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INVESTIGATION OF THE MAGNETOSTRICTION OF THE METAMAGNETIC ALLOY $MnAu_2$

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The transverse and longitudinal magnetostriction of the alloy $MnAu_2$ were investigated in external magnetic fields up to 19 and 24 kOe respectively at temperatures below and above the Néel point. The experimental results obtained indicate that in fields H exceeding the threshold value H_{th} the magnetostriction of the alloy $MnAu_2$ is mainly due to the destruction of the helicoidal spin structure. An anomalously large volume effect was observed on destruction of the antiferromagnetic structure by an external magnetic field: at 20°C the relative change of the sample volume reached -500×10^{-6} in a field of 19 kOe. At temperatures near the Néel point in fields $H > H_{th}$ the magnetostriction of the alloy $MnAu_2$ varied linearly with the square of the magnetization. The construction of a capacitance pickup used for measurements of the temperature variation of magnetostriction is described.

AMONG antiferromagnets having a variety of forms of the appearance of magnetic-moment ordering, there is a special group of substances known as metamagnets. This group includes several rare-earth elements (dysprosium, erbium, etc.) and some alloys based on manganese, in particular $MnAu_2$.[1] Below the Néel point the antiferromagnetic structure of metamagnets may be destroyed easily by applying an external magnetic field greater than a certain threshold value H_{th}. The whole range of magnetic fields can be divided into two regions: antiferromagnetic ($H < H_{th}$), where the metamagnet exhibits antiferromagnetic properties, and ferromagnetic ($H > H_{th}$), in which first the antiferromagnetic structure is destroyed and then, as the field increases, a transition to magnetic saturation is observed.

Recent neutron-diffraction studies indicate that metamagnets have helicoidal magnetic structure, i.e., the magnetoactive atoms form layers in which the spins have ferromagnetic ordering and lie in the layer plane, but the resultant magnetic moments of the layers are rotated with respect to one another by a certain constant angle other than 180°, forming a helicoid.

The nature of the helicoidal ordering is still not clear. We may assume[2] that such ordering is the result of competition between two exchange interactions: positive in the layers and between neighboring layers, and negative between every second layer.

Comprehensive studies of the various properties of metamagnets should give information on the nature of the helicoidal structure.

One of the best known metamagnets is the intermetallic alloy $MnAu_2$.

According to the data of Meyer and Tagland,[1] the magnetic transition temperature for this alloy is 90°C, while according to Karchevskiĭ and Nikolaev,[3] it is 100°C; the threshold field is about 10 kOe and depends weakly on temperature.

The magnetostriction of the alloy $MnAu_2$ has not yet been studied. An investigation of the magnetostriction may give information of use in determining the nature of the helicoidal ordering of spins, since the exchange and magnetic interaction forces appear directly in magnetostriction.

The present work was concerned with the study of the longitudinal and transverse magnetostriction of the alloy $MnAu_2$ at temperatures below and above the Néel point.

EXPERIMENTAL METHOD

Various methods exist for measuring magnetostriction. Among the simplest and most widely used are the method of wire strain gauges, employed in several variants, and the method based on measuring the change of capacitance in a capacitor with one of the plates rigidly fixed to the end of the test sample. In our work we selected the latter method to measure the magnetostriction of the alloy $MnAu_2$. When this method is used it is not necessary to calibrate the measuring circuit with a standard sample.

The electronic circuit employed was analogous to that described in the literature for a capacitance micrometer.[4]

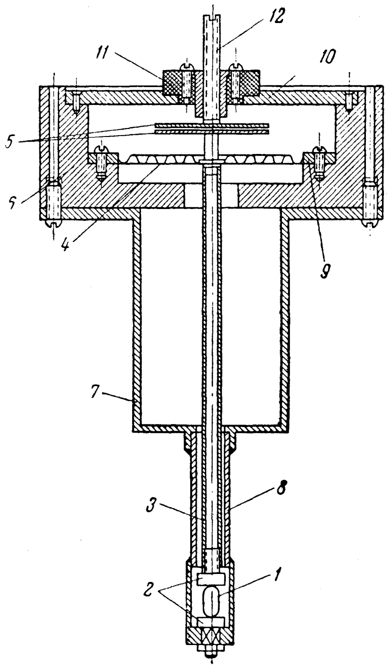

FIG. 1. Capacitance pickup for measurements of the magnetostriction. 1) Sample; 2) sample clamps; 3) rod; 4) diaphragm; 5) capacitor plates; 6) casing; 7) tubular part; 8) insert; 9) washer; 10) flange; 11) ebonite bushing; 12) regulating screw.

The high-frequency oscillations (f ≈ 1 Mc) of a stabilized quartz oscillator were applied to the two arms of an ac measuring bridge. The change of the pickup capacitance altered the natural frequency of one of the oscillatory circuits of the bridge and therefore changed the amplitude of the voltage across one of the bridge arms. This, in turn, disturbed the balance of the bridge and produced a current in its measuring diagonal. During measurements the electronic circuit was at a distance of several meters from the electromagnet and was connected to the pickup by means of a coaxial cable. Control tests with brass samples showed that the magnetic leakage fields did not affect the operation of the electronic circuit.

The capacitance pickup which we developed for measuring magnetostriction at various temperatures is shown in Fig. 1. Two brass clamps 2 were soldered to the ends of the sample 1. The sample with the clamps in place was screwed to a German silver rod 3 which had a phosphor bronze diaphragm 4 and one of the capacitor plates 5 soldered to its upper part. The rod together with the sample was placed in a brass jacket consisting of a massive casing 6 and a tubular part 7. To reduce heat flow along the jacket, a stainless-steel insert 8 was placed in the tubular part during measurements above room temperature. The lower clamp of the sample, of square cross section, fitted into a slot of similar shape and was fixed rigidly to the jacket. The position of the rod 3 was centered by the diaphragm 4 which had practically no effect on the axial motion of the rod. The diaphragm was attached by screws to the pickup casing by means of washers 9. The fixed plate of the capacitor was attached to a flange 10. Its position could be regulated with a screw 12. The capacitor plates were of 36 mm diameter. The fixed plate was insulated from the casing by an ebonite bushing 11. After a suitable value of the capacitance (about 50—100 μF) had been selected the regulating screw 12 was locked with a special tightening nut. All the measurements were carried out in atmospheric air at normal pressure.

An electric furnace with bifilar winding was used as the heater. The sample temperature was measured with a copper-constantan thermocouple, one junction of which was in contact with the lower brass clamp close to the sample. In all tests the sample temperature was kept constant to within ± 0.5 deg C.

The alloy $MnAu_2$ was prepared by the technique described by Meyer and Tagland.[1] The magnetization of alloy samples from the same ingot was measured at temperatures from − 196 to 130°C in magnetic fields of up to 20 kOe intensity. The measurements were carried out with a vibrating magnetometer,[5] and also by the ballistic method. The results of the measurements agreed qualitatively with the data of Meyer and Tagland[1] and have been published in part earlier[6] (sample 1).

The test sample was close to an ellipsoid in shape, with semi-axes of 5 and 3.5 mm.

The absolute error in determining the sample dimension changes amounted to 2×10^{-6} cm.

RESULTS OF MEASUREMENTS AND DISCUSSION

Figures 2—4 give the results of measurements of the transverse and longitudinal magnetostriction

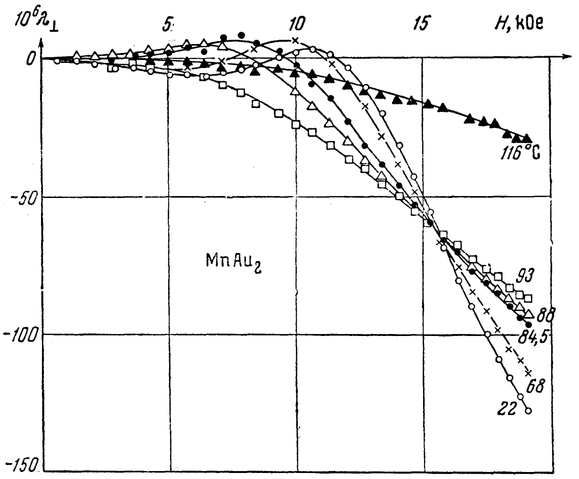

FIG. 2. Isotherms of the transverse magnetostriction $\lambda_\perp$ of the alloy $MnAu_2$.

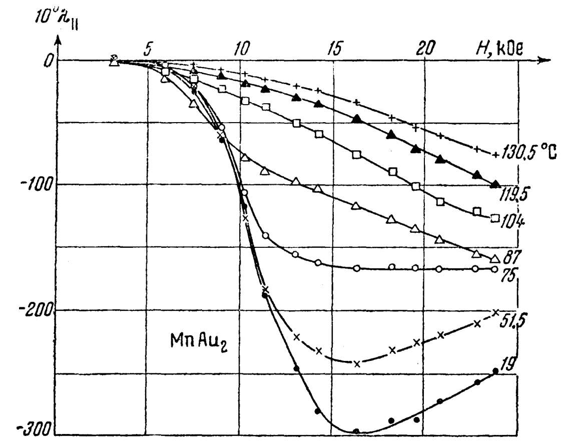

FIG. 3. Isotherms of the longitudinal magnetostriction $\lambda_{\parallel}$ of the alloy $MnAu_2$.

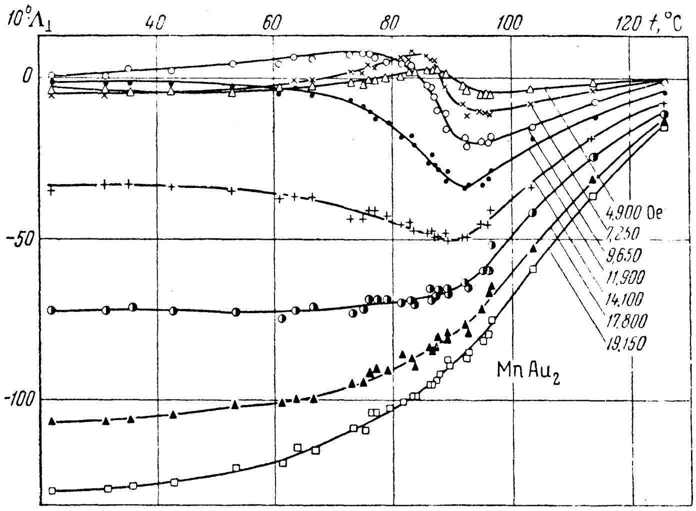

FIG. 4. Temperature dependence of the transverse magnetostriction $\lambda_{\perp}$ of the alloy $MnAu_2$ in various magnetic fields.

in external magnetic fields of up to 19 and 24 kOe respectively, at temperatures above and below the Néel point. The curves in Fig. 2 show that the transverse magnetostriction in the antiferromagnetic region is relatively small. The transition to the ferromagnetic state is accompanied by a sharp contraction of the sample. The dependence of $\lambda_{\perp}$ on the field shows saturation at about 20 kOe.

The dependence of the longitudinal magnetostriction $\lambda_{\parallel}$ on the magnetic field intensity at various temperatures (Fig. 3) is qualitatively the same as for the transverse effect. In contrast to the latter the longitudinal magnetostriction is negative over the whole range of magnetic fields and temperatures (cf. Fig. 2). At temperatures below 75°C the $\lambda_{\parallel} = f(H)$ curve passes through a minimum at about 16 kOe. At temperatures above 75°C the value of the longitudinal magnetostriction increases monotonically with increase of the magnetic field.

It is interesting to note that the temperature dependence of the transverse magnetostriction (Fig. 4) shows no singularities, characteristic of normal ferromagnets near the Curie point, in the ferromagnetic region at temperatures near the Néel point. This is obviously related to the fact that in $MnAu_2$ the magnetostriction is mainly due to the disruption of the helicoidal structure. On approaching the Néel point the ordered distribution of spins is gradually disturbed by the thermal motion, which reduces the value of the magnetostriction. The magnetostriction related to the destruction of the helicoidal spin structure was first observed by Belov and Nikitin[7] in dysprosium samples.

The most characteristic feature of the magnetostriction of the alloy $MnAu_2$ is the very large volume effect accompanying the destruction of the helicoidal structure by a magnetic field. Thus, at 20°C the relative change of volume in a field of 19 kOe reached -500×10^{-6}.

The destruction of the helicoidal structure by an external magnetic field should alter the exchange energy of the interaction between spin layers. The occurrence of a large volume effect indicates a strong dependence of this energy on the interatomic spacings.

In the ferromagnetic region the alloy $MnAu_2$ exhibits spontaneous magnetization.[1] The appearance of the spontaneous magnetization should produce a corresponding spontaneous deformation of the lattice. The phenomenological theory of the

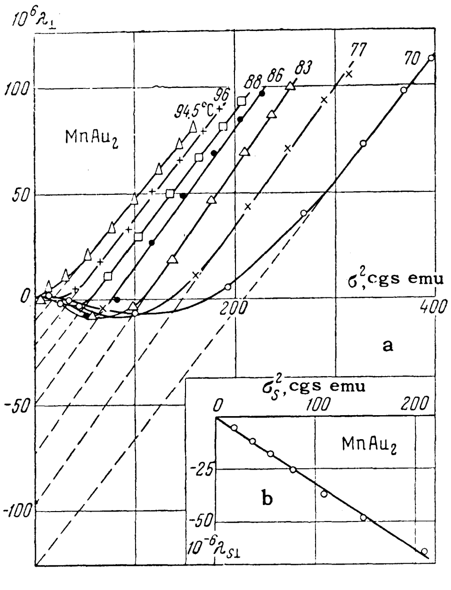

FIG. 5. a) Dependence of the transverse magnetostriction $\lambda_{\perp}$ of the alloy $MnAu_2$ on the square of the magnetization, σ^2, at temperatures close to the Néel point; b) dependence of the spontaneous deformation λ_s on the square of the spontaneous magnetization σ_s^2 for the alloy $MnAu_2$.

magnetic transition, developed for ferromagnets, gives the following relationship between the spontaneous deformation λ_s and the spontaneous magnetization σ_s:

$$\lambda_s + \lambda_i = a\,(\sigma_s + \sigma_i)^2, \qquad (1)$$

where σ_i is the magnetization produced by the external field and is equal to $\sigma - \sigma_s$ (σ is the total magnetization); λ_i is the corresponding magnetostriction produced by the field; and a is a numerical factor which depends on temperature. Figure 5a gives curves of the dependence of the transverse magnetization of the alloy $MnAu_2$ on the square of the specific magnetization for various temperatures near the Néel point. This figure shows that the curves have rectilinear portions. If it is assumed that the dependence (1) also applies to metamagnets, then by extrapolating the rectilinear parts of the curves in Fig. 5a to the ordinate and abscissa we can determine the quantities λ_s and σ_s^2 at various temperatures. Figure 5b shows the dependence $\lambda_s = f(\sigma_s^2)$ obtained in this way, which is linear as for ferromagnets.

The results obtained from measurements of the magnetostriction of the alloy $MnAu_2$ may be compared with the data of Klitzing and Gielessen,[8] who investigated the effect of omnidirectional (hydrostatic) compression on the magnetization of the alloy $MnAu_2$ at room temperature. The volume magnetostriction $(\partial V/\partial H)_{p,T}$ and the variation of the magnetization I with the pressure p are related by the following thermodynamic equation:

$$(\partial V/\partial H)_{p,T} = -(\partial I/\partial p)_{H,T}. \qquad (2)$$

According to our data in a field of 15 kOe at $p = 1$ atm and $T = 20°C$, we have $\partial V/\partial H = -4 \times 10^{-8}$ cgs emu. From the data of Klitzing and Gielessen [8] the value of $\partial I/\partial p$ can be estimated for $H = 15$ kOe, $T = 20°C$ by approximating to a linear dependence of I on p; this value is found to be 1.4×10^{-8} cgs emu, which agrees satisfactorily in order of magnitude with Eq. (2).

Thus the present investigation of the transverse and longitudinal magnetostriction of the alloy $MnAu_2$ has shown that in the ferromagnetic region it exhibits an anomalously large volume magnetostriction accompanying the destruction of the helicoidal structure.

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