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Pressure effect on the Curie temperature of CrBr_3

H. Yoshida *, J. Chiba, T. Kaneko, Y. Fujimori, S. Abe

IMR, Tohoku University, Sendai, 980-77 Japan

Abstract

The pressure dependence of T_C of anhydrous CrBr_3 was measured with a clamped microbomb. dT_C/dP was obtained to be -0.2 K/kbar . This negative sign is discussed in terms of distance dependence of exchange interaction between Cr^{3+} .

Keywords: CrBr_3 ; Pressure effect; Curie temperature; Superexchange interaction

It is well known that anhydrous CrBr_3 is a transparent ferromagnet with the Curie temperature $T_C = 32.55 \text{ K}$ [1], the crystal structure of which is a rhombohedral BiI_3 -type. CrCl_3 is an antiferromagnet ($T_N = 16.8 \text{ K}$) which has a monoclinic symmetry at room temperature. The crystal structure of CrCl_3 is transformed to a BiI_3 -type at 240 K. The BiI_3 -type crystal structure are essentially constructed with three kinds of cation honeycomb layers, and double layers of halogen ions are between Cr^{3+} layers. CrI_3 with the same crystal structure as CrBr_3 is also a ferromagnet with $T_C = 68 \text{ K}$. For CrX_3 ($X = \text{Cl}, \text{Br}, \text{I}$), the transition temperature has a linear relation with the lattice constant and increases with increasing a or c . Thus, the transition temperature is expected to decrease with pressure. On the other hand, it is reported that the pressure derivative (dT_C/dP) of T_C through the superexchange interaction has a positive sign because of the increase of transfer integral by compressing as observed for magnetic oxides [2], which is different from the above expectation. In this paper, the pressure dependence of T_C of CrBr_3 is directly measured in order to clarify the relation between magnetic transition temperature and lattice parameter.

The flaky single-crystal samples were prepared by heating the powder one in an evacuated fused quartz tube at 800°C for two days. The lattice constant a and c in hexagonal index were obtained to be 6.30 and 18.35 \AA . The Curie temperature under pressure has been determined by measuring the AC susceptibility with 1 kHz. We made the high-pressure bomb in which a manganin pressure gauge and a thermocouple of $\text{Au}(\text{Fe})$ and Ag are set directly near the sample. The manganin gauge was calibrated using the pressure dependence of the superconducting transition temperature of Pb . The pressure dependence of T_C at temperatures down to 4.2 K was measured by monitoring the pressure with the calibrated manganin gauge. It was also found that an initial pressure at room temperature has been held down to liquid He temperature.

The temperature dependence of AC susceptibility (χ_{AC}) of CrBr_3 is shown in the inset of Fig. 1. Approaching the ferromagnetic ordering temperature, χ_{AC} shows an abrupt increase near T_C in the paramagnetic state and shows two peaks in the ferromagnetic state. The magnetic transition temperature is defined as shown in the figure. The values obtained of T_C at ambient pressure is $35.2 \pm 0.5 \text{ K}$. This temperature is in good agreement with the transition temperature obtained from the static magnetization

* Corresponding author.

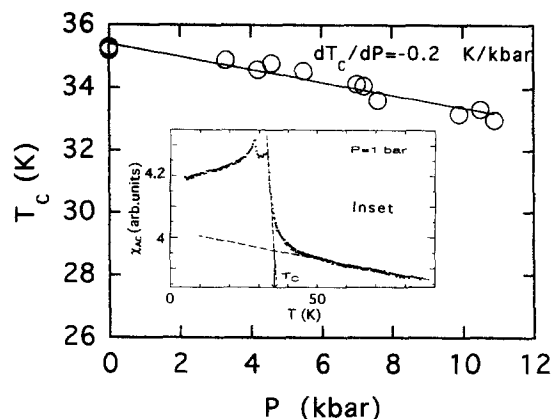


Fig. 1. Pressure dependence of T_C for CrBr_3 . Inset shows the χ_{AC} versus T curve at 1 bar and a measure in the determination of T_C .

versus temperature curve. The pressure dependence of T_C for CrBr_3 is shown in Fig. 1. The Curie temperature decreases with increasing pressure. The pressure derivative of T_C (dT_C/dP) is obtained to be -0.2 K/kbar .

Recently, it has been reported that T_N for CoI_2 [3] and NiI_2 [4] increases with compression [3,4]. This fact has been explained that the exchange interaction becomes stronger with decreasing atomic distance due to the increase in transfer integral. There has been no report on negative pressure effect ($dT_N/dP < 0$) in halides. The exchange interactions in the c -plane (J_{plane}) and between the c -planes (J_{axis}) for CrX_3 are estimated using the spin wave approximation on the basis of the results of inelastic ND [6] and NMR [5, 7–9] and the results are shown in Fig. 2. The figure shows that both J_{plane} and J_{axis} decrease with decreasing distance. These distance dependences of the J_{plane} and J_{axis} are consistent with $dT_C/dP < 0$ observed above, but inconsistent with that of superexchange interaction. The J_{plane} and J_{axis} are considered to contain not only a superexchange interaction but also a direct exchange one. Therefore, the results of $dT_C/dP < 0$ should be considered in terms of distance dependence of direct exchange interaction between Cr^{3+} in the c -plane. If the pressure shift of the J_{axis} affects mainly T_N or T_C , it is expected that T_N increases and T_C decreases by compression as seen in Fig. 2(b). This mechanism is still an open question.

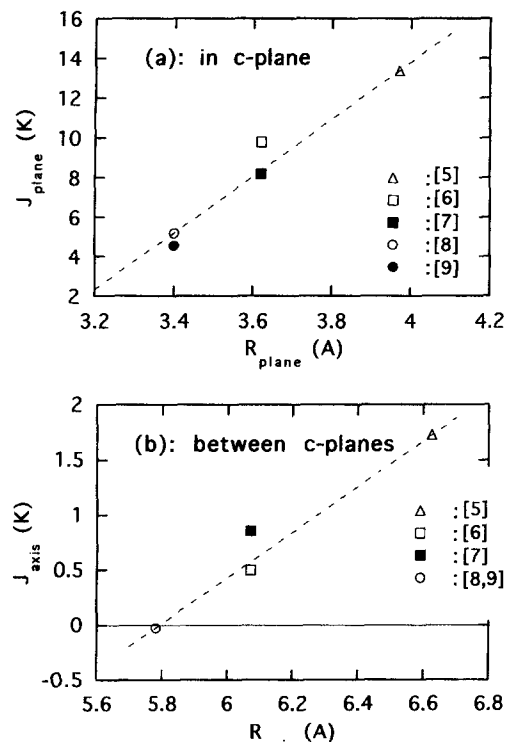


Fig. 2. The relationship between exchange interaction and Cr^{3+} 's distance in CrX_3 ($X = \text{Cl}, \text{Br}, \text{I}$). (a) J_{plane} versus distance in c -plane (R_{plane}) and (b) J_{axis} versus distance between c -planes (R_{axis}), where dotted lines are just a guide to the eye.

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