Heat capacity measurements on h.c.p. solid solutions of lanthanum in gadolinium have been performed in an adiabatic calorimeter over a wide temperature range, and the temperature-dependence of the ferromagnetic transition of Gd by alloying with La has been evaluated. The hardening effects of this alloying are pointed out.

A linear dependence of the molar volume on the concentration, close to Vegard's law, is found at room temperature; the effects of a second-order transition are outlined.

It is well known that the magnetic ordering in the rare earth metals (R) is due to a long-range indirect interaction responsible for the coupling between 4f orbitals, which involves the polarization of the conduction electrons.

The theory is associated with the names of Rudermann, Kittel, Kasuja and Yosida (RKKY). Reviews have been given, for example, by Kittel [1]. Such an interaction is capable of giving rise to a variety of periodic spin structures, as are indeed observed for the heavy R. The neighboring R are quite similar in their physical and chemical properties (excluding those depending directly on the 4f electrons) because of the regular filling of the inner 4f level. This similarity has an important effect on the intra-R binary alloys. There is a tendency for these to behave as ideal alloys at high temperature: thus, there is no measurable difference in the liquidus and solidus temperature; further, the liquidus/solidus line is practically a straight line connecting the respective melting points of the pure metals. This behavior is closely followed if neighboring elements are alloyed.

Deviations from ideal behavior are to be expected when the atomic numbers of the two lanthanides become more and more different. However, an extended solid solubility is always to be expected.

Up to 16 at. % La enters the h.c.p. cell of Gd [2], resulting in the magnetic dilution of the Gd.

For concentrations between 16 and 42 at. % La, the Gd–La alloy system presents [3, 4] an intermediate phase (β) that has the same structure as metallic samarium. At concentrations higher than 42 at. % La, the d.h.c.p. structure of La is stable.
From a magnetic point of view, when the Gd/La ratio is decreased, a transition occurs in the magnetic phase diagram, from ferromagnetic dispositions to antiferromagnetic ones [2, 5].

In this paper, experimental results obtained during the study of the alloying effect on the ferromagnetic transformation of Gd will be reported.

**Experimental**

The starting materials, 3N La and 2N5 Gd, were obtained from Rare Earths Products Inc. and Koch–Light Co., respectively.

Alloys up to 12 at.% La (each consisting of ~ 6 g a stoichiometric mixture of the elements) were prepared for direct synthesis in an arc furnace under an argon inert atmosphere. The samples were melted 5 times to obtain a first homogenization. The buttons thus obtained were then wrapped in high-temperature degassed tantalum foil, sealed in vacuum in silica tubes, and annealed for a week at about 800°.

Every sample was examined micrographically and X-ray analyzed, and Vickers microhardness measurements were performed.

The reticular parameters obtained by the powder method of Debye–Sherrer showed, in agreement with the literature values [3], a linear dependence on the composition, following the Vegard law relationship in the considered range. The calorimetric measurements were made in a continuous heating adiabatic [6] computer-controlled [7] calorimeter. The microhardness measurements were carried out with a Leitz Durimet microhardness tester.

**Results**

In Table 1, experimental values of $C_p$ (for one mole of substance) and other thermodynamic data for Gd$_{1-x}$La$_x$ alloys are reported.

Figure 1 presents the molar heat capacities of such alloys vs. the temperature. The dilution of the magnetic rare earth is accompanied by a linear lowering of the Curie temperature (Fig. 2) with $dT_c/dC_{Gd} = 410$ K where $C_{Gd}$ is the gadolinium concentration. For this high dependence on the concentration, impurities of the order of 0.1 at.% will also depress the Curie temperature: this can account for the different values for $T_c$ found in the literature [2, 8].

The effect of impurities on the hardness can be seen in Fig. 3, where Vickers microhardness data are reported vs. Gd concentration, together with literature data.