The Magnetic Properties of Metallic Cerium*

The magnetic behavior of cerium has been studied as a function of field strength and temperature. Several unusual characteristics were found. The cerium had the following analysis: Ce 97 percent, Fe 0.5 percent, CeO_2 0.7 percent, and the remainder other earths. The measurements were made by a method previously described.[1] The experimental results are shown in Figs. 1 and 2, where σ is the magnetization per gram, χ is the high field strength differential susceptibility ($d\sigma/dH$) per gram, and all temperatures are °K. The intercept values plotted in Fig. 2 represent the value of σ found from Fig. 1 by a linear extrapolation back to zero field of the high field portion of the magnetization curve. If the magnetic behavior of cerium is considered as

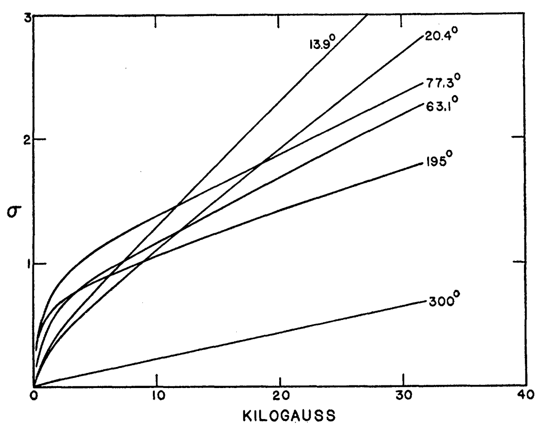

FIG. 1. The magnetization per gram as a function of the field strength for various °K.

a combination of paramagnetic and ferromagnetic terms, the magnitude of the intercept represents the saturation magnetization of the ferromagnetic term. The paramagnetic term χ appears to follow a Curie-Weiss law at high temperatures, becoming somewhat anomalous at low temperatures. The observed intercept values shown in Fig. 2 differ from that expected from the usual ferromagnetic impurity in that they decrease with decreasing temperatures at low temperatures, instead of approaching a maximum value.

The 0.5 percent Fe in the cerium may be in solution, precipitated, or as a Ce—Fe intermetallic compound. If the Fe were completely precipitated, it would be sufficient to account for the maximum observed intercept, but the effect should begin at the Curie point of Fe, 1043°K, be almost at its maximum at 300°K, and should not decrease at lower temperatures. Extension of the measurements to 800°K revealed no appreciable change in the room temperature value of the intercept, which is therefore probably due to a small amount of precipitated iron. The intermetallic compound $CeFe_2$ is reported to be ferromagnetic with a Curie temperature of 389°K, but no evidence of its presence was found. Apparently, whatever the cause of the unusual intercept characteristic, it is not due to a ferromagnetic impurity of the customary type.

The experimental results are reproducible and are not

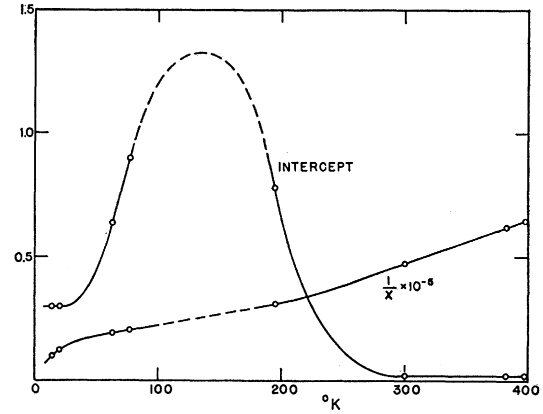

FIG. 2. The magnetization intercept and the reciprocal high field susceptibility as a function of temperature.

affected by repeated cooling and warming cycles below room temperature. There was no difference in the measurements at 20.4°K when the specimen was rapidly cooled (1 minute) from 300°K or slowly cooled (30 minutes). Since the rate of cooling has no effect, the results cannot be attributed to a sluggish phase transition occurring over a range of temperature. Prolonged aging at room temperature or high temperature heat treatment produces quantitative changes but not qualitative. A high temperature anneal at 500°C for one hour and 300°C for 12 hours resulted in an increase of the intercept at 300°K and a decrease at 77.3°K. It has been shown[2] that cerium has at least three stable phases, β (hexagonal) at room temperature, γ (cubic) above 393°C, δ above 440°C. Because of the sluggishness of the phase transitions the cerium has a mixture of these phases at any temperature, and the proportions of this mixture would be influenced by heat treatment. Trombe[3] made measurements on an impure cerium specimen down to 99°K where he found a dependence of susceptibility upon the field strength. He also reports a temperature-susceptibility hysteresis between 100 and 200°K, which may indicate another phase, α at low temperatures. In the present measurements at 13.9° and 20.4°K, the magnetization measured with increasing fields was several percent less than with decreasing fields. This magnetic hysteresis disappeared at higher temperatures.

In order to determine whether these unusual properties are characteristic of pure cerium or are caused by the presence of the iron impurity, an attempt will be made to obtain an iron-free sample of metallic cerium for further study.

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[2] F. M. Jaeger, J. A. Bottema and E. Rosenbohm, Rec. trav. chim. **57**, 1137 (1938).

[3] F. Trombe, Comptes rendus **198**, 1592 (1934).