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SEPARATION OF EXCHANGE AND ANISOTROPIC MAGNETOSTRICATIONS
IN THE FAN STATE IN MANGANESE PHOSPHIDE, SINGLE CRYSTAL

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Abstract. — This is the first experimental separation of exchange and anisotropic magnetostriction (MS), which are observed in the transformation from ferromagnetic to fan states under the magnetic field applied along the b axis at 77 °K. At first the total anisotropic MS is observed when the fanning is completely closed under the field of 45 kOe, and the anisotropic MS contribution from the fan state at the given field is calculated using the results of neutron diffraction. The forced MS is easily separated graphically. Finally, the exchange MS is separated by subtracting the anisotropic and forced ones from the observed total MS.

Manganese phosphide (MnP) is ferromagnetic between 291.5 °K and 47 °K, below which it has a screw spin structure. The moments of the screw rotate in the bc plane, the period running along the a axis is nine times of $a_0$, the a-axis lattice parameter, at 4.2 °K. In the ferromagnetic state, the easy magnetization axis is the c axis, the hard the a axis, and the b axis is intermediate. The screw spin structure transforms to a ferromagnetic or a fan state when an external magnetic field $H$ increases along the c axis at 2.03 kOe or along the b axis at 5.4 kOe, at 4.2 °K [1, 2]. Magnetic field‐induced transformations of spin structure revealed many interesting magnetic and electrical properties [1, 3, 4]. In these transformations the magnetoelastic energy will play an important role, and it is needed to be investigated on the magnetostriction in these transformations. We have done this and many valuable results were obtained, which will be published in an other journal in the near future. This paper is presented to report a noticeable one of them, the first experimental separation of an exchange and an anisotropic magnetostrictions.

When $H$ is applied along the b axis, there are noteworthy problems in the field‐induced transformations, and the results are summarized by the spin structure diagram shown in figure 1 [1, 4]. The measurements of magnetostriction were carried on by a conventional strain gauge method. The disk shaped samples were cut out from a single crystal block 8 mm in diameter and 2 mm in thickness. A strain gauge (Type S. 104 K-M, manufactured by the Shinkoh Commu. Co.) was bonded on the sample surface. The $H$ was always applied along the b axis, and the results for the strains along the b, c, and a axes are shown in curves 1, 2, and 3 respectively, in figure 2, where the observed strains with respect to the ferromagnetic state in zero field have been subtracted. Curves 1 and 2 correspond to the cases of gauges bonded along the b, and c axes in the bc plane of the same sample, respectively, and Curve 3 to the case of a conventional strain gauge measurement direction.
gauge bonded along the a axis in the ab plane of another sample. The curve 1 is considered at first: the abrupt jump at 9 kOe is caused by the transformation from the ferromagnetic to fan states; after this jump, the strain gradually decreased with increasing \( H \) up to 22 kOe. This can be ascribed to the gradual closing of the fan with increasing \( H \). At 22 kOe the fanning will be almost closed along the b axis. After this a forced magnetostriction was observed in linear increase with \( H \). The abrupt increase of strain at 9 kOe is caused mainly by the exchange and anisotropic magnetostrictions in the fan state, but the strain on the kink point at 22 kOe is mainly due to the anisotropic one, because the fanning is almost closed and no variations of the exchange one will be expected.

The details of the fanning and the field dependence of the period of fan, that is, the arrangement of the moments in the fan have been studied by a neutron diffraction method at various strength of \( H \) at 77 °K [6], and the \( H \)-dependence of the period is shown in figure 3, where the numeral \( n \) on the ordinate means so that the period of the fan is \( n a_0 \). The field-induced transformation of the fan structure has been studied theoretically by Kitano and Nagamiya [7], and the angle \( \theta_i \) between the i-th moment in the fan and the reference axis (here, the b axis) along which \( H \) is applied is expressed by

\[
\sin \frac{i}{2}(\theta_i - \varphi) = \xi_i \cos (i q_0 + \alpha) \tag{1}
\]

where \( \varphi \) is the angle between the center line of the fan and the b axis, \( \xi_i \) is a half of the amplitude of the fan, \( i \) means the number of i-th moment, and \( q_0 \) is a pitch angle, \( 2 \pi/n \). From the eq. (1) and figure 3, the value of \( \theta_i \) of the i-th moment was calculated at a given field. On the other hand, we measured the b-axis magnetostrictions under a high field of 45 kOe which rotated in the bc plane at 77 °K. In this case the fanning is almost closed and all moment are aligned along a direction near \( H \) and the magnetostriction will be mainly anisotropic one including the forced one. The results for the anisotropic contribution are shown in figure 4a, where the abscissa indicates the angle between the moment and the b axis. In practice the angle between \( H \) and the b axis was observed but the moment delays always from the \( H \) direction, therefore the actual direction of moment was calculated using the anisotropy energy.

Using the anisotropic magnetostriction contribution for each moment at the given direction in figure 4a, the anisotropic magnetostriction contribution in the fan state was calculated as given by the average of the anisotropic contribution of each moment in the fan. The results obtained are shown by the broken curve in figure 5. The forced magnetostriction was separated as follows: the part above 22 kOe was obtained by shifting the
observed straight curve above 22 kOe so that it crosses the ordinate axis at the point zero. The forced one below 9 kOe was obtained from figure 4a and the angle between the moment and the b-axis magnetization curve below 9 kOe. The forced one in the region of 9 kOe and 22 kOe was obtained by connecting with a straight line the values of the forced magnetostriction at 9 kOe and 22 kOe. And the result obtained is shown by the cross point curve in figure 5. Finally the exchange magnetostriction was separated by subtracting the latter two from the total measured one (the open circle point curve), and is shown by the dotted curve in figure 5. The separation for the c-axis magnetostriction was also performed by the similar method mentioned above using figure 4b, and the results of the analysis are shown in figure 6. The a-axis analysis was not able to be performed since the observation such as figure 4 was not achieved because the preparation of the sample used for this case was very troublesome.

References

[7] Kitano (Y.), and Nagamiya (T.), Progr. Theor. Phys. (Kyoto), 1964, 31, 1 (see eq. (3.34)).