SATURATION MAGNETIC MOMENT AND CRYSTALLINE ANISOTROPY OF SINGLE CRYSTALS OF LIGHT RARE EARTH COBALT COMPOUNDS RCo5

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Résumé. — Des mesures de l'aimantation de monocristaux sphériques de composés de Y, Ce, Pr, Nd et $SmCo_5$ ont permis de déterminer la valeur du moment magnétique par unité de formule moléculaire 7,9 ; 6,6 ; 10,4 ; 10,4 et 7,7 μ_B respectivement. Les constantes d'anisotropie K_1 (0) et K_2 (0) à 0 °K ont été évaluées, à partir des courbes K_1 et K_2 en fonction de la température, à 6,5 et ~ 0 ; 5,5 et ~ 0 ; — 7 et 18 ; — 40 et 19 ; 10,5 et ~ 0 ($\times 10^7$ erg.cm^{-3}) pour les composés ci-dessus respectivement. La variation linéaire de K_1 (0) et K_2 (0) en fonction de x obtenu dans $Y_{1-x}Nd_xCo_5$ semble indiquer que le modèle à ion est applicable à ces cas.

Abstract. — Magnetization measurements of single crystal spheres of Y, Ce, Pr, Nd and $SmCo_5$ compounds yield the magnetic moment per formular unit 7.9, 6.6, 10.4, 10.4 and 7.7 μ_B, respectively. The anisotropy constants K_1 (0) and K_2 (0) at 0 °K estimated from the K_1 and K_2 vs temperature curves measured are 6.5 and ~ 0, 5.5 and ~ 0, — 7 and 18, — 40 and 19, 10.5 and ~ 0 ($\times 10^7$ ergs.cm^{-3}) for the above compounds, respectively. Linear variation of K_1 (0) and K_2 (0) with x obtained in $Y_{1-x}Nd_xCo_5$ gives evidence in support of single ion model.

I. **Introduction.** — For investigation of light rare earth cobalt RCo_5 compounds with large magnetic anisotropy, it is important to have the saturation magnetic moment and the magnetocrystalline anisotropy constants determined on their single crystals, which have not yet been obtained except Y and Sm compounds [1], [2]. It may also be worth-while to measure the magnetocrystalline anisotropy as a function of x in $Y_{1-x}Nd_xCo_5$ for investigating the applicability of single ion model, since Nd is assumed to be a typical light rare earth element for the model.

II. **Sample Preparation.** — Single crystals used are YCo_5, $CeCo_5$, $PrCo_5$, $NdCo_5$, $SmCo_5$ and $Y_{1-x}Nd_xCo_5$. The purity of rare earth elements except Ce, 99.5 %, is 99.9 % and that of Co is 99.99 %. The compounds were prepared as button ingots by plasma-jet melting in argon atmosphere. The single crystals were grown by annealing the button ingots at high temperatures and were ground into approximate spheres 1-2 mm in diameter for the samples.

III. **Saturation Magnetic Moment.** — To determined the saturation magnetic moment per gram σ_s, the magnetization was measured along the easy direction by placing a sample freely in a small quartz basket attached to a magnetic balance, so that the easy direction of the sample may always lie in the direction of fields applied up to 16 kOe. The determined σ_s is plotted against temperature in figure 1. All the curves appear to be composed of the magnetic moment vs temperature curves of rare earth atoms in RCo_5 and Co which may mostly be responsible for the Curie temperature. The value of σ_{s0} at 0 °K estimated from the σ_s vs T^2 curve is 116.0, 84.0, 133.6, 132.3 and 96.0 emu/g^{-1} for Y, Ce, Pr, Nd and Sm compounds, respectively. The Curie temperature T_c determined from the isothermal σ/H vs σ^2 curves and the magnetic moment per formular unit $\mu(RCo_5)$ evaluated from σ_{s0} are listed in Table I. Exception of both T_c and σ_{s0} for $CeCo_5$ may be ascribed to the existence of some Ce atoms having no magnetic moment like its 4^+ ion. On the assumption that Ce

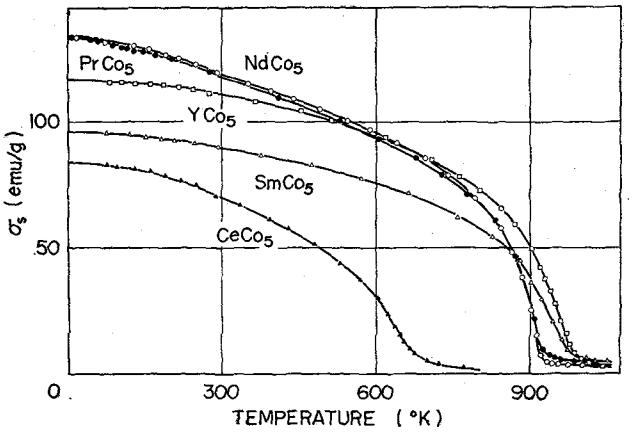

FIG. 1. — The saturation magnetic moment vs temperature curves.

TABLE I

	T_c (°K)	$\mu(RCo_5)$ (μ_B)	$K_1(0)$ (10^7 erg.cm^{-3})	$K_2(0)$ (10^7erg.cm^{-3})
YCo_5	978	7.9	6.5	~ 0
$CeCo_5$	673	6.6	5.5	~ 0
$PrCo_5$	921	10.4	— 7	18
$NdCo_5$	913	10.4	— 40	19
$SmCo_5$	984	7.7	10.5	~ 0

atom as well as Y has no magnetic moment, and the magnetic moments of rare earth atoms are the same as those of their respective 3^+ ions and exactly parallel to the magnetization of Co at 0 °K, the magnetic moment per atom of Co are evaluated from $\mu(RCo_5)$ as 1.57, 1.32, 1.44, 1.43 and 1.40 μ_B for Y, Ce, Pr, Nd and Sm compounds, respectively.

IV. **Magnetocrystalline Anisotropy.** — Magnetocrystalline anisotropy constants K_1 and K_2 in the anisotropy energy expression

$$E_a = K_1 \sin^2 \theta + K_2 \sin^4 \theta$$

are determined from the pure rotation magnetization curve measured in the direction parallel or per-

pendicular to the c-axis, to which one of the following expressions is applied [3].

$$\frac{H}{M_{\parallel}} = -\frac{2K_1 + 4K_2}{M_s^2} + \left(\frac{4K_2}{M_s^4}\right) M_{\parallel}^2 \qquad (1)$$

$$\frac{H}{M_{\perp}} = \frac{2K_1}{M_s^2} + \left(\frac{4K_2}{M_s^4}\right) M_{\perp}^2 . \qquad (2)$$

Here M_s is the saturation magnetic moment per cm^3, and θ is the polar angle of M_s from the c-axis, and H is the effective field, and $M_{\parallel}$ or $M_{\perp}$ is the magnetization measured in the direction of H which is applied in the direction parallel or perpendicular to the c-axis, respectively. This measurement was accomplished with the samples, the crystal orientation of which was analysed by a back Laue pattern technique. The determined K_1 and K_2 are plotted against temperature in figure 2. For Y, Ce and Sm compounds K_1 is positive in value at all temperatures and K_2 is negligible. A broad maximum of the K_1 curve of $SmCo_5$ may be attributable to the fact that the high J states mix more with the ground state with decreasing temperature owing to the exchange interaction with Co. For Pr and Nd compounds K_2 is positive in value and sharply decreases with increasing temperature, but K_1 changes the value from negative to positive with increasing temperature. For $NdCo_5$ it is especially noted that both the K_1 and K_2 vs temperature curves are similar to those obtained on the oriented powder [4], but both magnitudes are, on the average, larger by one order. The values of $K_1(0)$ and $K_2(0)$ at 0 °K estimated from the result in figure 2 are given in Table I. In figure 3 these are plotted against x for $Y_{1-x}Nd_xCo_5$. Both the $K_1(0)$ and $K_2(0)$ are linear in x. This result approves single ion model, on the basis of which the anisotropy constants $K_{1R}(0)$ and $K_{2R}(0)$ of Nd atom may be estimated as the differences in $K_1(0)$ and $K_2(0)$ between $NdCo_5$ and YCo_5, respectively. The values of $K_{1R}(0)$ and $K_{2R}(0)$ thus estimated for not only Nd, but also Ce, Pr and Sm in their respective compounds are − 199 and 83, − 4 and ~ 0, − 59 and 77, and 18 and ~ 0 (cm^{-1}), respectively. These values, however, in poor agreement with the crude theoretical ones tried with the Stevens factor [5].

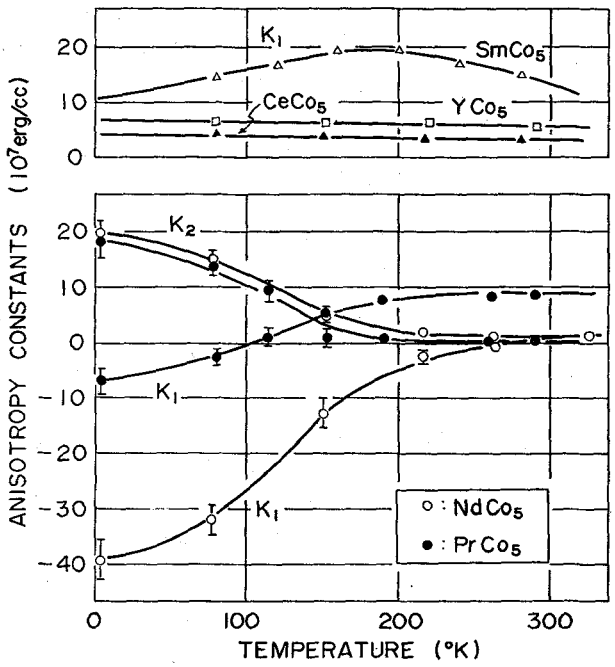

FIG. 2. — Plot of the anisotropy constants against temperature.

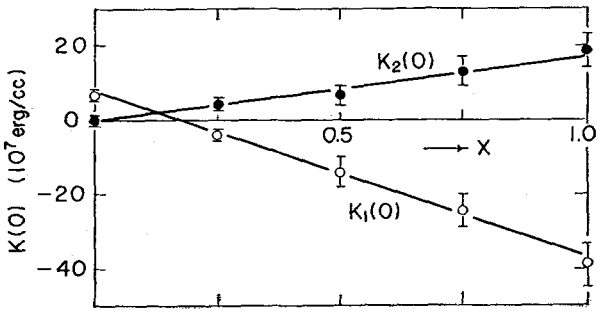

FIG. 3. — Plot of the anisotropy constants at 0 °K against x in $Y_{1-x}Nd_xCo_5$.

In figure 4 the easy direction referred to the c-axis, β, which was found by torque measurements is plotted against temperature for $PrCo_5$ and $Y_{1-x}Nd_xCo_5$. For $PrCo_5$ and $NdCo_5$ the variation of the easy direction with temperature is consistent with that deduced from the values of K_1 and K_2 in figure 2. The critical temperature at which the easy direction begins to tilt from the c-axis is 105 °K for $PrCo_5$ and for $NdCo_5$ 283 °K which is in agreement with that determined by neutron diffraction [4]. The critical temperatures of $Y_{1-x}Nd_xCo_5$ are all in good agreement with those determined from the temperature dependences of K_{1R} of Nd atom and K_1 of YCo_5 on the basis of single ion model.

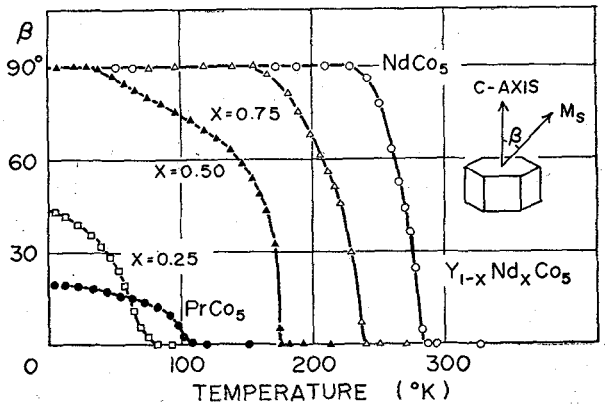

FIG. 4. — Plot of the easy direction against temperature.

References

[1] HOFFER (G.), STRNAT (K.), *J. Appl. Phys.*, 1967, **38**, 1377.
[2] BUSCHOW (K. H. J.), VELGE (W. A. J. J.), *Z. angew. Phys.*, 1969, **26**, 157.
[3] SUCKSMITH (W.), THOMPSON (J. E.), *Proc. R. Soc.*, 1954, **225**, 362.
[4] BARTHOLIN (H.), VAN LAAR (B.), LEMAIRE (R.), SCHWEIZER (J.), *J. Phys. Chem. Solids*, 1966, **27**, 1287
[5] STEVENS (K. W. H.), *Proc. Phys. Soc.* (London), 1952, **A65**, 209.