$MnAu_2$

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EFFECT OF PRESSURE ON THE MAGNITUDE OF THE THRESHOLD FIELD AND TEMPERATURE OF THE ANTIFERROMAGNETIC TRANSFORMATION OF $MnAu_2$

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The electric resistance and galvanomagnetic effect of the helicoidal antiferromagnetic $MnAu_2$ are measured at an hydrostatic pressure up to 10,000 kg/cm^2 in the region of the magnetic transformation temperature. The shift of the Neel point T_N and threshold field H_{th} in $MnAu_2$ under the influence of uniform compression is determined. It is found that pressure appreciably lowers the threshold field: $dH_{th}/dp = -0.67 \pm 0.07$ Oe-cm²/kg, whereas the antiferromagnetic transformation temperature increases: $dT_{th}/dp = (0.68 \pm 0.05) \times 10^{-3}$ deg-cm²/kg. Possible explanations of the observed variation of T_{th} and H_{th} are considered.

INTRODUCTION

THE magnetic properties of the compound $MnAu_2$ have many specific features[1] due to the complicated magnetic structure of this compound. Neutron-diffraction investigations[2] have established that in the tetragonal lattice of $MnAu_2$ the magnetic moments lying in the neighboring basal planes are turned through an angle $\varphi = 51°$ relative to each other, forming a helix-like spin configuration. The magnetic moments lying in one and the same basal plane are parallel to one another. It was established recently that a similar magnetic structure is possessed also by a large group of rare-earth metals, some compounds of the rutile type, and compounds with general chemical formula $Mn_{2-x}Cr_xSb$.

An investigation of the magnetic structure of $MnAu_2$ has made it possible to explain one of the main features of the magnetic behavior of helicoidal antiferromagnets, consisting in a destruction of the antiferromagnetic order by relatively weak fields, when $\mu H_{th} \ll kT_N$ (in $MnAu_2$ the threshold field is $H_{th} = 8000$ Oe, and the Neel temperature is $T_N = 365°$). However, the nature of the forces that lead to the occurrence of the helicoidal structure itself is not yet completely clear at present. In the theoretical investigations [3,4], and the analysis of general problems of helicoidal antiferromagnetism, the hypothesis is made that the main forces responsible for the establishment of a helicoidal order of the spin magnetic moments are exchange forces. In one and the same crystal there exist simultaneously various types of exchange interactions, which differ from one another both in magnitude and in sign.

From this point of view it seems to us of interest to carry out an all-inclusive investigation of the electric and magnetic properties of helicoidal antiferromagnets under hydrostatic compression, for one can expect in this case large changes in their magnetic properties which in turn yields information on the variation of the exchange interactions as a function of the volume of the crystal elementary cell.

We present here the results of an investigation of the influence of high hydrostatic pressure on the Neel temperature and on the threshold field in the $MnAu_2$ compound.

RESULTS OF MEASUREMENTS AND THEIR DISCUSSION

Isotropic hydrostatic compression was produced in a high-pressure chamber; the medium transmitting the pressure was a 50 per cent mixture of transformer oil and pentane. The procedure for measuring the galvanomagnetic effect $\Delta R/R$, the electric resistance, the temperature, and the pressure was analogous to that described by us previously[5].

1. The influence of the hydrostatic compression on the temperature of the magnetic transformation of $MnAu_2$ was determined by measuring the temperature dependence of the electric resistance $R(T)$ at pressures $P_1 = 1$ kg/cm², $P_2 = 4600$ kg/cm², and $P_3 = 8850$ kg/cm². In all cases the value of T_N was determined from the kink on the $R(T)$ curve.

The results of the measurements of the influence of the pressure on the electric resistance of

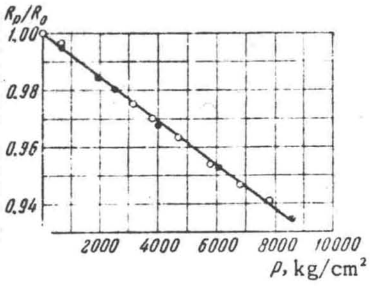

FIG. 1. Effect of pressure on the electric resistance of $MnAu_2$ at room temature: ○ – at rising pressure, ● – at decreasing pressure.

$MnAu_2$ at room temperature are shown in Fig. 1. It is seen from the figure that the measurements carried out both while increasing the pressure and while decreasing it give practically the same results: hydrostatic compression leads to a reduction in the electric resistance of $MnAu_2$. The value of the baric coefficient $R_T^{-1}dR/dP$ at room temperature is -7.6×10^{-6} kg/cm². The temperature of the antiferromagnetic transformation at atmospheric pressure according to our measurements is 364.6°K. At a pressure of 4600 kg/cm² we have $T_N = 368$°K, while at $P = 8850$ kg/cm² it amounts to $T_N = 370.7$°K. Figure 2 shows the R(T) curves measured at atmospheric pressure (curve 1) and at $P = 8850$ kg/cm² (curve 2). It follows from the data obtained that the hydrostatic compression causes a rise in the temperature of antiferromagnetic transformations; the magnitude of this effect amounts to

$$dT_N/dP = (0.68 \pm 0.05) \cdot 10^{-3} \text{ deg-cm}^2/\text{kg}.$$

2. Changes in the threshold field of $MnAu_2$ under the influence of pressure were determined by us by measuring the transverse galvanomagnetic effect $\Delta R_\perp/R$. Figure 3 shows the dependence of the specific magnetization (curve 1) and of the galvanomagnetic effect (curve 2) on the intensity of the external magnetic field, measured at atmospheric pressure and room temperature. As can be seen from the plots presented, the $\sigma(H)$ and $\Delta R/R = f(H)$ curves are outwardly similar; in either case they can be broken up into three regions: a) for fields less than 8000 Oe (antiferromagnetic region) the magnetization is small and proportional to the field; in this field region $\Delta R/R = 0$, that is, the magnetic field does not change noticeably the electric resistance of the specimen, and at any rate these changes are smaller than the sensitivity of our measuring setup; b) in fields from 8000 to 16,000 Oe the magnetization increases sharply, and the electric resistance of the specimen decreases rapidly, this decrease being observed starting with fields above the threshold value $H_{th} = 8000$ Oe; c) for fields exceeding 17,000 Oe, both the magnetization and $\Delta R/R$ begin to approach saturation.

From an examination of these curves we can conclude that the galvanomagnetic effect in $MnAu_2$ is determined principally by the magnetization, the variation of which in the transition region (8000–17,000 Oe) is connected with the destruction of the helicoidal antiferromagnetism and the establishment of ferromagnetic spin ordering, while in the region of strong magnetic fields the change $\Delta R/R$ is determined by the true magnetization. In this connection, the threshold field was determined by us from the $\Delta R/R = f(H)$ curves, as the field starting with which a variation of the electric resistance in the magnetic field is observed.

Figure 4 shows the results of the measurement of $\Delta R/R$ as a function of the magnetic field intensity, plotted at room temperature at six different values of the pressure: atmospheric, 2600, 5400, 7025, 8850, and 10,800 kg/cm². It is seen from these plots that the threshold field of $MnAu_2$ decreases rapidly with increasing pressure, but the character of the $\Delta R/R = f(H)$ curves remains unchanged.

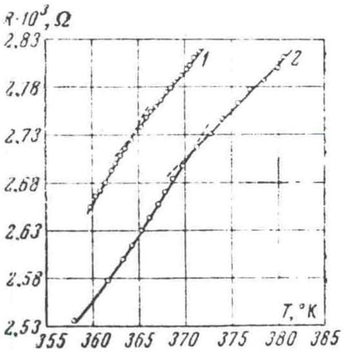

FIG. 2. Temperature dependence of electric resistance: 1 – at atmospheric pressure ($T_N = 364.6°$), 2 – at T = 8850 kg/cm² ($T_N = 370.7°$).

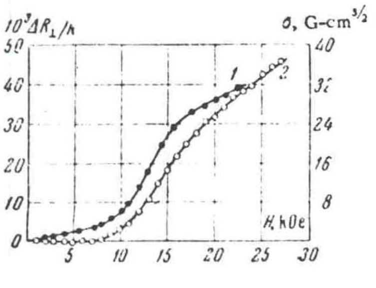

FIG. 3. Dependence of the specific magnetization of $MnAu_2$ on the magnetic field intensity (1) and dependence of $\Delta R/R$ on H (2). Room temperature.

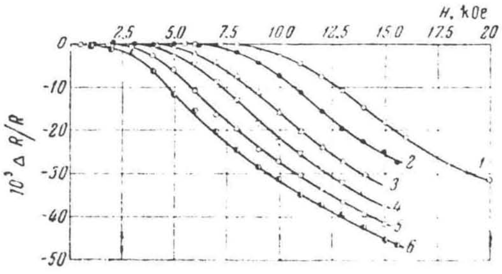

FIG. 4. Dependence of $\Delta R/R$ on H. Curve 1 – atmospheric pressure; curves 2-6 at pressures (P) 2600, 5400, 7025, 8850, and 10800 kg/cm², respectively.

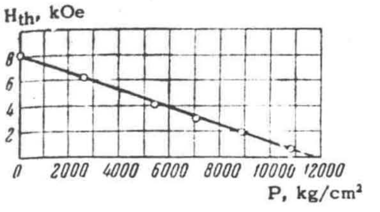

FIG. 5. Dependence of the threshold field H_{th} on the pressure. Room temperature.

Figure 5 shows the variation of the value of H_{th} as a function of the pressure, as determined from the curves of Fig. 4, from which it is seen that H_{th} decreases linearly with increasing pressure. Repeated measurements have shown good reproducibility of these data, so that the variation of H_{th} under the influence of hydrostatic compression can be given by

$$dH_{th}/dP = -0.67 \pm 0.07 \text{ Oe} \cdot \text{cm}^2/\text{kg}.$$

The data we obtained on the variation of the threshold field with pressure are in qualitative agreement with the results of an investigation of the magnetization of $MnAu_2$ under hydrostatic compression up to 4500 kg/cm², carried out by Klitzing and Gielessen[6], who have shown that the hydrostatic compression increases the slope of the magnetization curve and simultaneously shifts the start of the rise in the $\sigma = f(H)$ curves toward smaller magnetic fields. On the basis of the data we obtained it can be assumed that the increase in the magnetization observed in [6], amounting to a factor of $2\frac{1}{2}$ at a pressure of 4600 kg/cm², is apparently connected essentially with the strong decrease in the threshold field under the action of the hydrostatic compression of the specimen.

3. Using for $MnAu_2$ a compressibility $\kappa = 6 \times 10^{-7}$ cm²/kg and a thermal coefficient of volume expansion $\alpha = 6.55 \times 10$ deg^{-1}[7], we can easily verify that a pressure of 10,000 kg/cm² is equivalent (in the sense of the change in distance between atoms) to a change in temperature by 92°. If the change in the threshold field $MnAu_2$ is due only to the change in the parameters of the crystal cell, then we can expect H_{th} to drop to 700 Oe at $T = 200$°K, which corresponds to the value of H_{th} at $P = 10{,}000$ kg/cm². However, the temperature dependence of the threshold field, which we determined on the basis of the measurements of the isotherms of the magnetization of $MnAu_2$ in the temperature range 86–310°K, shows that when the temperature drops H_{th} does not decrease, but increases somewhat. Thus, for example, at $T = 77$°K, we have $H_{th} = 10{,}000$ Oe, and at $T = 2000$°K it amounts to $H_{th} = 9400$ Oe.

4. Taking into account the helicoidal magnetic structure of $MnAu_2$, the variation of T_N and H_{th} with pressure as observed by us can be explained in the following manner. If we assume that T_N is determined by the largest of the exchange interactions existing in this crystal, then we can assume that the decrease in the distance between the manganese atoms that lie in the basal planes and are nearest neighbors leads to an increase in the positive interaction, for T_N increases with increasing pressure. At the same time, the decrease in distance between basal planes brought about by the pressure, that is, between every other plane, leads to an attenuation of the negative interactions, the values of which depend very strongly on the distance. According to Herpin, Meriel, and Villain[4], the interaction between the manganese atoms lying in neighboring basal planes is the sum of two interactions, one positive between the atoms of the neighboring layers, and one negative between the atoms of every other layer.

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