Thermal expansion of the quasi two-dimensional magnetic layered compound \(\text{BaNi}_2\text{V}_2\text{O}_8\) under magnetic fields along \(c\)-axis.

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Abstract

The quasi two-dimensional magnetic \(\text{BaNi}_2\text{V}_2\text{O}_8\) is studied by using high-resolution thermal expansion in magnetic fields up to 10 T applied along the \(c\)-axis. A slight increase of about 1 % of the three-dimensional antiferromagnetic ordering temperature \(T_N\) is observed at 10 T. Positive and negative pressure dependencies of \(T_N\), respectively, are inferred from the thermal expansion \(\alpha(T)\) for pressures applied along the \(a\)- and \(c\)-axes.

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Although the properties of quasi-two dimensional (2D) magnetic systems have been studied for almost three decades [1], a lot of activity is still devoted to their study. Of particular relevance is the question of a Kosterlitz-Thouless description [2] for such systems, continuing to be an open and challenging debate. One of the main motivations related to these works comes from the fact that the high \(T_c\) cuprates are also quasi-2D magnetic systems. Attention focused recently on experimental studies of the layered compound \(\text{BaNi}_2\text{V}_2\text{O}_8\) [3,4]. This system, which is constituted of a honeycomb arrangement of spin-1 ions of \(\text{Ni}^{2+}\), is characterized by a planar magnetic exchange responsible for a strongly 2D character. A three-dimensional (3D) long-range ordering (with the spins aligned in the plane) sets in below \(T_N \approx 48\) K and is explained as a consequence of a tiny, but non-zero, out-of-plane exchange [3,4]. An isotropic, thus Heisenberg-like, susceptibility was also reported for temperatures above 100 K, and a description within a 2D-XXZ picture has been proposed to relate the behavior just above \(T_N\) to a Kosterlitz-Thouless-like picture [3,4,5].

To validate or not such a description, an effort has to be made to determine precisely the role of the exchange parameters (in and between planes) and of the single-ion anisotropy (planar, in-plane, etc.), but also the magnetic-field and pressure dependencies of those quantities.

We present here a study of the thermal expansion of a single crystal of \(\text{BaNi}_2\text{V}_2\text{O}_8\) with magnetic fields \(B\) applied along the \(c\)-axis, thus perpendicular to the easy plane. The sample of about 15 mm\(^3\) was grown using the self-flux method. Thermal expansion was measured using a high-resolution capacitive dilatometer with a heating rate of 20 mK/s. The length \(L\) along \(a\) - and \(c\)-axes was measured with

\[\alpha(10^{-6}\,\text{K}^{-1})\]

\(T\) (K)

\[B // c\]

\[L // a\]

\(B = 10\) T

\(B = 6\) T

\(B = 3\) T

\(B = 0\) T

Fig. 1. Thermal expansion of \(\text{BaNi}_2\text{V}_2\text{O}_8\) for fields \(B\) applied along \(c\), the length change being measured along \(a\).
the field applied in the $c$-direction. The thermal expansion coefficient was then extracted using $\alpha = 1/L \times \partial L/\partial T$.

In Fig. 1, the temperature variation of the thermal expansivity obtained in the set-up with $L // a$ is shown for applied magnetic fields $B = 0$, 3, 6, and 10 T. A clear step-like anomaly is observed at $T_N$; in contrast, only a change of slope was reported previously in the specific heat measured at $B = 0$ [3], which we attribute to insufficient resolution of the specific-heat data. In the thermal expansion obtained with $L // a$, a positive anomaly signals the antiferromagnetic ordering. We take for the Néel temperature the temperature of the steepest slope of $\alpha(T)$, i.e. the minimum of $\partial \alpha/\partial T$. Hence $T_N \approx 47.4$ K at $B = 0$. The application of a magnetic field along the $c$-axis results in a slight increase of $T_N$ up to 47.8 K at $B = 10$ T, i.e. of about 1%. A small increase of the size of the anomaly is also obtained for the fields $B = 6$ and 10 T. Fig. 2 shows the thermal expansion coefficient $\alpha$ obtained in the set-up with $L // c$ for the magnetic fields $B = 0$, 3, 8, and 10 T. The jump associated with $T_N$ is negative and thus of opposite sign compared to the previous configuration. The Néel temperature $T_N$ deduced from this anomaly has a variation with field which is consistent with that deduced from the transverse measurements, while the size of the anomaly does not seem to change with field. The phase diagram derived from these two sets of measurements is plotted in Fig. 3. Using the Ehrenfest relation, the jump $\Delta \alpha$ of the thermal expansion at the magnetic ordering can be related to the pressure dependence of the Néel temperature by $\partial T_N/\partial p \propto \Delta \alpha$, where $p$ is the pressure. Our data thus show a positive pressure dependence $\partial T_N/\partial p_a > 0$ for $p$ applied along $a$ and a negative pressure dependence $\partial T_N/\partial p_c < 0$ for $p$ applied along $c$, independently of the magnetic field. Interpreting these pressure dependencies is not easy, since they result from the combination of several effects, such as the pressure dependence of the anisotropy, sensitive to the domain arrangement, or the pressure dependence of the exchange, and thus the different super-exchange paths of the system. The increase of $T_N$ when a magnetic field is applied along the $c$-axis is associated with an increase of the effective easy-plane anisotropy, and thus of the XY-character of the spins. Such a picture was already proposed by Takeda and Koyama to explain the phase diagram of Mn(HCOO)$_2$2H$_2$O [6], which was recently compared to the result of Monte Carlo simulations by Cuccoli et al. [7].

In conclusion, we have performed thermal expansion measurements on the quasi-2D magnetic system BaNi$_2$V$_2$O$_8$ under magnetic fields along the $c$-axis. We have obtained a slight increase with field of the 3D-ordering temperature $T_N$, while positive and negative pressure dependencies of $T_N$ are obtained for $p$ applied along $a$ and $c$, respectively. A forthcoming article will present a complete study of BaNi$_2$V$_2$O$_8$ using the combination of thermal-expansion, specific-heat, and magnetization measurements performed with magnetic fields applied along $c$ and $a$ [8].

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