 hours. Fig. 1 shows inelastic spectra of selected temperatures around the estimated phase transition. Unfortunately we could not clearly observe any increased low-energy excitations in a temperature regime between 90 and 230 K. Currently, we are further analyzing the inelastic spectra to see, if weak anomalies are present near the structural transition, which so far have been missed.

Additionally, to get a better insight in what is really happening with the dispersion of the phonons in $Lu(Pt_{1-x}Pd_x)_2In$ and especially how the phonon softening occurs close to the structural QCP, we are going to grow single crystalline samples for further investigations. The better sample quality of single crystals and the possibility of studying the phonon dispersion should definitely help to follow the evolution of low-energy fluctuations on approaching a structural QCP and to find out, how they are related to the enhancement of superconductivity.

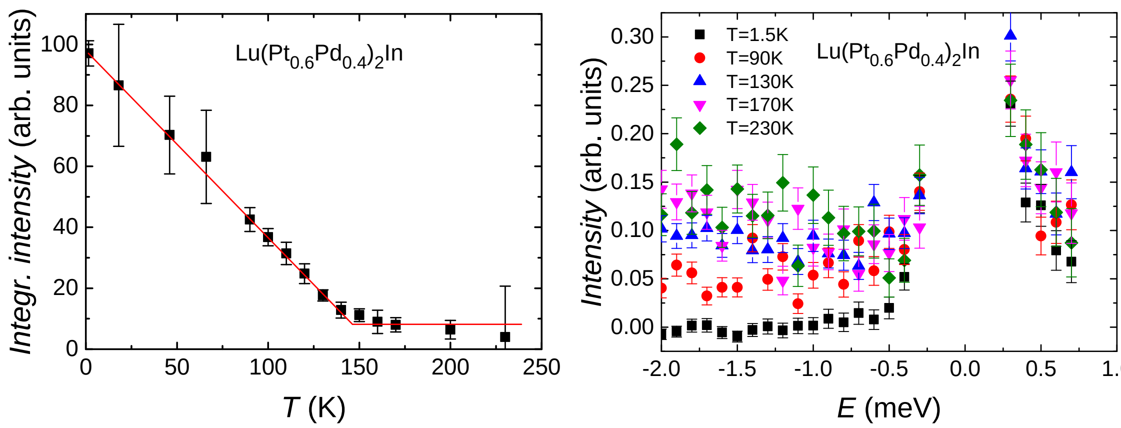

Figure 1: *Left:* Integrated intensity of the superstructure peak at $Q = 2.45\,\text{Å}^{-1}$ in $Lu(Pt_{0.6}Pd_{0.4})_2In$. The red line shows the linear temperature dependence of the superstructure intensity leading to a critical exponent $\beta \approx 0.5$. *Right:* Inelastic response of $Lu(Pt_{0.6}Pd_{0.4})_2In$ at $Q = (2.45 \pm 0.05)\,\text{Å}^{-1}$ for different temperatures. No indications of enhanced fluctuations could be found. The increase in intensity with increasing temperature at negative energy transfers is due to the Bose factor.