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On the pressure and temperature dependence of the magnetization and anisotropy behavior of YCo_4B

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Abstract
The YCo_4B exhibits peculiar behavior of the magnetization curves related to the occurrence of a spin reorientation phenomenon at low temperature and of a first-order magnetization process. We present here a detailed investigation of the pressure dependence of this anomaly in a wide temperature range 5–300 K. The evolution of the saturation magnetization versus pressure is also presented on both sides of the spin reorientation transition. Studies were performed on single-crystalline samples under hydrostatic pressure up to 1 GPa pressure and in a magnetic field up to 5 T. Remarkable pressure effects on the magnetocrystalline anisotropy parameter and on the critical field at which the first-order magnetization process occurs are analyzed and discussed.

1. Introduction

Rare-earth (R)–transition metal (M) intermetallics such as $SmCo_5$ or $Nd_2Fe_{14}B$ are technologically important permanent-magnet materials because of their excellent intrinsic magnetic properties. The $R_{n+1}Co_{3n+5}B_{2n}$ compounds form a physically interesting class of materials because of the large variety of cobalt environments that are present in the different hexagonal crystal structures [1–7]. For $n = 1$ (RCo_4B) a superstructure of the RCo_5 type is obtained leading to a doubling of the unit cell [1–10]. They are obtained by the ordered substitution of boron for cobalt in RCo_5 ($n = 0$). Compounds of this series are known to exhibit interesting magnetic properties which have motivated intensive research these last few years [6, 12–18]. Among the RCo_4B, YCo_4B has been found to exhibit a unique magnetic behavior characterized by a spin reorientation below room temperature, spin reorientation resulting from the competition of the magnetocrystalline anisotropy of the two inequivalent Co sites of the $CeCo_4B$ type of hexagonal structure. Such behavior has been studied in detail by magnetic measurements [8, 19–21], neutron diffraction investigation [3, 8], Mössbauer spectroscopy [22], NMR [23] or band structure calculations [24]. The pressure dependence of this phenomenon has also been reported [20, 21]. A general investigation of the magnetic properties of YCo_4B has been performed by Thang and coworkers [19, 25]. This extensive study of the magnetocrystalline behavior of this phase has shown the complexity of the magnetic phase diagram of YCo_4B. In their article Thang and coworkers have studied the magnetic properties of the YCo_4B phase, demonstrating novel properties such as the first-order magnetization process (FOMP) occurring in a wide temperature range. YCo_4B has been described as a unique compound where a FOMP is associated with the Co sublattice only. Following these earlier works, we report here on the pressure and temperature dependence of the magnetic properties of monocrystalline YCo_4B in order to investigate more deeply the unusual magnetic properties of this compound.

2. Experimental details

A single-crystalline YCo_4B sample has been prepared by the Czochralski arc melting technique in a cold copper crucible under an argon atmosphere, using elements with purity better than 99.9% for Y and Co and 99.8% for B. The sample studied along the c axis is the one previously used in [21]. It consists of a plate-like sample of approximately 1.7 mm × 1.7 mm × 0.4 mm. The second YCo_4B sample was thicker with

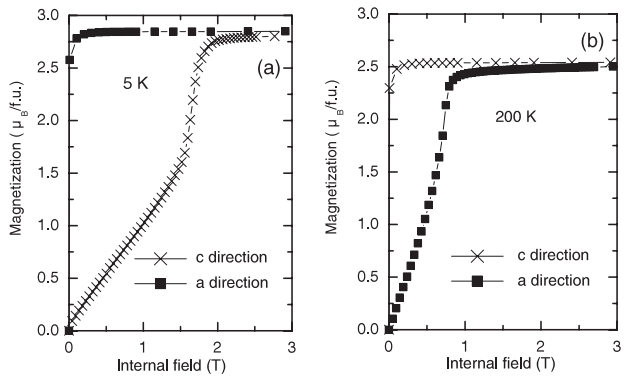

Figure 1. Isothermal magnetization curves recorded along the *c* and *a* directions on single-crystal YCo_4B at 5 K (left) and 200 K (right) at atmospheric pressure.

dimensions of 1.7 mm × 1.7 mm × 0.6 mm and was oriented along the *a* axis that is parallel with one of the 1.7 edges.

The magnetization measurements at high hydrostatic pressure up to about 1 GPa were performed in a SQUID magnetometer (Quantum Design Co.) in magnetic fields up to 5 T in the temperature range from 5 to 300 K. The spin reorientation temperatures T_{sr} under different pressures were determined from the temperature dependence of the dc susceptibility measured in a magnetic field of 100 Oe at a heating rate of 1 K min^{-1}. T_{sr} was defined as the inflection point on susceptibility versus temperature curves. The saturation magnetization at different pressures was determined from the isothermal magnetization curves. The demagnetization factor has been determined in both *c* and *a* orientation from the magnetization curves recorded when applying the field along the easy direction.

A miniature piston–cylinder CuBe pressure cell was filled with a mixture of mineral oils as a pressure transmitting medium. The pressure was determined at low temperatures using the known pressure dependence of the critical temperature of the superconducting state of the Pb sensor placed inside the cell [26].

3. Magnetic measurements

Following earlier measurements on the pressure effects on the magnetic properties of RCo_4B compounds [20, 21, 27, 28] we will concentrate here on the R = Y compound and analyze in more detail the evolution of magnetocrystalline anisotropy. Indeed the pressure dependence of the Co sublattice anisotropy in YCo_4B has been clearly shown by following the pressure effect on magnetic phase transitions. To further study this anisotropy we will successively analyze the magnetic field dependence and temperature dependence of the spin reorientation and of the first-order magnetization process. The next section will be devoted to the evolution of these magnetic transitions versus pressure.

3.1. Spin reorientation transition and its field dependence

The magnetization curves plotted in figure 1 show that the easy magnetization of the YCo_4B compound varies versus temperature. By comparing measurements along the *a* and *c* axes, we indeed see that at high temperature it is the *c* axis which is favored whereas at low temperature a basal plane anisotropy is observed, the *a* axis being favored. As has been discussed earlier, this indicates the occurrence of a spin reorientation phenomenon, a spin reorientation which has been extensively studied elsewhere by complementary techniques such as magnetic measurements [8, 10, 19–21, 23, 25] or neutron diffraction [3, 8]. This has been shown to result from the competition between the two inequivalent Co crystallographic sites: the Co2c preferring an alignment along the *c* axis of the structure whereas the Co6i, which dominates at low temperature, prefers basal plane anisotropy with an alignment of the magnetization along the *a* axis. The strong exchange interaction arising from the Co 3d band in this compound forces a ferromagnetic alignment of the two Co sublattice magnetic moments but at low temperature the magnetization is aligned along the *a* axis and it reorients towards the *c* axis at higher temperature. It is worth recalling that previous investigations have demonstrated that the in-plane anisotropy is negligibly small [19, 20].

As can be seen from figure 2 the application of an applied field along the *c* axis, which is the hard magnetization direction at low temperature, induces a shift of the spin reorientation transition temperature towards lower temperature. This corresponds to a reduction and an increase of the temperature range with basal and axial anisotropy, respectively. This effect is dramatic and linear, a value of about $\mathrm{d}\ln T_C/\mathrm{d}\mu_0 H = 0.34\ \mathrm{T}^{-1}$ can be extracted from the present investigation. The spin transition temperature at which the spin reorientation occurs is thus observed to vary from 158 to 110 K for an applied field of 0.01–1 T, respectively. This effect can easily be understood since the application of a magnetic field along the *c* axis favors a rotation of the magnetic moments toward this direction, thus modifying the magnetic phase diagram of the compound and favoring the *c* axis versus the basal plane domain.

3.2. First-order magnetization process

Another peculiar behavior of the magnetic properties of YCo_4B is the step-like shape of the magnetization curves recorded along the hard *c* axis at low temperature or even along the *a* axis above the spin reorientation transition. It is worth mentioning that this step-like magnetization curve is only observed along the hard magnetic axis—see figure 1. As can be seen in figure 1(b), this step-like shape is less pronounced at 200 K than at 5 K due to the proximity to the spin reorientation phenomenon. Furthermore this behavior vanishes at temperatures higher than 220 K. This peculiar behavior of the magnetization curves recorded along the hard axis has been interpreted as a first-order magnetization process (FOMP) and is characterized by a critical field at which the magnetization increases rapidly versus the applied field. This FOMP, which is clearly seen in figure 1, has been previously reported elsewhere [19, 25]. Here we take the maximum value of the field derivative of the magnetization curves recorded along the *c* axis of the structure as the critical

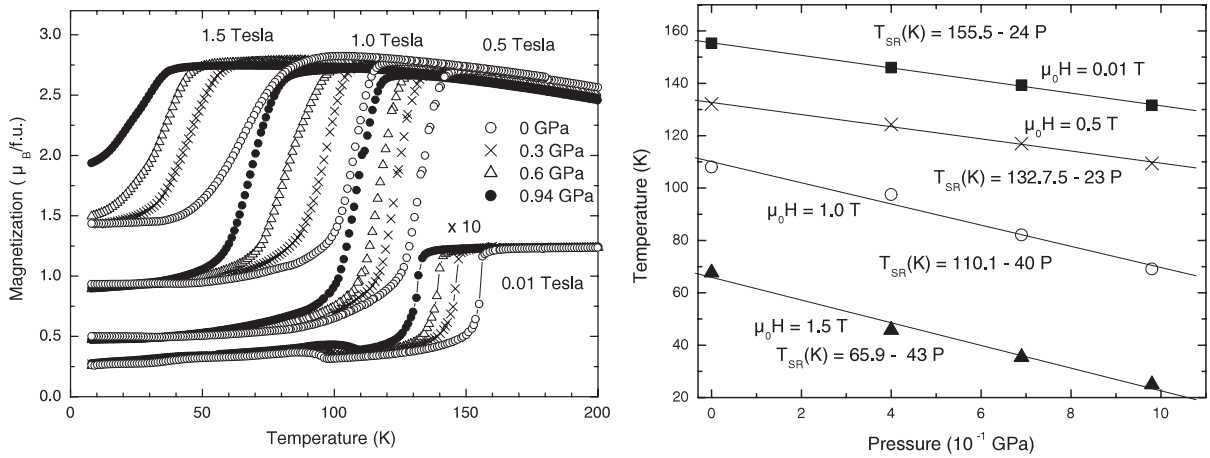

Figure 2. Left: isofield magnetization curves recorded along the hard magnetization axis *c*, showing a transition field at the spin reorientation. Right: pressure dependence of the transition field as plotted for different applied fields.

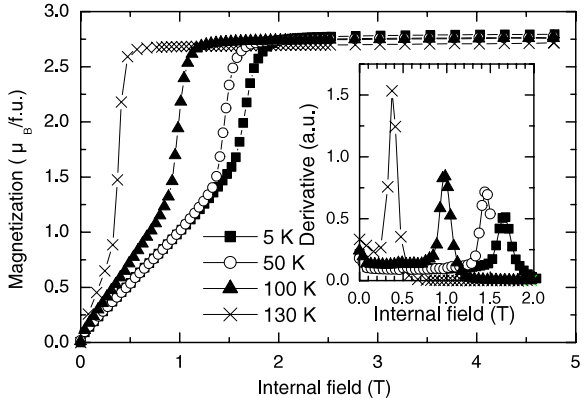

Figure 3. Temperature evolution of the first-order magnetization process observed in the magnetization curves recorded along the *c* axis of YCo_4B single crystal. Inset: evolution of the field derivative of the magnetization curves.

field of the FOMP (see figure 3). The critical field of this FOMP decreases when the temperature increases. A critical field of 1.67 T is measured at 5 K whereas it goes down to 0.98 and 0.38 T at 100 and 130 K, respectively. The decrease observed here is similar to that studied in detail elsewhere [19, 25]. Above the spin reorientation, a critical field is also observed up to about 220 K. In this temperature domain the critical field increases linearly with temperature with a slope of 0.012 T K^{-1} going from ca. 0.17 to 0.718 T for 170 and 210 K, respectively. The disappearance of the step in the magnetization curves recorded above 220 K may originate from the overall change of the magnetocrystalline anisotropy parameters upon increasing the temperature. Indeed the increase of the critical field may lead to a crossover with the anisotropy field, thus leading to the disappearance of the observed FOMP in the magnetocrystalline curves. The presence of a FOMP in a magnetization curve requires certain condition concerning the anisotropy constant to be fulfilled—see the articles of Asti and Bolzoni for more details [29, 30]. For a hexagonal symmetry such as for the YCo_4B compound, the anisotropic part of the free energy is expressed as

$$F = K_1 \sin^2\Theta + K_2 \sin^4\Theta + K_3 \sin^6\Theta - \mu_0 H_0 (M_s + \chi_{hf}\mu_0 H_0)\cos(\Theta - \Theta_H) \quad (1)$$

where M_s is the spontaneous magnetization, H_0 is the internal magnetic field and χ_{hf} is the high-field differential susceptibility. The K_1, K_2 and K_3 are the anisotropy constants. As can be seen in equation (1), we had to develop the anisotropy energy to the sixth order but we could neglect the in-plane anisotropy which normally appears at this sixth order. This assumption is in agreement with the low anisotropy within the plane reported previously [19–25]. Θ denotes the angle between the magnetization direction and the *c* axis of the crystal structure whereas Θ_H corresponds to the angle of the magnetic field versus *c* axis. Since the magnetic field is applied perpendicularly to the EMD, if the EMD is along (resp. perpendicular to) the *c* axis, the Θ_H value is normally 90° (resp. 0°). However, a possible misalignment of the single crystal in the pressure cell with respect to the direction of the applied magnetic field has been taken into account by varying Θ_H between 85 and 90° (resp. 0 and 5°). The 5 K isothermal magnetization curve recorded when applying the field along the *c* axis of the structure has been fitted according to the minimization of equation (1). The retained value for Θ_H was 1.8°, leading to the following anisotropy parameters: $K_1 = -2.3 \pm 0.3 \times 10^{-23}$ J f.u.$^{-1}$, $K_2 = 0.0 \pm 0.2 \times 10^{-23}$ J f.u.$^{-1}$ and $K_3 = -0.7 \pm 0.3 \times 10^{-23}$ J f.u.$^{-1}$. Similar fits of the magnetization curves have been performed at 50 and 100 K, leading to the refined anisotropy parameters given in table 1. The K_1 anisotropy parameter goes from −2.3 to -1.3×10^{-23} J f.u.$^{-1}$ at 5 and 100 K, respectively. If the values are slightly different from the one reported earlier [19], the trend is in agreement with this paper which has demonstrated the change of sign of the anisotropy parameters at the spin reorientation transition. In the temperature range below the spin reorientation transition the K_1 parameter remains negative as expected since $T < T_{SR}$. The refined values for K_2 are close to zero at the three investigated temperatures, showing that the anisotropy of the YCo_4B compound results mainly from

Table 1. Anisotropy parameters of the YCo_4B compound as determined from the fit of the isothermal magnetization curves recorded along the hard axis (c axis below 150 K and a axis above) of the crystal structure at ambient pressure.

T (K)	M_s (μ_B f.u.$^{-1}$)	d ln M_S/dP(10^{-2} GPa^{-1})	K_1(10^{-23} J f.u.$^{-1}$)	K_2(10^{-23} J f.u.$^{-1}$)	K_3(10^{-23} J f.u.$^{-1}$)
5	2.764	−3.45	−2.32	0.0	−0.73
50	2.750	−3.4	−1.99	0.05	−0.82
100	2.730	−3.9	−1.35	0.0	−0.53
170	2.680	−3.6	0.76	−0.667	0.36
190	2.590	−3.6	1.38	−0.82	0.33
230	2.410	−6.6	1.70	−0.29	0.045

the two other terms K_1 and K_3. Unlike the K_1 parameter, K_3 is about the same at 5 and 50 K; only at 100 K is a significant reduction of the value obtained. In conclusion the K_1 coefficient is by far the more sensitive to the applied pressure below the spin reorientation temperature.

It is worth mentioning that Thang *et al* [19] have reported a type I FOMP. It was, however, difficult to exclude the possibility for a type II FOMP. As classified by Asti and Bolzoni [28, 29] a type I FOMP should be characterized after the transition by a magnetization immediately reaching the saturated value. In contrast, in the case of a type II FOMP a higher field is required to saturate the magnetization. The refined values of the anisotropy parameters found here are at the limit of the onset of a FOMP type II behavior. As will be seen below, the application of pressure leads to an evolution of the anisotropy constants, thus favoring type II FOMP. For consistency we have analyzed the ambient pressure data with the same method.

Similar refinement of the anisotropy parameters has been undertaken at room pressure at 170, 190 and 230 K. The obtained values are summarized in table 1. The anisotropy parameters are found to change sign above the spin reorientation temperature. The refined values are consistent with an uniaxial anisotropy above T_{SR} since, at 190 K, values of 1.38, $-0.82, 0.33\times10^{-23}$ J f.u.$^{-1}$ are obtained for $K_1 K_2$ and K_3, respectively. It is also worth noting that K_2 and K_3 are of similar magnitude, unlike what was obtained previously below T_{SR}. As can be expected, in this temperature range between 170 and 230 K, the anisotropy parameters are increasing when the temperature increases. This reflects that the anisotropy is larger away from the spin reorientation.

4. Pressure effects

As has been reported earlier the magnetization of YCo_4B is very sensitive to the external applied pressure [20, 21]. A value of $\mathrm{d}\ln M_S/\mathrm{d}P = -3.3 \times 10^{-2}$ GPa^{-1} has been obtained [21], a value much larger than that observed for the $CeCo_4B$ and $GdCo_4B$ isotype compounds and an order of magnitude larger than the pressure effect on the magnetic moment of metallic cobalt [21]. In the present study the obtained value is -3.45 and -3.62×10^{-2} GPa^{-1} for 5 and 170 K, respectively, showing that the pressure dependence coefficient of the magnetization is almost constant whatever the temperature—see table 1. At 230 K due to the proximity to the Curie temperature an even larger pressure dependence of the magnetization is observed: -6.6×10^{-2} GPa^{-1}. The Curie temperature also has been found to vary versus the applied pressure $\mathrm{d}\ln T_C/\mathrm{d}P = -3.1 \times 10^{-2}$ GPa^{-1}. It is worth recalling that the close values of the logarithmic derivatives of both T_C and M_s has been ascribed to the itinerant electron ferromagnetism character of the Co magnetism in YCo_4B, an interpretation in agreement with the Wolfarth model [31, 32]. More recently, Burzo has further studied the degree of itinerancy of the 3d magnetism in the $R_{n+1}Co_{3n+5}B_{2n}$ compounds [7, 33, 34]. Here we will focus on the pressure evolution of the spin reorientation transition as well as on that of the FOMP. Then the pressure dependence of the anisotropy coefficient will be presented.

4.1. Pressure dependence of the spin reorientation transition

As can be seen from figure 2 the transition temperature at which the spin reorientation phenomenon occurs is significantly reduced upon applying an external pressure. This effect is important and a sensitivity of $\mathrm{d}T_{SR}/\mathrm{d}P = -24$ GPa^{-1} and $\mathrm{d}T_{SR}/\mathrm{d}P = -43$ GPa^{-1} is obtained for an applied field of 0.01 and 1.5 T, respectively. The left part of figure 2 also shows that the sensitivity of the transition temperature to the applied field increases as the field applied along the c axis increases. An internal chemical pressure can be obtained by substitution; this has been performed earlier by La for Y substitution and led first to an increase of the spin reorientation phenomenon [15]. Such an increase of T_{SR} occurring upon an internal chemical pressure is in agreement with the decrease observed here of the spin reorientation upon applying an external pressure on YCo_4B. Comparison of the volume dependence of the transition temperature from pressure measurements and chemical substitution has led to the conclusion that the volume plays a crucial role in determining T_{SR}. A recent investigation of the $ThCo_4B$ has pointed out that the number of electrons brought by the R element could additionally play a role in the magnetic properties of non-isoelectronic substitution like in the case of the Th for Y substitution in YCo_4B [27, 35]. Indeed in the case of the Th for Co substitution the spin reorientation disappears despite the fact that neither Th nor Y are magnetic elements.

The overall magnetocrystalline energy of YCo_4B results from the competition of two contributions arising from the Co ions at the two 2c and 6i sites, contributions having opposite sign and comparable magnitude [19, 23, 25]. Consequently, the reduction of the spin reorientation temperature upon applying pressure can be interpreted as a reduction of the temperature domain where the Co 6i site anisotropy is dominant, imposing the alignment of the magnetization along the c axis: in

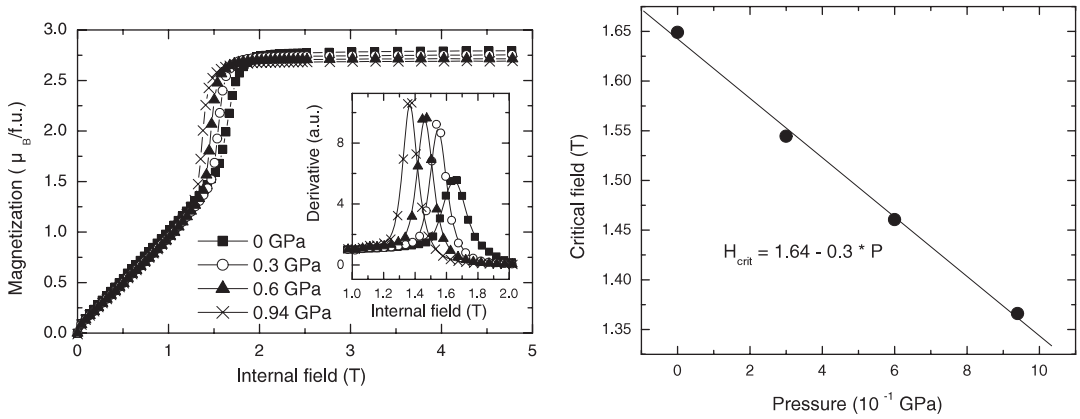

Figure 4. Left: isothermal magnetization at 5 K recorded at the indicated pressures along the *c*-axis YCo_4B monocrystalline sample. Inset: temperature evolution of the derivative showing the critical field. Right: pressure evolution of the critical field determined at the indicated temperatures at 5 K.

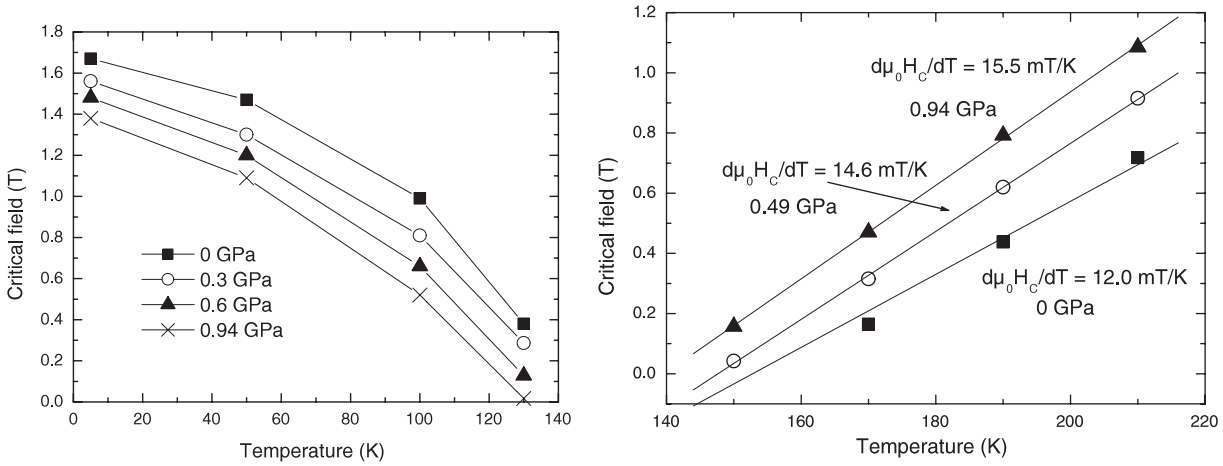

Figure 5. Temperature dependence of the FOMP critical field as measured on a YCo_4B sample for the indicated pressures. Left: below the spin reorientation; right: above the spin reorientation.

other words, a reinforcement of the Co2c contribution to the magnetocrystalline anisotropy against the Co6i one. It appears that the two inequivalent Co crystallographic sites do not behave the same way versus the external applied pressure. This result is in agreement with earlier reported results obtained by χ_{ac} susceptibility on a powder YCo_4B sample [20]. The mechanism by which the Co magnetocrystalline anisotropy is modified upon applying an external pressure is not yet understood even if the anisotropic spin–orbit energy is known to be responsible for the magnetocrystalline anisotropy energy of compounds like YCo_4B [11, 19, 23] and YCo_5 [36]. Further experimental work is needed in particular to determine the pressure behavior of the spin and orbital contribution to the Co magnetic moment of the two inequivalent crystal sites in YCo_4B. It is worth recalling at this point that the Co 2c and 6i sites exhibit many different features in the YCo_4B structure due to the different local atomic environments and the different hybridization states with boron in particular. Indeed, in addition to the opposite anisotropy preference discussed above, Chacon and Isnard have shown that the Co 6i carries a much smaller magnetic moment than the Co 2c one [3, 8]. In this context, it is not surprising to expect a large difference in the pressure dependence of their magnetic properties also, including the magnetocrystalline anisotropy.

4.2. Pressure dependence of the FOMP

4.2.1. Pressure dependence of the FOMP below the spin reorientation. As can be seen from figure 4, the critical field at which the FOMP manifests itself is also pressure-dependent. Indeed, at 5 K this critical field decreases when the applied pressure increases from 1.67 to 1.38 T (internal field) for 0 and 0.94 GPa, respectively. This feature is general and has been observed at all the studied temperatures ranging from 5 to 130 K. As expected the critical field vanishes at the spin reorientation temperature where the anisotropy is very weak due to the compensation of the contribution of the different Co sublattices (2c and 6i); see figure 5. A sensitivity of $\mathrm{d}\ln H_c/\mathrm{d}P = -1.83 \times 10^{-1}$ GPa^{-1} is calculated from our present investigation at 5 K. The pressure dependence of the critical field value is not the same at all the temperatures. The logarithmic derivative $\mathrm{d}\ln H_c/\mathrm{d}P$ is about three time larger at 100 K than at 5 K (-4.79 and -1.83×10^{-1} GPa^{-1}), indicating that the sensitivity of the

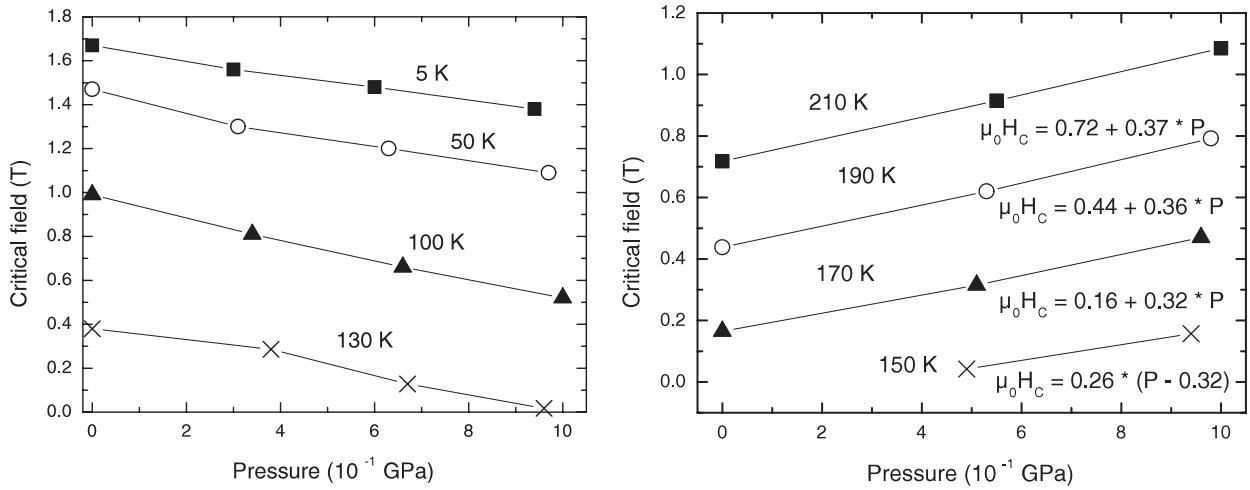

Figure 6. Pressure dependence of the FOMP critical field as measured on a YCo_4B single crystal for the indicated temperatures.

Table 2. Anisotropy parameters of the YCo_4B compound as determined from the fit of the 5 K isothermal magnetization curves recorded along the *c* axis of the crystal structure at the indicated pressure.

P (GPa)	M_s (μ_B f.u.$^{-1}$)	K_1 (10^{-23} J f.u.$^{-1}$)	K_2 (10^{-23} J f.u.$^{-1}$)	K_3 (10^{-23} J f.u.$^{-1}$)	E_A (10^{-23} J f.u.$^{-1}$)
0	2.764	−2.32	0.0	−0.73	3.05
0.3	2.730	−2.1	0.0	−0.8	2.92
0.6	2.700	−1.9	−0.02	−0.8	2.74
0.94	2.680	−1.8	0.06	−0.8	2.59
1@ 100 K	2.620	−0.7	0.0	−0.30	0.95

FOMP to the applied pressure is increased when going closer to the spin reorientation temperature. Figure 6 presents the pressure dependence of the FOMP critical field as measured on a YCo_4B single crystal at different temperatures below the spin reorientation temperature.

According to the procedure described above, the anisotropy parameters have been refined from a fit of the magnetization curve recorded below the spin reorientation when applying the magnetic field along the *c* axis of the crystal structure. An example of such a fit of the magnetization is given at 5 K and 0 GPa in figure 7. Whereas the K_2 coefficient remains negligible whatever the pressure is, the magnitude of the K_1 and K_3 coefficients is found to be significantly modified by an applied pressure. As can be seen from the values listed in table 2, the decrease is from $K_1 = -2.3 \pm 0.2 \times 10^{-23}$ J f.u.$^{-1}$ to $-1.8 \pm 0.2 \times 10^{-23}$ J f.u.$^{-1}$ at ambient and 0.94 GPa pressure, respectively. The K_3 parameter is less sensitive and varies only from -0.7 ± 0.2 to $-0.8 \pm 0.2 \times 10^{-23}$ J f.u.$^{-1}$ for ambient pressure and 0.94 GPa, respectively. It is worth mentioning that the values of the anisotropy constants determined under pressure are all consistent with the occurrence of a type II FOMP; a result also consistent with the fact that at the critical field the magnetization does not immediately reach the saturation but a higher field is required to reach the saturation magnetization.

4.2.2. Pressure dependence of the FOMP above the spin reorientation. As discussed in section 3.2, a step-like shape of the magnetization curves recorded along the *a* axis is also observed above the spin reorientation. Its pressure evolution has been probed by applying an external pressure to the single-crystalline sample, the critical field being defined as the maximum of the derivative of the $M(H)$ curve. An example of such a magnetization curve is given in figure 8. As can be seen from figures 5(b), and 8, the critical field is increased by applying pressure to the YCo_4B sample above T_{SR}. At 210 K, the critical field goes from 0.718 to 1.085 T for 0 and 0.85 GPa, respectively. As can be seen from figure 6, this evolution is opposite to that observed at low temperature. Once again, the observed changes bear witness to the modification of the anisotropy of the Co sublattice upon applying pressure. The

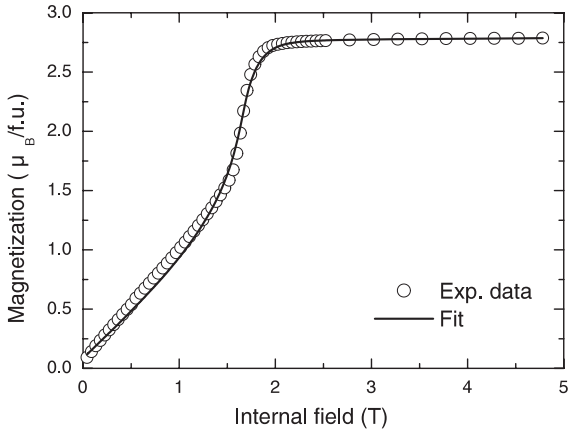

Figure 7. Fit of the magnetization curves recorded along the *c* axis of the YCo_4B single crystal at 5 K and 0 GPa.

Table 3. Anisotropy parameters of the YCo_4B compound as determined from the fit of the isothermal magnetization curves recorded along the *a* axis of the crystal structure at the indicated pressures and temperatures.

T (K)	P (GPa)	M_s (μ_B f.u.$^{-1}$)	K_1 (10^{-23} J f.u.$^{-1}$)	K_2 (10^{-23} J f.u.$^{-1}$)	K_3 (10^{-23} J f.u.$^{-1}$)	E_A (10^{-23} J f.u.$^{-1}$)
150	0.5	2.70	0.23	−0.057	0.0	0.18
	0.96	2.65	0.75	−0.663	0.36	0.45
170	0.52	2.63	1.09	−0.645	0.28	0.72
	0.98	2.57	1.45	−0.81	0.33	0.97
190	0.54	2.55	1.55	−0.52	0.1	1.13
	1	2.495	1.70	−0.41	0.06	1.35
210	0.57	2.46	1.67	−0.24	0.0	1.43
	1.02	2.39	1.84	−0.25	0.03	1.62
230	1.04	2.24	1.78	−0.12	0.01	1.67
250	0.61	2.20	1.73	−0.09	0.0	1.64
	1.06	2.17	1.83	−0.08	0.01	1.76

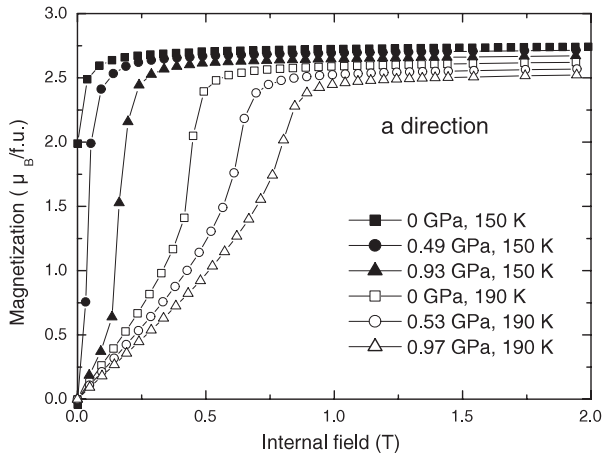

Figure 8. Isothermal magnetization curves recorded above the spin reorientation temperature along the *a* direction on a single-crystal YCo_4B at the indicated temperature and pressure.

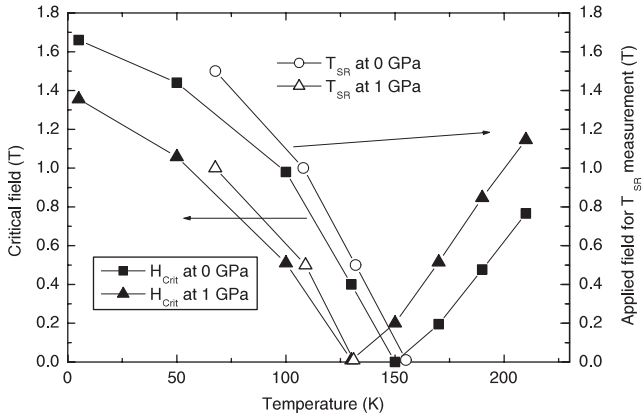

Figure 9. Temperature evolution of the critical field and T_{SR} determined at ambient pressure and estimated values of the same quantities for the pressure of 1 GPa.

temperature dependence of the critical field is also enhanced by the application of pressure since $d\mu_0 H_c/dT$ goes from 0.012 T K^{-1} to 0.0146 and 0.0155 T K^{-1} for 0, 0.49 and 0.94 GPa, respectively.

A comparison of figures 5(a) and (b) clearly shows that the proximity to the spin reorientation temperature induces a reduction of the critical field at which the FOMP manifests itself, this behavior being true for both orientation of the *c* axis below T_{SR} and the *a* axis above T_{SR}.

We have seen that both the spin reorientation and the critical field at which the FOMP manifests itself are dependent upon pressure and temperature. Figure 9 presents the thermal evolution of two fields for two different pressures 0 and 1 GPa. The thermal evolution of the internal critical field which induces the FOMP process is given in figure 9. It has been shown—see figure 2—that a spin reorientation transition can be induced by applying a critical field along the *c*-axis direction. The thermal evolution of this critical field is also presented in figure 9. It is clearly seen that both transition fields have similar thermal and pressure dependence.

The anisotropy parameters have also been refined from a fit of the isothermal magnetization curve recorded above the spin reorientation. Whereas the K_3 coefficient becomes negligible at temperatures of 190 K and above, the magnitude of the K_1 and K_2 coefficients is found to be significant and to be modified by an applied pressure. As can be seen from the values listed in tables 1 and 3, at 170 K, K_1 increases from $0.76 \pm 0.2 \times 10^{-23}$ J f.u.$^{-1}$ to $1.45 \pm 0.2 \times 10^{-23}$ J f.u.$^{-1}$ at ambient and 0.98 GPa pressure, respectively. The K_2 parameter variation is less significant if one takes into account the typical standard deviation of 10^{-23} J f.u.$^{-1}$. Only a large increase is observed at 150 K where K_2 goes from −0.06 to -0.66×10^{-23} J f.u.$^{-1}$ at 0.5 and 0.96 GPa, respectively. This reflects the sensitivity of the anisotropy parameters around the spin reorientation temperature. At temperatures further above T_{SR}, the influence of pressure on the value of K_2 is much reduced. In contrast, the K_1 anisotropy parameter continues to increase upon applying a pressure up to going at 250 K from 1.73 up to 1.83×10^{-23} J f.u.$^{-1}$ for 0.61 and 1.06 GPa, respectively.

5. Conclusions

Large sensitivity of the Co magnetocrystalline anisotropy to external excitations like temperature, field and pressure has been observed. As an example the spin reorientation temperature dramatically changes versus the applied pressure

showing that the pressure dependence of the two inequivalent Co crystal site contributions to the anisotropy is different. An increase of the applied isostatic pressure leads to a reduction of the spin reorientation transition, thus increasing the thermal domain where the *c* axis is the easy magnetization direction. That is to say, increasing the pressure leads to reducing the overall magnitude of the planar character of the YCo_4B anisotropy, thus favoring an enhancement of the KCo_{2c}/KCo_{6i} ratio between the individual site contributions to the magnetocrystalline anisotropy. YCo_4B can be regarded as a sample very sensitive to the external pressure since almost all its magnetic properties are changing versus pressure: the ordering temperature, the magnetization but also the spin reorientation temperature and the field at which the FOMP occurs as well as the anisotropy energy have been found to vary with pressure.

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