Thermal Expansion and Grüneisen parameter of URh$_{0.62}$Ru$_{0.38}$Ge

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Outline

- Motivation
- Material -> $\text{URh}_{0.62}\text{Ru}_{0.38}\text{Ge}$
- Experimental setup
- Experimental results
- Outlook
Coworkers

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**Quantum criticality**

Quantum Critical Point (QCP) -> in system tuned to a Quantum Phase Transition (QPT) at \( T=0 \)

\[
\Gamma = \frac{\beta}{c_p} = -\frac{1}{V_m T} \frac{\partial S / \partial p}{\partial S / \partial T}
\]

\( T \) exponent of Grüneisen ratio in QPT

\[\uparrow\]

system properties at finite temperature

The Grüneisen ratio diverges at the QCP

Zhu et al, PRL 2003
Theoretical prediction for SDW-QCPs in quantum critical regime with $d=3$

$z = 3$ **FM**

\[
\begin{align*}
\alpha_{cr} & \propto T^{1/3} \\
c_{cr} & \propto T \log \frac{1}{T} \\
\Gamma_{cr} & \propto (T^{2/3} \log \frac{1}{T})^{-1}
\end{align*}
\]

$z = 2$ **AFM**

\[
\begin{align*}
\alpha_{cr} & \propto T^{1/2} \\
c_{cr} & \propto -T^{3/2} \\
\Gamma_{cr} & \propto -T^{-1}
\end{align*}
\]

\[
\text{CeIn}_{3-x}\text{Sn}_x \\
\text{CeNi}_2\text{Ge}_2 \\
\ldots
\]
Grüneisen parameter of CeCu$_{6-x}$Au$_x$
Theoretical prediction for SDW-QCPs in quantum critical regime with $d=3$

\[ \alpha_{cr} \propto T^{1/3} \]

\[ c_{cr} \propto T \log \frac{1}{T} \]

\[ \Gamma_{cr} \propto (T^{2/3} \log \frac{1}{T})^{-1} \]

$z = 3$ FM
Thermal expansion

\[ \beta = \frac{\partial \ln V}{\partial T} \bigg|_p = \frac{1}{V} \frac{\partial V}{\partial T} \bigg|_p \]

\[ \beta \propto T, \ T \gg \Theta_D \]

\[ \beta \propto aT + bT^3, \ T \to 0 \]

\[ \alpha = \frac{1}{l} \frac{\partial l}{\partial T} \bigg|_p \]

\[ \beta = \alpha_1 + \alpha_2 + \alpha_3 = 3\alpha \]

for cubic structures or isotropic solids (as polycrystals)
URhGe

• Orthorhombic structure
• Ferromagnetism ($T_C=9.5$ K) and superconductivity ($T_s=0.25$ K) at $p_{atm}$ (Aoki et al., Nature 413, 2001)
• Sommerfeld coefficient $\gamma=160$ mJ/mol K$^2$

Sakarya et al., 2003
Sample

- Polycrystalline button $\text{URh}_{0.62}\text{Ru}_{0.38}\text{Ge}$ prepared by arc melting
- Cut from sample used for specific heat
- Plane-parallel shaped using spark erosion
- Sample dimensions: $5 \times 4 \times 4 \text{ mm}^3$
Experimental setup

- OI $^3$He refrigerator ($T_{\text{base}} = 250\text{mK}$)
- Three terminal parallel-plate capacitance dilatometer

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

- Capacitance bridge (sensitivity $10^{-7}$ pF)
Dilatometer

The cell was made in the WZI with OFHC copper

De Visser, PhD thesis 1986
Dilatometer

sample

spring
We consider different contributions:

\[
\alpha_s(T) = -\frac{1}{L_s} \left( \frac{\Delta d}{\Delta T} \right)_{\text{cell+sample}} + \frac{1}{L_s} \left( \frac{\Delta d}{\Delta T} \right)_{\text{cell+Cu}} + \alpha_{Cu}(T)
\]

\[
\alpha(T) = \sum_{n \text{ odd}, >0} A_n T^n
\]

\[
2 \text{ K} \leq T \leq 20 \text{ K}
\]

Cell calibration curve

cell effect becomes bigger at low temperature

\[ \frac{\Delta d}{\Delta T} = A_1 e^{-T/t_1} + A_2 e^{-T/t_2} + y_0 \]
Comparison with measurement

\[ \Delta d / \Delta T (\text{Å/K}) \]

\[ T (\text{K}) \]

Sample

\[ \text{URh}_{0.62} \text{Ru}_{0.38} \text{Ge} \]

Graph showing the comparison between sample and cell data.
Experimental results

$\alpha (10^{-7} K^{-1})$

$T (K)$

$URh_{0.62}Ru_{0.38}Ge$
Experimental results

\[
\beta/T \left(10^{-7} K^{-2}\right) \quad C/T \left(J/mol_{U} K^{-2}\right)
\]

\[URh_{0.62}Ru_{0.38}Ge\]
Grüneisen ratio

UERh$_{0.62}$Ru$_{0.38}$Ge
Summary

• We measured the thermal expansion of polycrystalline URh$_{0.62}$Ru$_{0.38}$Ge
• We obtained $\beta$ by averaging over 3 directions
• Relatively small thermal expansion for a correlated metal
• $\beta$ does not follow $T^{1/3}$ dependence as predicted by the theory for itinerant FM QCP
• Grüneisen ratio is not diverging down to 1 K
Outlook

• Improvement of dilatometer below 1 K (reduce the cell effect)
• Experiment on single crystals (anisotropy)
• Follow the FM contribution as function of Ru content