Pressure and field induced novel-phenomena in single-layered ruthenates

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To explore novel quantum phenomena such as unconventional superconductivity, related magnetism and Mott transition is one of the most attractive subjects in condensed matter physics. Single-layered ruthenates have gained more attention because they display versatile quantum phenomena. As well known, Sr_2RuO_4 (SRO) is a strong candidate for the spin-triplet superconductor. In contrast, Ca_2RuO_4 (CRO), which has a larger U/W than SRO, is a Mott insulator with an antiferromagnetic (AF) ground state. Since pressure and magnetic fields are generally known as unique techniques to tune internal parameters without introducing disorder to superclean systems. To bridge the gap between a Mott insulator and an unconventional superconductor, we have studied pressure and field effects on CRO and SRO. We report here two projects as follows:

1. Temperature and magnetic fields dependences of elastic moduli of Sr_2RuO_4

As theoretically predicted by M.Sigrist [1], a change of order parameters of superconductivity is sensitively reflected in the elastic moduli. To find the evidence of the triplet superconductivity with two-dimensional order parameter, we have measured the elastic moduli of C_{11}, $(C_{11}-C_{12})/2$ and C_{66} in the fields along the a axis. A step like change has been observed at superconducting transition in T and $\mu_0 H$ dependences of C_{11}, $(C_{11}-C_{12})/2$ and C_{66}. In particular, we pay an attention to the jump of C_{66} as an evidence of the triplet superconductivity. Moreover, we have also explored the field-induced multi phases with the different order parameters reported by Tenya, *et al.* [2]. However, we have not yet conformed the evidence of the new phase.

2. Peculiarity of pressure-induced ferromagnetism in Ca_2RuO_4

We introduced pressurisation to Ca_2RuO_4 transforms it from a Mott insulator with an antiferromagnetic ground state to a quasi-2D metal with a ferromagnetic (FM) ground state. We report here that pressurised Ca_2RuO_4 shows a wide variety of attractive quantum phenomena.

(a) Anisotropic giant magnetoresistance (MR) in the vicinity of the Mott transition in pressurised CRO

The negative longitudinal MR ($\sim -80\%$ at T_C) is interpreted as a reduction of a FM spin fluctuation at T_C. In contrast, the large positive transverse one ($\sim +80\%$ at LT) is rare and most likely due to metal-nonmetal transition induced by applying fields along the c axis.

(b) Itinerant ferromagnetism (FM) in Q2D metal

The observed FM is interpreted in terms of an itinerant magnet because of following reasons. Firstly, $M_{\rm rem} \sim 0.35\mu_B$ is quite smaller than the saturated moment of $2\mu_B$ of localised Ru^{4+} ion. Secondly, a ratio of $p_{\rm eff}/M_{\rm rem} \sim 5$ is much larger than 1 of localized spins systems. Lastly, M is not easily saturated with H. In particular, the magnetisation process at low temperatures exhibits good linearity in an Arrott plot ($M^2_{\rm rem}$ versus H/M plot). These FM natures are comparable to a typical itinerant ferromagnet MnSi. Moreover, strongly anisotropic magnetisation-process is interesting to compare the properties of the itinerant-FM Q2D-metal with theoretical predictions [3].

(c) Existence of quantum critical point and expectation of new superconducting phase

With pressurising the FM T_C rises, reaching 25K at $\sim$ 5GPa, then it decreases gradually. Extrapolation of T_C suggests the induction of a FM quantum critical-point at $\sim$ 8 GPa. We have strong interest in the connection between the triplet superconductivity of Sr_2RuO_4 and the itinerant FM of metallic Ca_2RuO_4. That is, we explore the pressure-induced superconductivity, and then compare the Q2D metallic state of pressurised CRO to that of SRO.

[1] M. Sigrist, Progr. Theor. Phys. **107** (2002) 917.
[2] K. Tenya, et al., J. Phys. Soc. Jpn., **75** (2006) 023702.
[3] M. Hatatani and T.Moriya, J. Phys. Soc. Jpn., **64** (1995) 3434.