MAGNETIC PROPERTIES OF GADOLINIUM AT HIGH PRESSURES AND HIGH TEMPERATURES

K. P. Belov, Yu. V. Ergin, A. A. Katsnel'son, and A. V. Ped'ko
Moscow State University
Submitted 24 February 1965

1. It was established[1] that polycrystalline gadolinium heated to 400°C and simultaneously exposed to hydrostatic pressure (for 15 minutes) goes over from a hexagonal close packed crystalline configuration into a rhombohedral configuration of the samarium type. According to [1], however, this rhombohedral modification of gadolinium is unstable at atmospheric pressure, and when cooled to the temperature of liquid nitrogen it changes almost completely into the normal hexagonal modification. It was also pointed out there that the saturation magnetization of "rhombohedral" gadolinium, measured in fields on the order of 15000 Oe, is approximately 1.5 - 2 times smaller than the saturation magnetization of hexagonal gadolinium at all temperatures, down to that corresponding to the destruction of the rhombohedral modification.

2. To clarify the question of the cause of the strong change in the saturation magnetization of "rhombohedral" gadolinium, we have measured, besides the saturation magnetization, the Curie point and the temperature dependence of the magnetic susceptibility.

The investigated gadolinium samples contained less than 0.5% impurities. As in [1], the samples were subjected to 40 kbar pressure in a high-pressure chamber at 450 ± 50°C for 15 minutes. The temperature was then abruptly reduced, after which the pressure was removed. The measurements of the magnetization (in a 15000 Oe field), of the paramagnetic susceptibility (in a 7000 Oe field), and of the Curie point were made with a Domenicali pendulum magnetometer at atmospheric pressure. The x-ray patterns of the samples were obtained with an RKU-86 camera using CuKα radiation.

3. The x-ray results were:

Gadolinium prior to pressure treatment, d, Å	3.01	2.79	2.67	2.07	1.78	1.61	1.51	1.48	-
After treatment (at 450°C), d, Å	3.43	3.10	3.03	2.90	2.80	2.75	2.60	2.41	2.22
Phase	-	r[1)]	r	r	r	hd[2)]	r	r	r
After treatment (at 450°C), d, Å	2.13	1.99	1.85	1.75	1.67	1.64	1.61	1.55	1.52
Phase	hd	r	hd	r	r	hd	r	hd	r

All the x-ray pattern lines listed in the second row coincide with the lines observed in [1], with the exception of the line with d = 3.43 Å. Most lines correspond to a rhombohedral phase of the samarium type. Several weak lines are due to the existence in the sample of a phase with double hexagonal (four-layer) packing of the lanthanum type. In view of the low intensity of these lines, we can assume that the volume occupied by this phase is small.

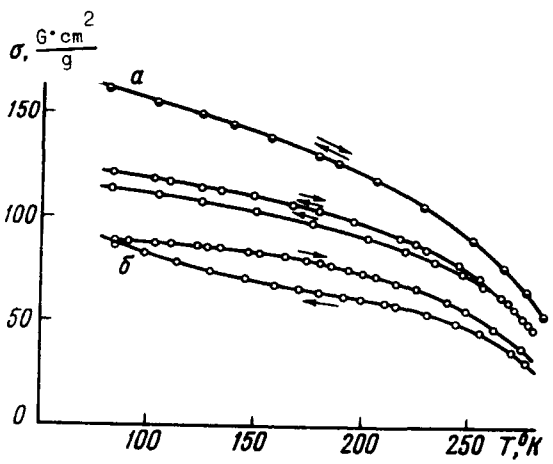

Figure 1
Temperature dependence of the saturation magnetization of gadolinium

Figure 1 shows the temperature dependence of the saturation magnetization of the untreated gadolinium sample (curves a) and of the same sample after treatment with pressure up to 40 kbar at 450°C (curve b). Curve b was plotted as the sample was being cooled from room temperature to the boiling point of nitrogen. We see that the saturation magnetization is approximately half that of the initial sample at all temperatures, in accord with the results of [1]. In cyclic heating and cooling, this difference in saturation magnetization de-

creases gradually, as seen from Fig. 1. Eventually the magnetization ceases to depend on the number of heating and cooling cycles and remains constant, but never attains the initial value.

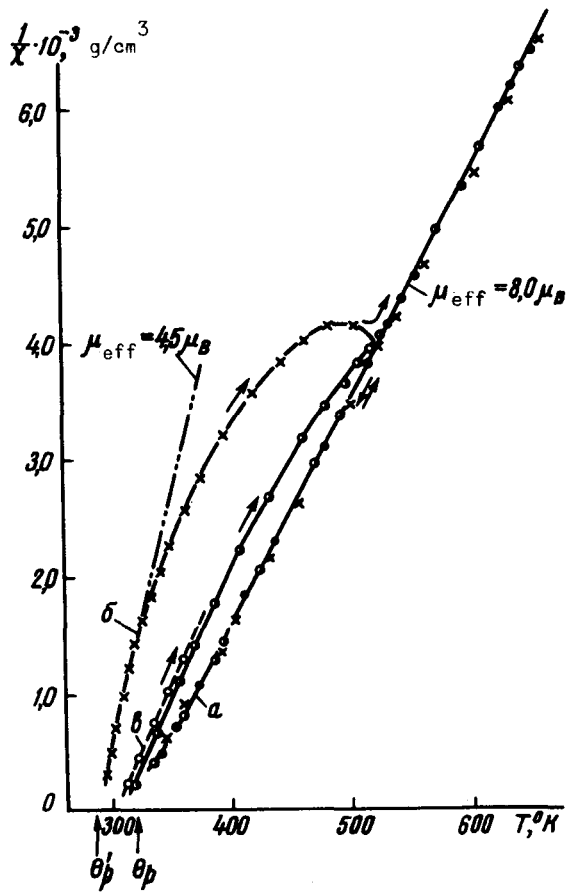

Figure 2

Temperature dependence of the reciprocal of the paramagnetic susceptibility of gadolinium: ● ● ● - hexagonal Gd, x x x - rhombohedral Gd, o o o - Gd subjected to pressure and kept 15 hours at 78°K, ◐ ◐ ◐ - Gd subjected to pressure and kept 2 hours at 4.2°K.

Figure 2 shows the temperature dependence of the reciprocal of the initial paramagnetic susceptibility (curve a) and after application of 40 kbar at 450°C (curve b). We see that curve b has a complicated temperature variation. Above 500°K it practically coincides with the curve for the initial sample. In the temperature range 300 - 340°K curve b can be approximated by a straight line. From the slope of this line we can estimate the effective moment per atom of "rhombohedral" gadolinium, found to be equal $\sim 4.5\ \mu_B$, i.e., almost half the moment of the initial gadolinium with hexagonal structure ($\sim 8\ \mu_B$). The ratio of these moments corresponds to measurements of the saturation magnetization at temperatures below the Curie point (Fig. 1).

In the temperature interval 300 - 500°K the metastable rhombohedral phase is gradually transformed in the sample into a hexagonal phase. With increasing temperature, the amount of the latter increases, and at 500°K practically the entire volume is occupied by the hexagonal phase. The x-ray patterns of the gadolinium sample treated with pressure at 450°C and heated above 500°K show no lines corresponding to the rhombohedral and double hexagonal structures. Thus, the rhombohedral modification of the gadolinium goes over into the initial hexagonal stage not only after cooling below the boiling temperature of liquid nitrogen, as established in [1], but also after heating above 500°K.

When the gadolinium sample is maintained at 78°K for 15 hours after pressure-working at 450°C, its $\chi^{-1}(T)$ curve is similar to that obtained for hexagonal gadolinium (curve c on Fig. 2). Soaking for two hours at 4.2°K likewise annihilates the rhombohedral configuration almost completely, as verified by x-ray investigations.

The Curie temperature determined by the thermodynamic-coefficient method [2] is $\Theta = 295°K$ for the initial gadolinium sample and $\Theta = 283°K$ for the sample pressure-worked at 450°C, i.e., pressure-working of gadolinium has lowered the Curie temperature by 12°. The paramagnetic Curie temperature, determined by extrapolating $\chi^{-1}(T)$ curve to the temperature axis, is 315°K and 295°K for the initial and pressure-worked samples, respectively.

It follows from our measurements that gadolinium of "rhombohedral" modification has a lower effective magnetic moment per atom than the gadolinium with hexagonal structure. This may be connected with the fact that strong heating and pressure cause the electron structure of the 4f-layer in the gadolinium to experience a realignment similar to that observed in cerium[3].

The authors thank Yu. S. Genshaft and L. D. Livshits for processing the gadolinium samples in the high-pressure chamber, V. D. Deripasko for taking the x-ray pictures, and R. Z. Levitin for participating in an evaluation of the results.

[1] A. Jayarmann and R. C. Cherwood, Phys. Rev. Lett. 12, 22 (1964).
[2] K. P. Belov, Magnitnye prevrashcheniya (Magnetic Transformations),

Fizmatgiz, 1959.

1) r - rhombohedral phase (of the Sm type)
2) hd - hexagonal double phase (of the Ln type).

PRODUCTION OF GIANT LASER EMISSION PULSES IN NEODYMIUM ACTIVATED GLASS WITH THE AID OF TRANSLUCENT SOLUTIONS

O. L. Lebedev, V. N. Gavrilov, Yu. M. Gryaznov, and A. A. Chastov

Submitted 1 March 1965

Giant laser-emission pulses can be obtained by Q-switching the optical cavity with the aid of mechanical or electro-optical devices.[1-3]

Variation of cavity Q in a ruby laser can also be effected with translucent substances. To this end, one places in the optical cavity a cuvette with a solution of phthalocyanine or cryptocyanine[4-6], which have absorption maxima near the 6943 Å line. To obtain an analogous effect with a neodymium laser, it is necessary to use translucent substances that absorb radiation in the region of 1.06 μ. We used the polymethine dye 1,9-di(N-ethylquinoline-4)-5-acetoxynonemethineperchlorate, which has an absorption maximum at 1.03 - 1.09 μ, depending on the solvent.

We used in the laser a rod of glass activated with neodymium, 120 mm long and 10 mm in diameter, and external dielectric mirrors with reflection coefficients 68 and 90%. In the free lasing mode, at a pump energy on the order of 2000 J, the output power was 4 J. The cuvette with a solution of the dye in quinoline (maximum absorption at 10.9 μ) was placed in the optical cavity.

Compared with the free lasing mode, Q-switching with the aid of a translucent solution makes possible the production of a smaller number of pulses (down to a single pulse), but of shorter duration and higher power. With increasing transparency of the solution, the number of emission pulses decreases. At a cuvette transparency 57%, the number of pulses was approximately 50, and a single pulse was observed at 36% transparency. The pulse duration also depends on the transparency of the solution, as can be seen from Figs. 1 and 2.