# *EFFECT OF ATOMIC ORDERING ON EXCHANGE INTERACTION IN THE* $Fe_3Pt$ *ALLOY*

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The magnitude of the shift of the Curie point due to pressure and spontaneous deformation of the lattice is computed from the data on the measurement of the temperature dependence of magnetostriction in an alloy close to $Fe_3Pt$. It has been found that these quantities decrease with atomic ordering in the alloy. It is concluded that atomic ordering in the $Fe_3Pt$ not only changes the magnitude of exchange interaction but also the nature of its dependence on the interatomic distance.

1. The alloys of the system Fe-Pt are characterized by a number of extremely interesting magnetic properties. Compounds close to $Fe_3Pt$ display unusually sharp ferromagnetic anomalies in the thermal expansion coefficient[1] and strong magnetostrictive properties.[2] The manner in which both these properties manifest themselves depends on the heat treatment the alloys are subjected to, because atomic ordering takes place in this process. At the same time, a considerable change occurs in the Curie temperature. In alloys containing a large amount of Pt, i.e., those close in composition to $FePt_3$ and having suitable atomic ordering, antiferromagnetism is observed.[3] All of these considerations make the Fe-Pt alloys extremely interesting subjects in which to study the effect of atomic ordering in the lattice on the character of the exchange interaction.

We have undertaken in the present paper an investigation of the influence of atomic ordering on magnetostriction which accompanies the paraprocess in alloys close to $Fe_3Pt$ in composition. In an earlier paper one of the authors showed[4] that on the basis of an investigation of this magnetostriction (especially in connection with measurements made in the vicinity of the Curie point) it is possible to obtain information on the character of the dependence of the exchange interaction on the interatomic distance. For this reason the main attention in our work has been directed to the magnetostriction of the paraprocess in the alloy indicated, without going into all its other magnetic properties.

**2.** For this investigation, we chose an alloy containing 58% of Pt by weight, 42% Fe by weight, close in its stoichiometric composition to $Fe_3Pt$. The Kurnakov point for this alloy occurs in the vicinity of 900 or 1000° C.

The alloy was prepared, in the form of a small rod of length 150 mm and diameter 3 mm in an induction furnace, by pulling the melt in a quartz tube in vacuum. The rod was subjected to a homogenizing anneal at a temperature of 1020° C with subsequent water quench, which fixed the nonordered state. The ordered state was produced by annealing at 600° C (below the Kurnakov point) with various periods of heat treatment (20 minutes, 1 hour 20 minutes, 4 hours 20 minutes, 12 hours).

After each anneal, magnetostriction vs. temperature curves were obtained by using a remote wire strain gauge, which has been previously described in detail (see, for example, reference 4). Curves of the magnetization as a function of the temperature were also obtained. The precision of magnetostriction and magnetization measurements was ±5% and ±2% respectively.

**3.** Figure 1 shows the curves of magnetostriction as a function of the temperature for a sample

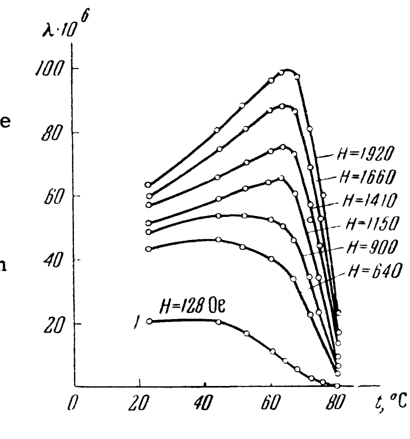


FIG. 1. Dependence of magnetostriction on the temperature in an alloy of 58% Pt, and 42% Fe (by weight) in the quenched condition (in water at 1020°C).

in the ordered state (water quenched at 1020° C) obtained in various magnetic fields. The appearance of these curves is characteristic for the magnetostriction of the paraprocess: as the temperature increases the magnetostriction of the paraprocess increases and reaches a maximum in the vicinity of the Curie point. As the degree of ordering increases (with various durations of anneal at 600° C) the character of the curves changes (see Figs. 2 and 3). Along with the magnetostriction of the paraprocess, magnetostriction appears as a concomitant to the processes of displacement and rotation; the latter is reduced monotonically with an increase in temperature and practically approaches zero at the Curie point. Superposition of both types of magnetostriction leads to a "saddle shaped" type of curve which is quite evident in Figs. 2 and 3. As the degree of ordering increases the magnetostriction of displacement and rotation becomes predominant while the magnetostriction of the paraprocess is reduced. Simultaneously the Curie point moves up from 70° to 170° C.

In Fig. 4 we have the curves of magnetostriction as a function of the square of the specific magnetization for an alloy annealed over a period of 1 hour 20 minutes at 600° C. It is evident that in the region of the paraprocess $\lambda$ is a linear function of $\sigma^2$. An analogous dependence is observed in the sample for other degrees of ordering as well as in the non-ordered state. Curves of this shape make it possible to determine not only the magnitude of the spontaneous magnetization $\sigma_s$ (by extrapolating the straight portions of the curves in Fig. 4 down to the abscissa) but, as has been shown in reference 5, we can also determine the magnitude of the spontaneous deformation of the lattice $\lambda_s$ (by the extrapolation of the straight portions of Fig. 4 to the ordinate axis — see dashed lines). Figure 5 shows $\lambda_s$ as a function of $\sigma_s^2$. Both quantities $\lambda_s$ and $\sigma_s^2$ were determined by the method given above. The results of the measurements correspond to conclusions drawn from thermodynamics (see reference 6), according to which

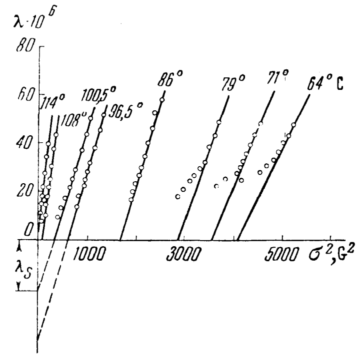


FIG. 4. Magnetostriction as a function of the square of the specific magnetization in an alloy consisting of 58% Pt and 42% Fe (by weight) after anneal at 600°C (1 hour 20 minutes).

$$\lambda_s = {}^1/_6\,\gamma\sigma_s^2, \tag{1}$$

where $\gamma$ is the coefficient for the spontaneous deformation of the lattice. It follows from Fig. 5 that the largest value for $\gamma$ is obtained for an alloy in the non-ordered state. The coefficient $\gamma$, and therefore the magnitude of the spontaneous lattice deformation, become smaller as the degree of ordering in the alloy increases.

**4.** Making use of the thermodynamic theory for ferromagnetic transformation[6] and data obtained from measurements on the magnetostriction as a function of temperature in the vicinity of the Curie point, we can compute the magnitude of

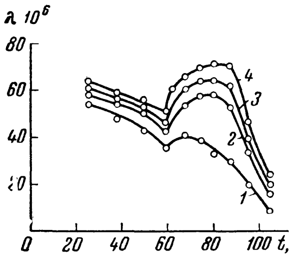


FIG. 2. The same as Fig. 1, but after anneal at 600°C (for 20 Min.): 1 – at H = 900, 2 – at 1410, 3 – at 1660, 4 – at 1920 oersteds.

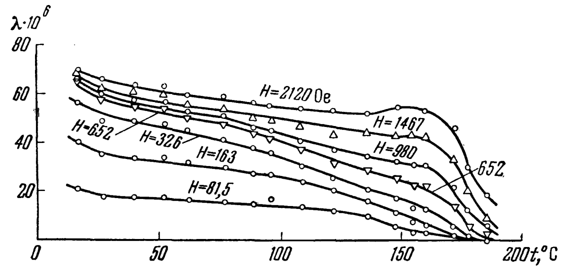


FIG. 3. The same as in Fig. 1 after anneal at 600°C (12 hours).

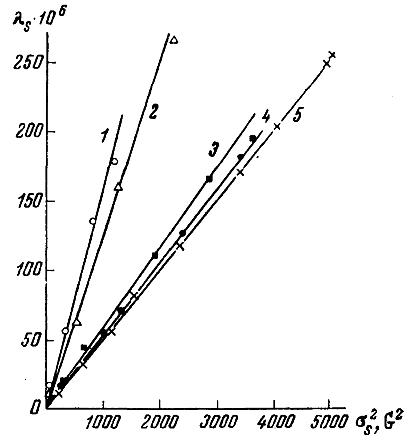


FIG. 5. Spontaneous lattice deformation as a function of the square of the spontaneous magnetization in an alloy containing 58% Pt by weight, 42% Fe by weight, for various degrees of atomic ordering: 1 – quenched condition, 2 – anneal for 20 min., 3 – anneal for 1 hour 20 min., 4 – anneal for 4 hours 20 min., 5 – anneal for 12 hours.

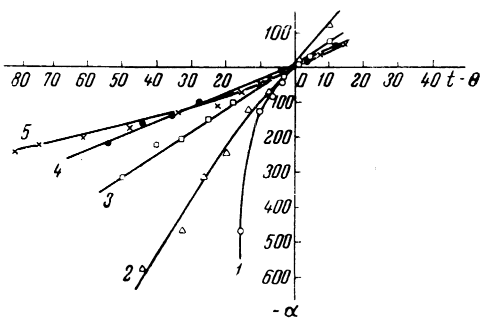


FIG. 6. Thermodynamic coefficient α as a function of the temperature in the vicinity of the Curie point for an alloy containing 58% Pt and 42% Fe (by weight), for various degrees of ordering: 1 – quenched condition, 2 – anneal for 20 min., 3 – anneal for 1 hour 20 min., 4 – anneal for 4 hours 20 min., 5 – anneal for 12 hours.

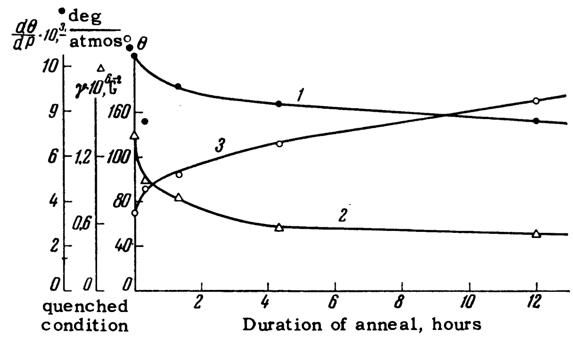


FIG. 7. 1 – effect of Curie point shift on the pressure, $d\Theta/dP$, 2 – coefficient $\gamma$, which determines the magnitude of the spontaneous lattice deformation, 3 – the Curie temperature $\Theta$, all vs. the degree of ordering.

the temperature shift of the Curie point as a function of the pressure:

$$d\Theta / dP = -\gamma / \alpha'_{\Theta}. \qquad (2)$$

Here $\gamma$ can be determined from relation (1), and $\alpha'_{\Theta}$ is the derivative of the thermodynamic coefficient $\alpha$ with respect to temperature obtained from the curves of the true magnetization in the vicinity of the Curie point (see, for example, reference 6). Figure 6 shows the curves of $\alpha(T)$ obtained for our alloy for various degrees of ordering. The quantity $\alpha'_{\Theta}$ may be determined by passing a tangent to the curve for $\alpha(T)$ as the point $\alpha = 0$. Substituting $\gamma$ and $\alpha'_{\Theta}$ in formula (2) we can determine the value of $d\Theta/dP$ for our specimen. In Fig. 7 we note that $d\Theta/dP$ falls off as a function of ordering, while $\Theta$ itself increases.

**5**. The value of $d\Theta/dP$ can serve as a quantitative characteristic of the variation of the exchange integral with volume or interatomic distance.[4] As a matter of fact, if we bear in mind that $\Theta = zA/2k$, where A is the exchange integral, z is the coordination number for the lattice, k is the Boltzmann constant, and $\kappa = -d\omega/dP$ ($\kappa$ is the compressibility coefficient, $\omega$ is the relative volume change), we can write

$$d\Theta / dP = (-z\kappa / 2k)(dA / d\omega). \qquad (3)$$

From this it follows that the larger the quantity $d\Theta/dP$ the stronger is the dependence of A in the present ferromagnetic material on $\omega$ or on the interatomic distance ($dA/d\omega$ is the "curvature" of the exchange integral if we neglect the s-d exchange interaction).

In accordance with the above, the curvature of the exchange integral for our alloy is especially large in the non-ordered condition; the curvature is reduced in the transition to the ordered state or to a partial atomic order. A large magnitude for the "curvature" of the exchange integral in the non-ordered alloy $Fe_3Pt$ must give rise to large values of spontaneous lattice deformation and as a consequence of the latter to considerable ferromagnetic anomalies in the thermal expansion. This has indeed been found to be true experimentally.[1]

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