22. On the Magnetostriction of Cobalt Single Crystals.

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In the case of iron and nickel single crystals, the magnetostriction due to magnetization was explained as a combined effect of tractive force due to an external magnetic field and the internal electrostatical force exerted by neighbouring atoms*. In the following pages we shall treat the case of cobalt single crystals, and the theoretical result obtained by the same considerations satisfactorily agrees with that observed.

As shown in the previous paper*, the electrostatic force acting between a pair of equal and parallel orbits of electron is given by

$$\Delta f = \frac{3e^2 a^2}{r^4} \left(1 - \frac{1}{2} \sin^2 \beta\right) \cos \beta.$$

In this expressions, r is the distance between two centers of orbits and β the angle between the direction of the magnetization and that of r .

Now if the cobalt crystal is magnetized to saturation in [0001] direction, then the force acting on the electron at O in Fig. 1 by neighbouring atoms 1, 2 and 3 are as follows :

$$\begin{aligned} \Delta f_1 &= 0.055 \frac{3e^2 a^2}{\delta^4} \\ \Delta f_2 &= 0.141 \quad \text{,,} \quad , \\ \Delta f_3 &= 0.678 \quad \text{,,} \quad , \end{aligned}$$

where δ is the lattice constant.

The number of atoms equivalent to those marked with 1, 2 and 3 are respectively 6, 1 and 3; hence the force acting on the atom O is

$$\begin{aligned} \Delta f_{(0001)} &= 6\Delta f_1 + \Delta f_2 + 3\Delta f_3 \\ &= 2.50 \times \frac{3e^2 a^2}{\delta^4}. \end{aligned}$$

Similarly

$$\Delta f_{(10\bar{1}0)} = 2.89 \times \frac{3e^2 a^2}{\delta^4}.$$

These forces act normally on each atom in the planes (0001) and (10 $\bar{1}$ 0), and so they depend also on the atom density in these planes. In the case of cobalt, the magnetic moment of atom is fairly large and hence its influence reaches to a large distance. Consequently the

Fig. 1.

* K. Honda and T. Hirone, Proc. Imp. Acad. Japan, 18 (1942), 237-245.

force acting on the unit area of each plane is assumed to be proportional to the square of the atomic density. The density in the (0001) plane is $2/\sqrt{3}\delta^2$; while in the plane (10 $\bar{1}0$), it is $2/c\delta^2$ ($c=1.66$), atom "3" being assumed to lie in the plane $A B C D$ in Fig. 1.

$$F_{(0001)} = 3.33 \times \frac{2}{\sqrt{3}\delta^2},$$

$$F_{(1010)} = 4.34 \times \frac{2}{c\delta^2}.$$

Thus, we have

$$\left(\frac{dl}{l}\right)_{(1000)} = \frac{4\pi I_\infty^2 - F_{(0001)}}{E_{(0001)}}$$

$$\left(\frac{dl}{l}\right)_{(1010)} = \frac{4\pi I_\infty^2 - F_{(1010)}}{E_{(1010)}}$$

In demagnetized state of a cobalt single crystal, each magnetic domain takes the direction of [0001] or [000 $\bar{1}$]. If the crystal is magnetized in the direction of hexagonal axis, then a rotation of spontaneous magnetization of 180° only occurs, so that no magnetostriction is observed in this case. Actually a very small constriction is observed; this is probably due to the deviation of the direction of the axis of the specimen from the crystallographical direction.

In the direction of [10 $\bar{1}0$] axis, the observed change of length is expressed by the following type of equation, namely

$$\left(\frac{dl}{l}\right)_{(1010)} = \left(\frac{dl}{l}\right)_{(1010)} - \sigma \left(\frac{dl}{l}\right)_{0(0001)}$$

where σ is Poisson's ratio and here as 1/3, and $(dl/l)_{0(0001)}$ is equal to $F_{(0001)}/E_{(0001)}$, E being Young's modulus; hence we have

$$\left(\frac{dl}{l}\right)_{(1010)} = \frac{4\pi I_\infty^2 - F_{(1010)}}{E_{(1010)}} - \frac{1}{3} \frac{F_{(0001)}}{E_{(0001)}}$$

According to the measurement due to Honda and Shirakawa,* we have

$$E_{(0001)} = 2.0 \times 10^{12} \text{ dyne/cm}^2$$

$$E_{(1010)} = 1.4 \quad ,,$$

Taking

$$a = 0.71 \times 10^{-10} \text{ cm}$$

$$I = 1470 \text{ emu}$$

$$\delta = 2.50 \times 10^{-8} \text{ cm},$$

then

$$F_{(0001)} = 48.0 \times 10^6$$

$$F_{(1010)} = 62.5 \times 10^6$$

* K. Honda and Y. Shirakawa, Oral statement at the annual meeting of the Physical Society of Japan (1947).

hence, we have

$$\left(\frac{dl}{l}\right)_{(10\bar{1}0)} = -33.3 \times 10^{-6}.$$

According to Dr. M. Takagi,* the relation between the magnetostriction and the intensity of magneton is given by

$$\left(\frac{dl}{l}\right)_{(10\bar{1}0)} = \left(\frac{dl}{l}\right)_{(10\bar{1}0)} \times \left(\frac{I}{I_{\infty}}\right)^2$$

The calculated curve of magnetostriction for different values of I is shown in Fig. 2. The points in the figure are data due to Nishiyama.** The theoretical values satisfactorily agree with those of observation.

Fig. 2.

* M. Takagi, Sci. Rep. Tohoku Univ., 28 (1939), No. 1.

** Z. Nishiyama, Sci. Rep. Tohoku Univ., 19 (1929), 341.