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MAGNETIC PROPERTIES OF THE ALLOY $MnAu_2$ IN INTENSE PULSED MAGNETIC FIELDS UNDER HIGH HYDROSTATIC PRESSURE

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Magnetization curves were obtained for the alloy $MnAu_2$, which has a helicoidal magnetic structure, in fields up to 80 kOe under high pressures, up to 14 kbars, at room temperature. The threshold magnetic field for transition to the ferromagnetic state H_c was plotted against pressure; it was found that the threshold field decreases to zero at ~15 kbars. The results were used to calculate the energies of exchange interaction n_1 and n_2 along the c axis of the tetragonal unit cell according to current theory with regard to the alloy $MnAu_2$. It was shown that the model of competing interaction does not correspond to the nature of the helicoidal ordering of magnetic moments in $MnAu_2$, since n_1 and n_2 do not manifest the dependence on pressure which follows from this model. Proceeding from the difference in relative volume change on transition from antiferromagnetic states to the ferromagnetic state under the influence of a magnetic field ($\Delta V/V = -5 \cdot 10^{-4}$) and under hydrostatic pressure ($\Delta V/V = -21 \cdot 10^{-4}$), a hypothesis is advanced regarding the difference in transition mechanisms for the two cases.

The intermetallic alloy $MnAu_2$ has an antiferromagnetic helicoidal structure, the angle of the helicoid being ~51° at room temperature and atmospheric pressure. In a magnetic field of ~10 kOe this alloy goes over to the ferromagnetic state.

The effect of hydrostatic pressure on the magnetization of $MnAu_2$ was first investigated in [1]. It was found that hydrostatic pressure shifts the beginning of the rise in the magnetization curve downfield. A detailed investigation of the magnetic properties at high pressures was carried out in [2]. It was shown there that the threshold magnetic field in the alloy $MnAu_2$ at 12 kbars should be equal to zero. In a recent paper [3] it is stated that the pressure of transition to the ferromagnetic state is 15 kbars. All earlier measurements of the magnetization of the given alloy under hydrostatic pressure were made in steady-state magnetic fields, except for a recently published study [4] in which the magnetic field reached 80 kOe, but the pressure was quite low, amounting to only 3.3 kbars. From these measurements one can hardly draw any definite conclusion as to the effect of hydrostatic pressure on the saturation magnetization of $MnAu_2$.

It was of interest to supplement the earlier work by studying the magnetic properties of the alloy $MnAu_2$ under high pressures in intense pulsed magnetic fields; a special method was developed for this.

1. EXPERIMENTAL PROCEDURE

Pressures up to 14 kbars were produced in an independent cell made of 40Kh ferromagnetic steel. The cell is described in [5] (inner diameter 5 mm, outer diameter 20 mm, and working volume 0.6 cm^3). It was placed in a solenoid in which a pulsed magnetic field was produced by discharging a 3600-μF capacitor bank. It was found experimentally that a magnetic-field pulse having a forward front of 0.63 msec duration permeates the cell completely.

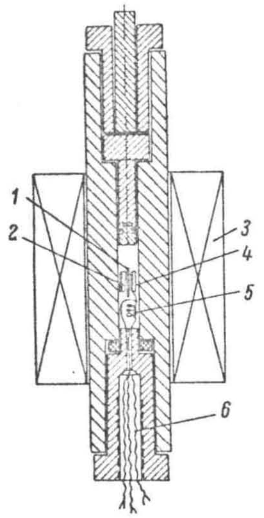

Fig. 1. Diagram of arrangement of high-pressure cell and measuring coils relative to solenoid. 1) Sample; 2) measuring coil; 3) pulse solenoid; 4) compensating coil; 5) manganin manometer; 6) electrical cable.

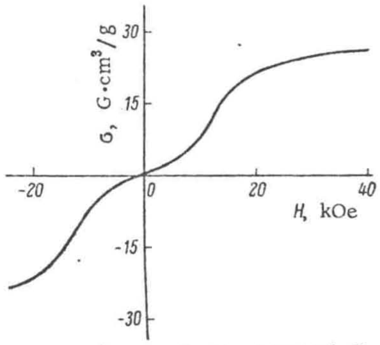

Fig. 2. Oscillogram of magnetization curve of alloy $MnAu_2$. T = 297°K, P = 1 atm.

The magnetization of the sample was measured by the induction method, for which two coaxial coils, connected differentially, were mounted in the cell. Figure 1 shows the arrangement of the high-pressure cell and measuring coils relative to the solenoid. The measuring coil 2, in which the sample 1 was placed, had 1000 turns of copper wire 0.03 mm in diameter, the average diameter of the turns being 1.2 mm; the compensating coil 4 had 120 turns with an average turn diameter 4.5 mm. Full compensation was attained by varying the number of turns of the inner measuring coil. Owing to the coaxial arrangement of the coils, shifting them along the solenoid axis had practically no effect on the compensation; hence taking the cell out of the solenoid (in order to raise the pressure in the cell) did not upset the compensation in the series of measuring coils. It is evident from Fig. 1 that the cylindrical hole 6, through which the leads enter the cell (high-pressure electrical cable), has a much larger diameter on the low-pressure side. We used this simple method in order to increase the area of adhesion of the filler (epoxy resin) to the walls of the electrical cable, which decreased the length of the seal and reduced the quality requirements of the epoxy resin used. The pressure in the cell was measured by a manganin manometer 5, Fig. 1.

Figure 2 shows an oscillogram of the magnetization curve of a sample placed in the cell at 1 atm pressure. Magnetic measurements were made on a sample investigated in [6]. It had the form of a cylinder 0.8 mm in diameter and 6.84 mm long. The magnetization σ was measured against the field H at room temperature. The threshold magnetic field H_c, corresponding to maximum susceptibility, was determined from the position of the peaks in the oscillogram of the curve of $\partial\sigma(H)/\partial t$.

As a standard for determining the absolute value of magnetization, we used a nickel sample of the same dimensions.

2. RESULTS OF MEASUREMENTS

Magnetization curves of the alloy $MnAu_2$ in magnetic fields having intensities up to 80 kOe at various pressures are given in Fig. 3. These curves show that the threshold magnetic field H_c decreases with increasing hydrostatic pressure, which agrees with the results of other authors. The threshold magnetic field is plotted against pressure in Fig. 4, which shows that H_c decreases nonlinearly with increasing pressure. Our $MnAu_2$ sample at 14 kbars is close to transition to the ferromagnetic state without any external field, since the threshold field is only 1.5 kOe in this case. It is also evident from Fig. 3 that increasing the pressure has no measurable effect on the saturation magnetization of the alloy. Moreover, the susceptibility in the ferromagnetic state in a field exceeding the threshold value decreases appreciably with increasing pressure.

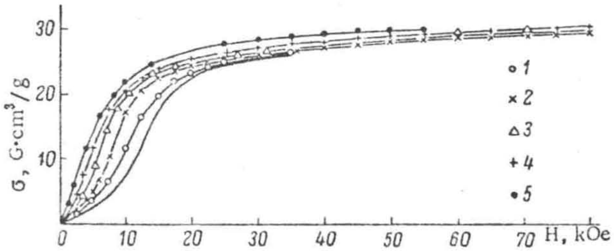

Fig. 3. Magnetization curves of alloy $MnAu_2$ at various pressures. The solid curve denotes 1 atm. P, kbars: 1) 4.76 kbars; 2) 6.43; 3) 10.15; 4) 11.76; 5) 14.1. T = 297°K.

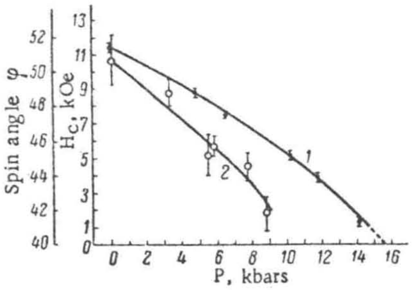

Fig. 4. Curves of threshold magnetic field H_C (1) and spin angle φ(2) versus pressure at room temperature.

TABLE 1

P, kbars	φ°	H_C, kOe	n_1, °K	n_2, °K
1 bar	50.7	11.4	25.1	−9.9
3.31	48.8	9.5	24.7	−9.4
5.79	45.7	8.0	28.8	−10.3
7.72	44.5	6.8	27.7	−9.7
8.83	41.8	6.1	32.8	−11.0

3. DISCUSSION OF RESULTS

Helicoidal magnetic order is regarded as the result of competition of ferromagnetic and antiferromagnetic exchange interactions through conduction electrons [7]. According to theory, the equilibrium value of the helicoid angle φ is determined by the equation

$$\cos\varphi = -\frac{n_1}{4n_2}, \quad (1)$$

where n_1 is the energy of positive exchange interaction between manganese atoms lying in adjacent planes; n_2 is the energy of negative exchange interaction between manganese atoms lying in more widely separated layers.

Theory gives an equation connecting the threshold magnetic field H_C, the equilibrium angle, and the energy of negative exchange interaction. In order to estimate values of n_1 and n_2 along the c axis for each pressure we used the relation between the angle φ and pressure, determined by neutron diffraction [8], and the relation between threshold magnetic field and pressure, determined by us. The magnetic moment of the Mn atom in $MnAu_2$ was taken to be $\mu_0 = 3.38\,\mu_B$ [9].

The results of the calculations are given in Table 1.

If it is assumed that the decrease in threshold magnetic field with increasing pressure is due to decrease in the negative or increase in the positive exchange interaction along the c axis, raising the pressure should increase n_1 or decrease n_2. Table 1 shows that this does not take place. Evidently, the model of competing interactions does not correspond to the nature of helicoidal order in $MnAu_2$.

From the results we drew certain conclusions regarding the antiferromagnetic–ferromagnetic transition in a magnetic field, as well as under pressure. Measurement of magnetostriction in the given transition in a magnetic field gives $\Delta V/V = -5\cdot10^{-4}$ [10]. At the same time, if we proceed from the compressibility of $MnAu_2$, measured at room temperature [11], $\varkappa = 1.42\cdot10^{-12}$ cm^2/dyn, and assume that it remains unchanged up to 15 kbars, the relative change in volume of the sample on transition to the ferromagnetic state due to pressure alone amounts to $\Delta V/V = -21\cdot10^{-4}$. Thus, the magnetostriction volume change is much less than the volume change due to transition from the helicoidal to the ferromagnetic state under pressure. This difference in volume change may be due to the substantial difference between the mechanisms of disruption of helicoidal order by a magnetic field and pressure.

As Fig. 4 shows, the threshold field decreases to zero with increasing pressure. Figure 4 also shows a curve of helicoid angle versus pressure, according to the data of neutron-diffraction investigations [8] at room temperature, up to 9 kbars. The helicoid angle decreases from 51° (at atmospheric pressure) to 41° (at 9 kbars), i.e., by only 10°. Since the helicoidal structure vanishes at 15 kbars, the helicoid angle should decrease abruptly to zero when the pressure is increased further by only 6 kbars.

Owing to this, one should expect the c parameter to vary anomalously with pressure above 9 kbars. Such behavior is observed at 77°K and pressures above 5.5 kbars ([8], Fig. 6).

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