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## Magnetization of NdIn<sub>3</sub>, GdIn<sub>3</sub> and DyIn<sub>3</sub> single crystals

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**Résumé.** — L'aimantation de monocristaux de NdIn<sub>3</sub>, GdIn<sub>3</sub> et DyIn<sub>3</sub> a été mesurée suivant trois axes cristallographiques principaux dans le domaine antiferromagnétique ordonné, sous champ magnétique continu jusqu'à 19 T. On a observé sur DyIn<sub>3</sub> un processus d'aimantation à plusieurs sauts attribué à la structure magnétique spécifique de ce composé. L'aimantation à saturation de NdIn<sub>3</sub> et DyIn<sub>3</sub> atteint des valeurs inférieures aux valeurs calculées pour les ions terres rares libres.

**Abstract.** — The magnetization of NdIn<sub>3</sub>, GdIn<sub>3</sub> and DyIn<sub>3</sub> single crystals has been studied in the antiferromagnetically ordered state along three principal crystallographic axes in stationary magnetic fields up to 19 T. The multiple-step magnetization process has been found in DyIn<sub>3</sub> due to its specific magnetic structure. Saturation magnetization of NdIn<sub>3</sub> and DyIn<sub>3</sub> reaches the values lower than those expected for free RE<sup>3+</sup> ions.

In the present work the results of the magnetization measurements of NdIn<sub>3</sub>, GdIn<sub>3</sub>, and DyIn<sub>3</sub> single crystals in the antiferromagnetically ordered state in high stationary magnetic fields up to 19 T are reported. In the former paper [1] similar data partially obtained in Service National des Champs Intenses at Grenoble have been presented for CeIn<sub>3</sub> and PrIn<sub>3</sub> single crystals.

The compounds investigated here are antiferromagnets with  $T_N$  equal to 7 K, 42-44 K, and 18.5-20 K for NdIn<sub>3</sub>, GdIn<sub>3</sub>, and DyIn<sub>3</sub>, respectively the applied magnetic field being equal to 2 T. For GdIn<sub>3</sub> and DyIn<sub>3</sub> the Néel temperature varies with crystallographic axis along which the magnetic field is applied (Figs. 1, 2) reaching the highest values along  $\langle 100 \rangle$  and  $\langle 110 \rangle$  for GdIn<sub>3</sub> and DyIn<sub>3</sub>, respectively. It should be mentioned here, that the observed change of  $T_N$  is expected for a spiral antiferromagnetic structure [2]. It has been found also that the Néel point values for DyIn<sub>3</sub> single crystal samples are lower than that for the polycrystalline material for which  $T_N = 23.5$  K being close to the value reported by Buschow *et al.* [3]. This effect is probably due to the influence of internal stresses in polycrystalline samples.

The characteristic feature of the field dependence of magnetization of all investigated compounds in ordered state is a markedly nonlinear behaviour at lower fields what according to Dzyaloshinsky *et al.* [4] may be caused by the appearance of quadratic (generally even) terms with respect to  $H$  in the field expansion of the magnetization of an antiferromagnet. The observed magnetic behaviour indicates an existence of noncolinear antiferromagnetic ordering in

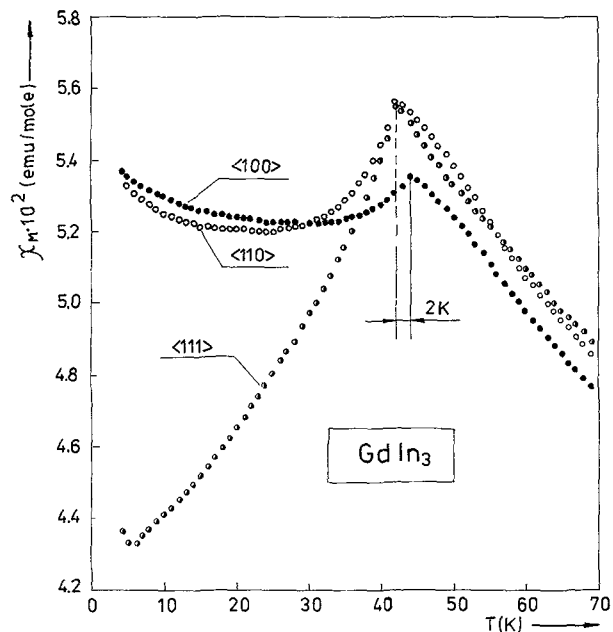


Fig. 1. — Temperature dependence of molar magnetic susceptibility at 2 T for GdIn<sub>3</sub> single crystal.

these compounds confirmed in the case of DyIn<sub>3</sub> by neutron diffraction method by Lethuillier *et al.* [5].

The magnetization of NdIn<sub>3</sub> along all three principal crystallographic axes as well as that of DyIn<sub>3</sub> along  $\langle 110 \rangle$  and  $\langle 111 \rangle$  axes reaches at 4.2 K saturation with the values equal to 2.20, 2.26, and 2.05  $\mu_B$  for NdIn<sub>3</sub> and 8.67, and 8.43  $\mu_B$  for DyIn<sub>3</sub> along the above mentioned axes, respectively. For

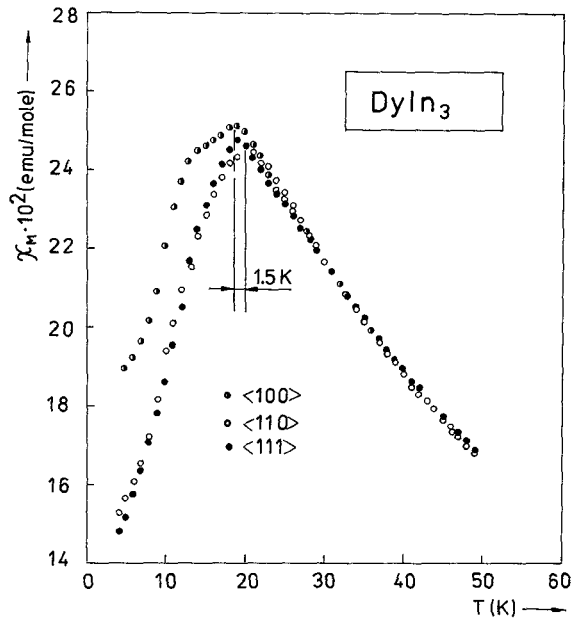


Fig. 2. — Temperature dependence of molar magnetic susceptibility at 2 T for DyIn<sub>3</sub> single crystal.

GdIn<sub>3</sub>, in magnetic field of 19 T, the magnetization reaches the values equal to but 1.74, 1.54, and 1.69 μ<sub>B</sub> along < 100 >, < 110 >, and < 111 > axes, respectively.

In the magnetization process of NdIn<sub>3</sub> one observes a hysteresis loops between 3.85 and 4.30 T (Fig. 3) for all three principal crystallographic axes. Moreover, the magnetization curves reveal an inflection point at about 6.5 T. The above behaviour cannot be understood an assuming the (ππ0) type [5] magnetic structure.

The magnetization of GdIn<sub>3</sub> along the < 100 > and < 111 > directions does not reveal any anomalies, and shows a tendency to reach the saturation in the

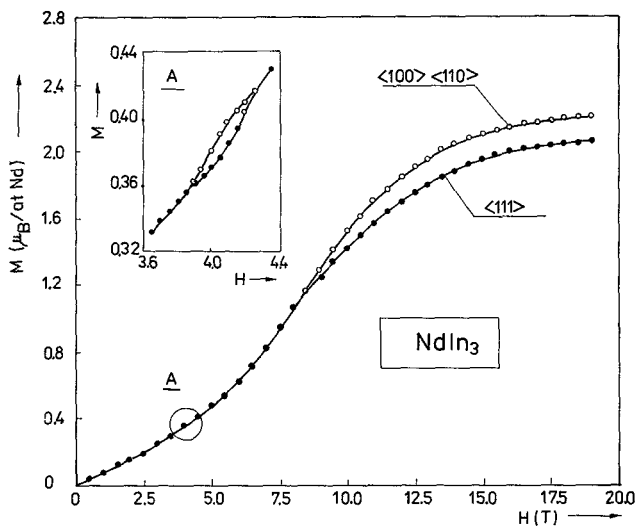


Fig. 3. — Magnetization vs. magnetic field at 4.2 K for NdIn<sub>3</sub> single crystal.

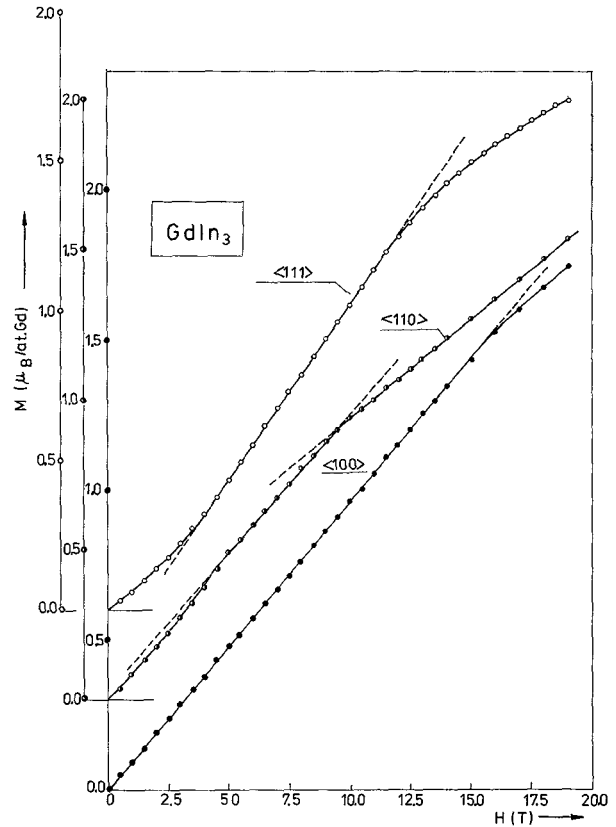


Fig. 4. — Magnetization vs. magnetic field at 4.2 K for GdIn<sub>3</sub> single crystal.

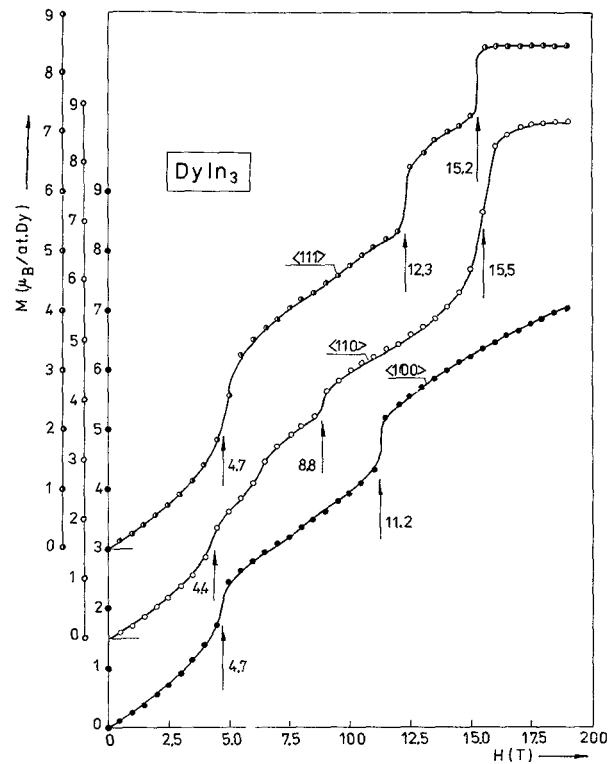


Fig. 5. — Magnetization vs. magnetic field at 4.2 K for DyIn<sub>3</sub> single crystal.

fields above 12.5 T. However, along the  $\langle 110 \rangle$  direction it has an inflection point at 2.6 T and above this field it consists of two straight lines intersecting each other at 9.5 T.

The magnetization of DyIn<sub>3</sub> exhibits three transitions along  $\langle 110 \rangle$  and  $\langle 111 \rangle$  axes and two along  $\langle 100 \rangle$  axis with almost discontinuous changes along

$\langle 111 \rangle$  direction. The critical fields determined from the positions of the maxima of  $dM/dH$  are as follows : 4.7 and 11.2 T for  $\langle 100 \rangle$ , 4.4, 8.8 and 15.5 T for  $\langle 110 \rangle$ , and 4.7, 12.3 and 15.2 T for  $\langle 111 \rangle$  axis. The character of the magnetization curves seems to be comprehensible on the basis of the proposed [5] magnetic structure of this compound.

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