

at the Curie temperature is of the first order as mentioned from the result of the Mössbauer experiment by Wäppling *et al.*⁷⁾ and also as being clear from our measurements of the thermal expansion and the electrical resistance which will be described later. But the well-defined jump of the magnetization due to the first-order transition cannot be seen in the magnetization vs temperature curve, although it is observed in the temperature dependences of the thermal expansion and the electrical resistance. This may be due to the induced magnetic moments by external field as mentioned by Grazhdankina *et al.*¹⁴⁾ in MnAs compound. The ferromagnetic to paramagnetic transition may be accompanied by the first-order transition with a lattice distortion.

Figure 4 shows the temperature dependence of the magnetization near the Curie temperature at various magnetic fields. The magnetization is almost constant below the Curie temperature and decreases abruptly near the Curie temperature. We therefore determined the ferromagnetic to paramagnetic transition temperatures by the inflection points of these curves. The magnetic transition temperature increases linearly with increasing field as shown in Fig. 4. The Curie temperature T_c was determined by the extrapolation of the magnetic transition temperature to zero field and then $T_c = 208.6$ K was obtained. The value of T_c thus determined is in good agreement with that obtained by Wäppling *et al.*⁷⁾ The paramagnetic susceptibility obeys the Curie-Weiss law in the higher temperature region as shown in Fig. 3. The paramagnetic Curie temperature is 395 K which is by about 200 K higher than T_c . The effective number of Bohr magneton is $3.39 \mu_B$ per Fe atom, which is larger than $2.79 \mu_B$ by Meyer and Candeville⁴⁾ and $3.2 \mu_B$ by Chiba,³⁾ but

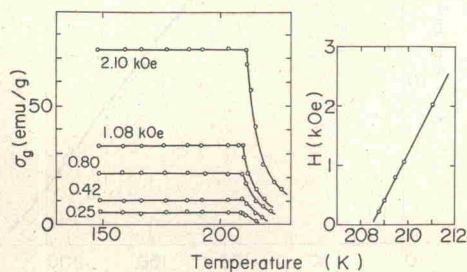


Fig. 4. Temperature dependence of the magnetization near the Curie temperature at various magnetic fields.

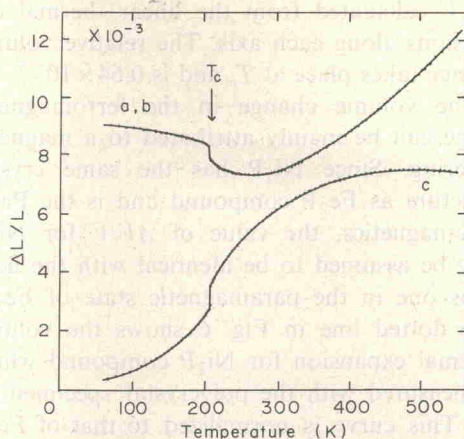


Fig. 5. Temperature dependence of the linear thermal expansion along the a , b and c axes.

smaller than $3.60 \mu_B$ by Nagase *et al.*¹⁵⁾

Figure 5 shows the temperature dependences of the linear thermal expansions along the a , b and c axes. In the ordered region, the relative length along the a and b axes, $(\Delta l/l)_a$ and $(\Delta l/l)_b$ decrease with increasing temperature, while that along the c axis, $(\Delta l/l)_c$ increases with increasing temperature. The thermal expansions along all the directions at T_c reveal the discontinuity which indicates that the ferromagnetic-paramagnetic transition is accompanied by the first-order transition of the lattice distortion as mentioned above. In this discontinuity there are the contraction of 0.74×10^{-3} for the a and b axes and the expansion of 0.84×10^{-3} for the c axis at T_c . In the disordered region, $(\Delta l/l)_a$ and $(\Delta l/l)_b$ are concave and $(\Delta l/l)_c$ is convex against temperature. Figure 6 shows the volume thermal expansion

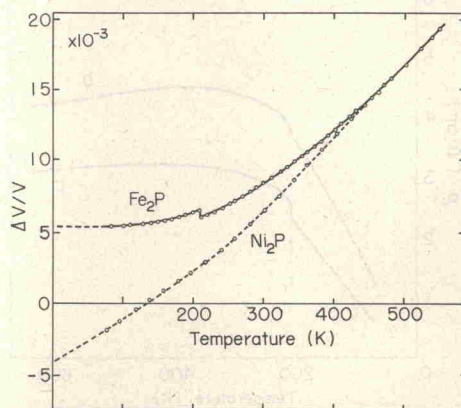


Fig. 6. Temperature dependence of the volume thermal expansion.

$\Delta V/V$ calculated from the linear thermal expansions along each axis. The relative volume change takes place at T_c and is 0.64×10^{-3} .

The volume change in the ferromagnetic range can be mainly attributed to a magnetic ordering. Since Ni_2P has the same crystal structure as Fe_2P compound and is the Pauli paramagnetics, the value of $\Delta V/V$ for Ni_2P may be assumed to be identical with the fictitious one in the paramagnetic state of Fe_2P . The dotted line in Fig. 6 shows the volume thermal expansion for Ni_2P compound which is measured with the polycrystal specimen by us. This curve is normalized to that of Fe_2P at 550 K, at which the paramagnetic susceptibility of Fe_2P begins to follow the Curie-Weiss law. The difference between the values of $\Delta V/V$ of Fe_2P and Ni_2P is considered to be indicative of the exchange striction caused by a magnetic ordering as shown in Fig. 6. The exchange striction at 0 K obtained from the extrapolation of each curve to 0 K and its value is estimated as 9.5×10^{-3} .

Figure 7 shows the temperature dependences of the electrical resistivities along the b and c axes. The change of the resistivity associated with the spin disorder in ferromagnetic region is larger along the b axis than along the c axis. Along each direction there is a rapid increase of the resistivity at T_c . This indicates that the first-order transition takes place at T_c . In the paramagnetic range, the resistivity along each axis decreases slightly with increasing temperature.

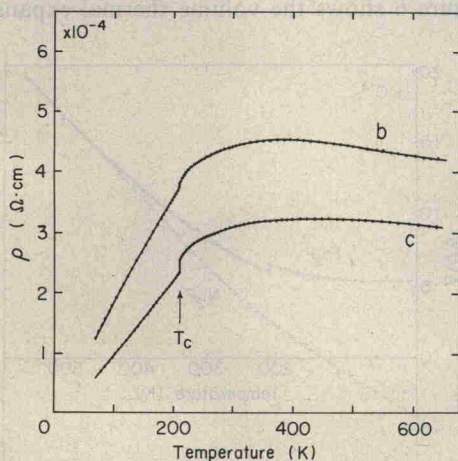


Fig. 7. Temperature dependence of the electrical resistivity along the b and c axes.

§4. Discussion

For a hexagonal crystal in the ferromagnetic state, the magnetocrystalline anisotropy is generally expressed by

$$E = K_1 \sin^2 \theta + K_2 \sin^4 \theta + \dots, \quad (1)$$

where K_1 and K_2 are the first- and second-order anisotropy constants, respectively, and θ is the polar angle of the magnetization vector to the c axis. From the minimum condition of the free energy containing the Zeeman energy, the following equation can be obtained.

$$\frac{H}{M} = \frac{2K_1}{M_s^2} + \left(\frac{4K_2}{M_s^4} \right) M^2, \quad (2)$$

where M_s is the saturation magnetization and M is the magnetization along the direction perpendicular to the c axis in the effective field, H . The anisotropy constants K_1 and K_2 were determined from measurements of M_s and M by the use of eq. (2). Since M is proportional to H as seen in Fig. 2, K_2 is negligibly small. Figure 8 shows the temperature dependence of K_1 . The value of K_1 is 2.32×10^7 erg/cm³ at 4.2 K and considerably larger than those in the other 3d-transition ferromagnetic compounds. According to Zener's theory,¹⁶⁾ the temperature dependence of K_1 would seem to be represented by the fifth power function of the saturation magnetization except for in the vicinity of the Curie temperature as shown by the dashed line. We calculated the anisotropy constant K_d due to the magnetic dipole-dipole interaction by

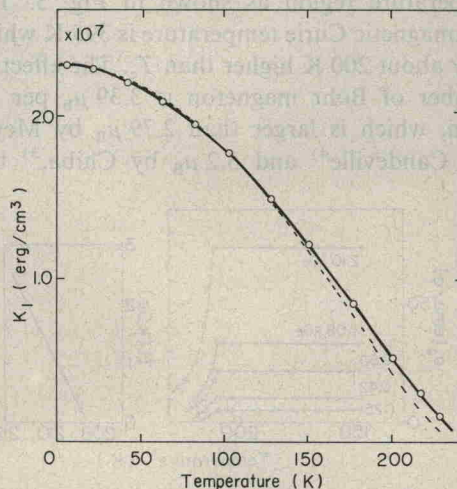


Fig. 8. Temperature dependence of the anisotropy constant.