Ferromagnetism Induced by Uniaxial Pressure in the Itinerant Metamagnet $Sr_3Ru_2O_7$

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Abstract. We report a uniaxial-pressure study on the magnetisation of single crystals of the bilayer perovskite $Sr_3Ru_2O_7$, a metamagnet close to a ferromagnetic instability. We observed that the application of a uniaxial pressure parallel to the c-axis induces ferromagnetic ordering with a Curie temperature of about 80 K and critical pressures of about 4 kbar or higher. This value for the critical pressure is even higher than the value previously reported (~ 1 kbar), which might be attributed to the difference of the impurity level. Below the critical pressure parallel to the c-axis, the metamagnetic field appears to hardly change. We have also found that uniaxial pressures perpendicular to the c-axis, in contrast, do not induce ferromagnetism, but shift the metamagnetic field to higher fields.

Keywords: $Sr_3Ru_2O_7$, metamagnetism, ferromagnetism, uniaxial pressure, ruthenate
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There has been increasing interest in the family of Ruddlesden-Popper type ruthenates $Sr_{n+1}Ru_nO_{3n-1}$ ($n \geq 1$) since the discovery of superconductivity [1] involving spin-triplet pairing in Sr_2RuO_4 (n = 1). $SrRuO_3$ (n = ∞) shows a ferromagnetic metallic ground state with a Curie temperature of 160 K [2]. In this context, $Sr_3Ru_2O_7$ (n = 2) is intermediate and an itinerant paramagnet close to a ferromagnetic instability [3]. In fact, metamagnetism has been reported in $Sr_3Ru_2O_7$ [4] and its metamagnetism field is 7.8 T and 5.6 T for H // c and H // ab, respectively [5]. Importantly, with improving sample quality [6], the H-T phase diagram in the vicinity of the quantum critical (end) point associated with the metamagnetic transition [7] has been revealed to be more complex and richer [8]. Also ferromagnetism is known to be induced by a uni-axial pressure along the c-axis [9].

We investigated uniaxial pressure effects on the magnetism of $Sr_3Ru_2O_7$. The crystals used were chosen from two batches (C667 and C634), grown by a floating-zone method [6], with different magnetic impurity levels. We used a uni-axial pressure cell with a SQUID (superconducting quantum interference device) magnetometer equipped with an automated background subtraction programme (MPMS, Quantum Design). The cell is piston-cylinder type, and is made of CuBe apart from the cylinder being made of oxygen-free copper to reduce the background signal. Applied pressures were determined from the force applied to the samples at room temperature, which was confirmed to show a reasonable agreement with low-temperature pressure determined by the superconducting transitions of tin and lead [10].

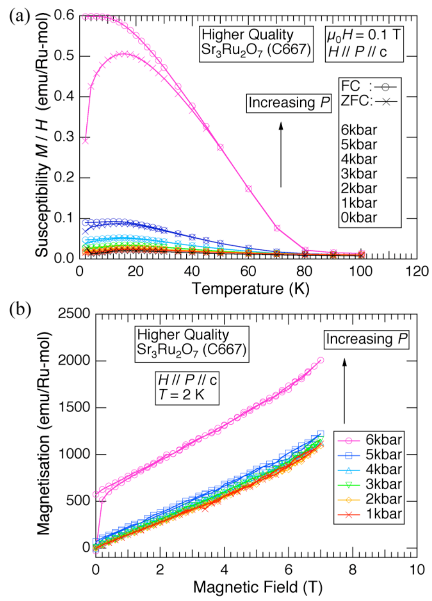

FIGURE 1. (a) Temperature dependence of the magnetic susceptibility at 0.1 T and (b) M-H curve at 2 K for the higher quality $Sr_3Ru_2O_7$ under uni-axial pressure along the c-axis.

Figure 1 shows the temperature dependence of the magnetic susceptibility at 0.1 T and the *M-H* curve at 2 K for the higher quality $Sr_3Ru_2O_7$ (C667) with a residual resistivity ρ_0 below 1 μΩcm, typically about 0.5 μΩcm, under uni-axial pressure along the c-axis. Clearly, ferromagnetic ordering is induced at a critical pressure between 5 and 6 kbar. The Curie temperature is about 80 K, at which a very abrupt increase in the magnetisation occurs. We have also made measurements on the lower quality $Sr_3Ru_2O_7$ (C634) with ρ_0 of 2-3 μΩcm and observed ferromagnetism induced with a considerably lower critical pressure of ~ 4 kbar and a similar Curie temperature of about 80 K, as shown in Fig. 2. In either case, the metamagnetic field is barely affected below the critical pressure, so that the pressure-induced ferromagnetic transition appears to be first order. In a previous report [9], ferromagnetism was induced by a uni-axial pressure along the c-axis with a critical pressure of about 1 kbar, which is much lower than the values obtained in the present study. Taking these facts together, it is inferred that the critical pressure is rather sample-dependent and possibly very sensitive to the impurity level.

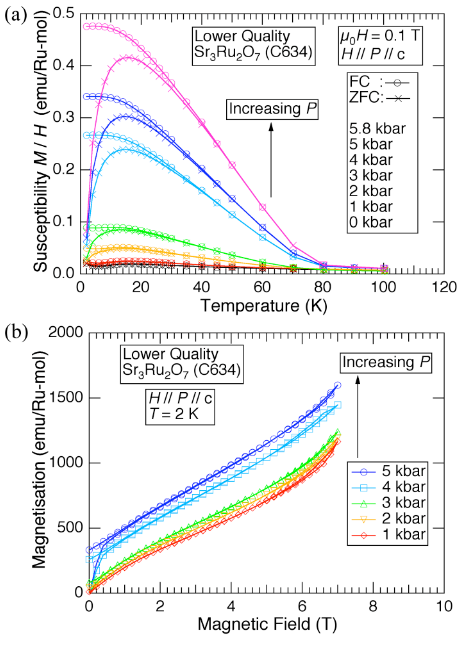

FIGURE 2. (a) Temperature dependence of the magnetic susceptibility at 0.1 T and (b) *M-H* curve at 2 K for the lower quality $Sr_3Ru_2O_7$ under uni-axial pressure along the c-axis.

We have also briefly investigated the effects of uniaxial pressure perpendicular to the c-axis using another sample from the higher quality $Sr_3Ru_2O_7$ (C667). The direction of the applied field is different, so that the metamagnetic field at zero pressure in this configuration is consistent with the reported value of about 5.6 T [5]. Figure 3 shows that, in contrast to uniaxial pressure along the c-axis, the metamagnetic field moves substantially to a higher magnetic field.

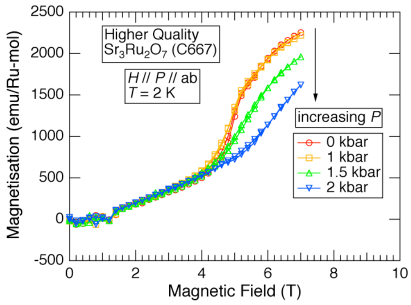

FIGURE 3. *M-H* curve at 2 K for the higher quality $Sr_3Ru_2O_7$ under uni-axial pressure parallel to the ab-plane.

In summary, uniaxial pressure parallel to the c-axis induces ferromagnetic ordering with a Curie temperature of about 80 K and critical pressures considerably higher than the value reported (~0.1 kbar) [9], which might be attributed to the difference of the impurity level. Below the critical pressure parallel to the c-axis, the metamagnetic field appears to hardly change. In contrast, uniaxial pressure perpendicular to the c-axis does not induce ferromagnetism, but shifts the metamagnetic field towards higher fields.

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REFERENCES

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1. Y. Maeno *et al.*, *Nature* **372**, 532 (1994).
2. P. B. Allen *et al.*, *Phys. Rev. B* **53**, 4393 (1996); L. Klein *et al.*, *J. Phys. Condens. Matter* **8**, 10111 (1996).
3. S-I. Ikeda *et al.*, *Phys. Rev. B* **62**, R6089 (2000).
4. R. S. Perry *et al.*, *Phys. Rev. Lett.* **86**, 2661 (2001).
5. S. A. Grigera *et al.*, *Phys. Rev. B* **67**, 214427 (2003).
6. R. S. Perry and Y. Maeno, *J. Crystal Growth* **271**, 134 (2004).
7. S. A. Grigera *et al.*, *Science* **294**, 329 (2001).
8. R. S. Perry *et al.*, *Phys. Rev. Lett.* **92**, 166602 (2004); S. A. Grigera *et al.*, *Science* **306**, 1154 (2004).
9. S-I. Ikeda *et al.*, *J. Phys. Soc. Jpn.* **73**, 1322 (2004).
10. T. F. Smith and C. W. Chu, *Phys. Rev.* **159**, 353 (1967).