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Angaben zur Veröffentlichung / Publication details:

Gegenwart, Philipp, F. Weickert, R. S. Perry, and Y. Maeno. 2006. "Low-temperature magnetostriction of Sr₃Ru₂O₇." *Physica B: Condensed Matter* 378-380: 117–18.
<https://doi.org/10.1016/j.physb.2006.01.047>.

Low-temperature magnetostriction of $\text{Sr}_3\text{Ru}_2\text{O}_7$

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Abstract

Itinerant-electron metamagnetism in the bilayer ruthenate $\text{Sr}_3\text{Ru}_2\text{O}_7$ is studied by c -axis magnetostriction measurements on a high-quality single crystal in magnetic fields up to 18 T and at temperatures down to 20 mK. The positive linear magnetostriction coefficient suggests an initial decrease of the magnetization under c -axis uniaxial pressure. A highly enhanced magnetic Grüneisen parameter $\Gamma_H = 106$ indicates a strong magnetoelastic coupling. The system is particularly sensitive to c -axis strain.

Keywords: Quantum criticality; Metamagnetism; $\text{Sr}_3\text{Ru}_2\text{O}_7$

The coupling of magnetic and lattice degrees of freedom leads to interesting phenomena such as incommensurate lattice distortions in spin-Peierls systems [1] or first-order metamagnetic transitions in metals [2]. Recently, the bilayer ruthenate $\text{Sr}_3\text{Ru}_2\text{O}_7$ attracted much interest because of a new type of quantum critical point that arises from the continuous suppression of the critical temperature T_c of a first-order itinerant-electron metamagnetic transition towards absolute zero [3,4]. In this specific case, the field angle acts as tuning parameter and the quantum critical end point occurs for a magnetic field of about 8 T applied along the c -axis. Subsequent investigations on high-quality single crystals ($\rho_{\text{res}} = 0.4 \mu\Omega\text{cm}$) have revealed an anomalous region of enhanced and temperature-independent electrical resistivity, which is bounded by two first-order transitions at 7.85 and 8.07 T and possibly related to novel phase formation linked to quantum critical fluctuations [5].

In this paper, we use high-resolution capacitive dilatometry to study the magnetoelastic coupling in $\text{Sr}_3\text{Ru}_2\text{O}_7$.

The linear magnetostriction $\Delta L_c(H, T = \text{const.})/L_c$ along the c -axis has been measured on a high-quality single crystal at temperatures down to 20 mK and fields $H \parallel c$ up to 18 T. The magnetostriction coefficient $\lambda_c(B) = d(\Delta L_c/L_c)/d(\mu_0 H)$ is determined from the differential length change in field intervals of 0.01 T.

The magnetostriction is displayed in Fig. 1. In the metamagnetic region near 8 T, three step-like increases of the length are resolved, whose positions in field perfectly match with those of peaks in the real part χ' of the ac-susceptibility [5]. Whereas the first anomaly is possibly a cross-over, clear peaks in χ'' at the second and third anomalies are indicative of (weak) first-order transitions. They mark the boundaries of a state in which the electrical resistivity is highly enhanced and almost temperature-independent indicative of dominating elastic scattering [5].

The Maxwell relation $\lambda_c V_m = -\partial M / \partial P_c|_{P_c \rightarrow 0}$ with the molar volume V_m and c -axis uniaxial pressure P_c relates the magnetostriction coefficient to the uniaxial pressure dependence of the magnetization in the limit of zero pressure [1]. Since $\lambda_c > 0$, the magnetization *initially* decreases under uniaxial pressure along the c -axis and the system is tuned away from the metamagnetic quantum critical end-point towards the paramagnetic regime. Interestingly, a first-order pressure-induced ferromagnetic

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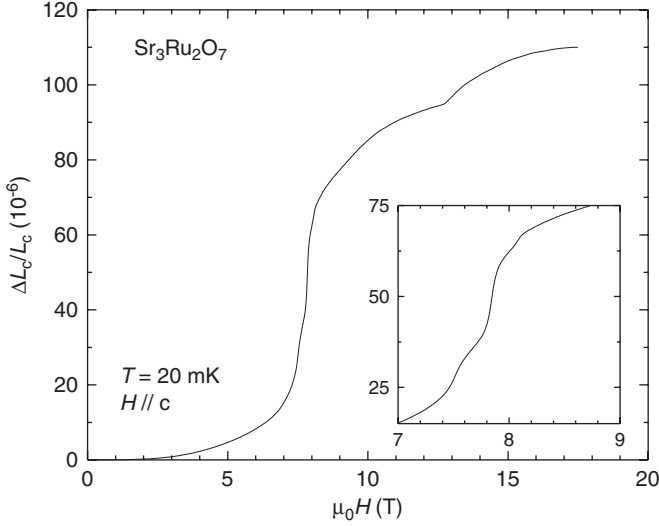


Fig. 1. Linear magnetostriction $\Delta L_c/L_c$ of $\text{Sr}_3\text{Ru}_2\text{O}_7$ measured at $T = 20$ mK for $H \parallel c$ along the c -axis. Inset enlarges metamagnetic transitions.

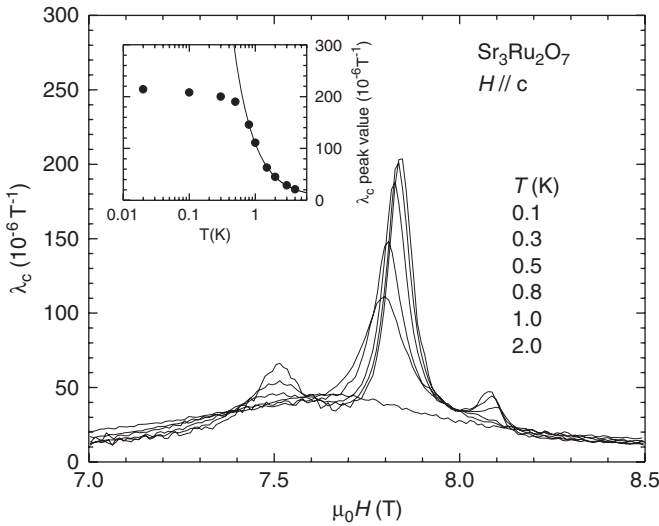


Fig. 2. Linear c -axis magnetostriction coefficient λ_c of $\text{Sr}_3\text{Ru}_2\text{O}_7$ vs field $H \parallel c$ at various different temperatures. Inset displays temperature dependence (on a log-scale) of λ_c at main peak. Solid line indicates $T^{-1.5}$ divergence.

ordering transition at $T_c \approx 80$ K, probably related to a change in the RuO_6 octahedron rotation angle, has been observed at a small c -axis uniaxial pressure of only 0.1 GPa [6]. Thus, $\text{Sr}_3\text{Ru}_2\text{O}_7$ is very sensitive to structural modifications.

Fig. 2 displays the linear magnetostriction coefficient $\lambda_c(B)$ at various temperatures for fields close to the metamagnetic region. The field and temperature depen-

dence of λ_c strongly resembles that of the real part of the ac-susceptibility [5] and differential magnetization [7]. The low-temperature λ_c value at the main peak is of the same order of magnitude as that observed at the metamagnetic cross-over in CeRu_2Si_2 [8,9] providing evidence for a similar strong magnetoelastic coupling in both systems. In CeRu_2Si_2 , the λ_c peak value follows a smooth T^2 dependence below 1.5 K, indicative of a cross-over that saturates in a Fermi-liquid ground state [9]. In contrast, for $\text{Sr}_3\text{Ru}_2\text{O}_7$ a $T^{-1.5}$ divergence is cut off around 0.7 K (see inset of Fig. 2) in agreement with a critical point at that temperature [5].

We now turn to the analysis of the magnetic Grüneisen parameter that is defined as $\Gamma_H = -(\text{d} \log H^* / \text{d} \log V)_S$ and quantifies at constant entropy the volume dependence of a characteristic field H^* . For $\text{Sr}_3\text{Ru}_2\text{O}_7$, using the isothermal compressibility $\kappa_T = 6.7 \times 10^{-12} \text{ Pa}^{-1}$ [10] and hydrostatic pressure dependence of the metamagnetic field $\mu_0 \text{d}H_m/\text{d}p = +5.6 \text{ T/GPa}$ [11], the magnetic Grüneisen ratio equals $\Gamma_H = (\kappa_T \cdot H_m)^{-1} (\text{d} H_m / \text{d} p) = +106$. Γ_H can also be derived from the ratio of the volume magnetostriction to the magnetic susceptibility: $\Gamma_H = V_{\text{mol}} / (\kappa_T \mu_0 H) \cdot \lambda_V / \chi$. At present, we cannot investigate ab-plane length changes upon applying the field along the c -axis. If the volume magnetostriction is determined by λ_c only, using the differential susceptibility data of [7], a value of 160 ± 30 that exceeds Γ_H is obtained. Thus, the in-plane magnetostriction coefficient must be negative and around five times smaller in magnitude than λ_c . This also suggests an increase of the lattice anisotropy upon tuning through the metamagnetic transitions.

To summarize, a highly enhanced magnetic Grüneisen parameter indicative of a strong magnetoelastic coupling has been observed in $\text{Sr}_3\text{Ru}_2\text{O}_7$. The system is particularly sensitive to c -axis length changes.

We thank A. P. Mackenzie for helpful discussions and the Deutsche Forschungsgemeinschaft and Royal Society (UK) for financial support.

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