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SATURATION MAGNETIC MOMENT AND CRYSTALLINE ANISOTROPY OF SINGLE CRYSTALS OF LIGHT RARE EARTH COBALT COMPOUNDS RCo$_5$

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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 $\mu_B$ 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 (× 10$^6$ 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$_x$Co$_5$ 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 formula unit 7.9, 6.6, 10.4, 10.4 and 7.7 $\mu_B$, 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 (× 10$^6$ erg.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$_x$Co$_5$ 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$_x$Co$_5$ 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$_x$Co$_5$. 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 $\sigma_0$, 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 $\sigma_0$ 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 possibly be responsible for the Curie temperature. The value of $\sigma_0$ at 0 K estimated from the $\alpha_0$ vs $T^2$ curve is 116.0, 84.0, 133.6, 132.3 and 96.0 emu/g for Y, Ce, Pr, Nd and Sm compounds, respectively. The Curie temperature $T_c$ determined from the isothermal $\sigma / H$ vs $T$ curves and the magnetic moment per formaulum unit $\mu$ (RCo$_5$) evaluated from $\sigma_0$ are listed in Table I. Exception of both $T_c$ and $\alpha_0$ for CoCo$_5$ may be ascribed to the existence of some Ce atoms having no magnetic moment like its 4$^+$ ion. On the assumption that Ce 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 $\mu_B$ 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

$$E_a = K_1 \sin^4 \theta + K_2 \sin^6 \theta$$

are determined from the pure rotation magnetization curve measured in the direction parallel or per-
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perpendicular to the c-axis, to which one of the following expressions is applied [3].

\[
\frac{H}{M_0} = \frac{2 K_1}{M_0^2} + \left(\frac{4 K_2}{M_0^4}\right) M_0^2, \quad (1)
\]

\[
\frac{H}{M_0} = \frac{2 K_2}{M_0^2} + \left(\frac{4 K_1}{M_0^4}\right) M_0^2. \quad (2)
\]

Here \(M_0\) is the saturation magnetic moment per cm\(^3\), and \(\theta\) is the polar angle of \(M_0\) from the c-axis, and \(H\) is the effective field, and \(M_0\) or \(M_1\) 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 \(\text{SmCo}_5\) 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 \(\text{NdCo}_5\) 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 \(Y_{1-x}\text{Nd}_x\text{Co}_5\). 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 \(\text{NdCo}_5\) and \(Y\text{Co}_5\), 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 \(~0\) (cmdl), respectively. These values, however, in poor agreement with the crude theoretical ones tried with the Stevens factor [5].

In figure 4 the easy direction referred to the c-axis, \(\beta\), which was found by torque measurements is plotted against temperature for \(\text{PrCo}_5\) and \(Y_{1-x}\text{Nd}_x\text{Co}_5\). For \(\text{PrCo}_5\) and \(\text{NdCo}_5\) 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 \(\text{PrCo}_5\) and for \(\text{NdCo}_5\) 283 K which is in agreement with that determined by neutron diffraction [4]. The critical temperatures of \(Y_{1-x}\text{Nd}_x\text{Co}_5\) are all in good agreement with those determined from the temperature dependences of \(K_{1R}\) of Nd atom and \(K_1\) of \(Y\text{Co}_5\) on the basis of single ion model.

References