Observation of ferromagnetic state in antiferromagnetic alloys of the $Mn_{1-x}Fe_xAs$ system

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It was observed in some of the investigated alloys that a strong magnetic field induces magnetic states that do not arise spontaneously when the temperature or pressure is varied.

It has been established experimentally[1,2] that in manganese arsenide the transition from ferromagnetism to paramagnetism occurs jumpwise at a temperature T_c and is characterized by a temperature hysteresis ΔT_c, and that when a certain critical pressure $P_c \approx 2.2$ kbar is reached a change of temperature cannot produce ferromagnetism in MnAs at all. Under these conditions, however, as observed in[3], a single application of a strong magnetic field $H \geqslant H_c$ can lead to an irreversible jump-like appearance of a ferromagnetic phase. It was expected that partial alloying of MnAs would make it possible to change the value of P_c and by the same token produce conditions for a more complete study of the singularities of field-induced magnetic transformations. To this end, we investigated the magnetic properties of alloys of the system $Mn_{1-x}Fe_xAs$ in the concentration

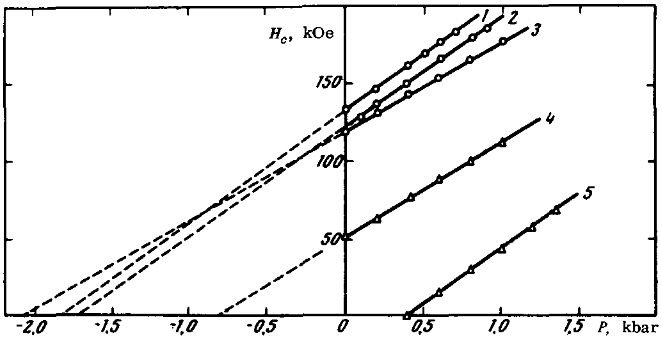

FIG. 1. Change of critical field of sample with $x = 0.02$ under pressure at various temperatures T, °K: 1—237, 2 and 4—248, 3 and 5—273; ○—H_{c_1}, △—H_{c_2}.

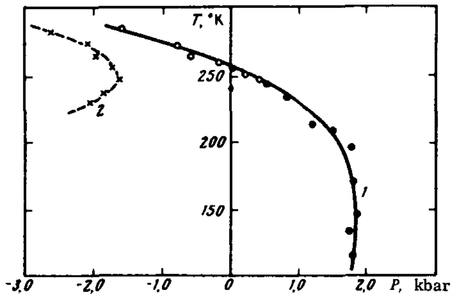

FIG. 2. P-T phase diagram of the alloy $Mn_{0.98}Fe_{0.02}As$: 1 and 2—limits of the vanishing and spontaneous appearance of the ferromagnetic phase.

range $0 \leqslant x \leqslant 0.10$ at pressures up to 5 kbar. The employed setup made it possible to perform the indicated measurements in the temperature interval from 115 to 400°K, using pulsed magnetic fields of intensity up to 185 kOe.

The measurements have shown that $P_c(x)$ is a linear function and that $P_c \leqslant 0$ at $x \geqslant 0.012$. It was also established that at $P > P_c$, all the investigated samples acquire antiferromagnetic properties with a clearly pronounced maximum of the magnetic susceptibility at the Néel temperature (T_N). The plot of $T_N(x)$ turned out to be a straight line with a slope $\partial T_N/\partial x = 160$°K. Greatest interest attaches, however, to the fact that ferromagnetism is produced irreversibly by a magnetic field at $x > 0.012$, when the ferromagnetic state is produced in the alloys neither by changing the temperature nor by changing the pressure. Once produced, this state is preserved also after the magnetic field is removed.

The region of the existence of the induced ferromagnetic phase can be obtained directly by studying its magnetic properties under pressure. It was possible, however, to determine also the limits of the region where the ferromagnetic phase is produced spontaneously. To this end we used $H_c(P)$ plots obtained at fixed temperatures. In the measurements we determined the two values of H_c corresponding to the onset (H_{c_1}) and to the vanishing (H_{c_2}) of the ferromagnetic phase. Figure 1 shows the results of the measurements for the alloy with $x = 0.02$. We note three conclusions that follow from an analysis of this figure: 1) the plot of $H_c(P)$ is linear for all temperatures; 2) extrapolation of $H_{c_1}(P)$ to $H_c = 0$ yields the pressure at which, at a given temperature, the ferromagnetic phase sets in spontaneously; 3) in the region of positive pressures, the limits for the vanishing of the ferromagnetic phase, obtained by direct measurements, agree with those obtained by extrapolating the plot of $H_{c_2}(P)$.

On the basis of these conclusions, and using the corresponding experimental results, we determined the limits of the spontaneous onset and vanishing of the ferromagnetic phase for different samples of the investigated system. Figure 2 shows the P-T phase diagram for the alloy with $x = 0.02$. The solid line 1 corresponds to the vanishing of the induced ferromagnetic phase, and the dashed line 2 corresponds to its onset. In addition, the different symbols on line 1 mark the experimental data obtained by direct measurements (dark circles) and by extrapolation (light circles). The region contained between curves 1 and 2 of Fig. 1 is metastable. In this entire region it is possible to induce irreversibly the ferromagnetic phase. It might seem that the induced phase, being metastable, would be short-lived. However, special investigations have revealed no decrease in the magnetization of the induced phase after 2000 hours.

The ferromagnetic state can also be produced field outside the limits of the metastable region by a strong magnetic field. Such a process, however, is reversible, since the initial state is restored after the action of the magnetic field.

For the samples with $x > 0.012$, the initial and induced states are qualitatively different from the magnetic point of view. Preliminary x-ray investigations indicate that different types of crystal lattices are realized in them. It is therefore correct to state that the magnetic field produces a new state in these substances. It appears that there exists in nature an entire class of substances that have at atmospheric pressure stable metastable states that can be realized only by application of a strong magnetic field. An exhaustive study of the process whereby such possible states are induced will add to our understanding of the phase-transition mechanism and can turn out to be useful for practical applications.

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