CHANGE OF SATURATION MAGNETIZATION AND OF ELECTRICAL RESISTANCE OF IRON-NICKEL ALLOYS UNDER HYDROSTATIC COMPRESSION AT LOW TEMPERATURES

E. I. KONDORSKII and V. L. SEDOV

Moscow State University

Submitted to JETP editor April 23, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 845-853 (October, 1958)

The changes of saturation magnetization and of electrical resistance of binary iron-nickel alloys, with nickel contents 38 and 45%, under the influence of pressure, have been studied. Measurements were made in the temperature range 1.7 to 77°K in fields up to 7000 Oe. It was established that the limiting values of the saturation magnetization and of the electrical resistance for $T \rightarrow 0$ change under hydrostatic compression, and that the signs of the changes are opposite for the two quantities. These limiting values also change upon increase or decrease of the field in strong magnetic fields, and the differential magnetic susceptibility in the region of magnetic saturation does not vanish at $T \rightarrow 0$. The ratio of the change of the limiting value of the saturation magnetization to the change of the limiting value of the electrical resistance under the influence of pressure, and the corresponding ratio under the influence of field, are close to each other.

IN theories of ferromagnetism based on the model of a nonconducting lattice of hydrogen-like atoms,[1] the specific saturation magnetization σ_0 at absolute zero is equal to $n\mu$, where n is the number of atoms in unit mass, and where μ is the Bohr magneton. The product $n\mu$ obviously is independent of temperature and pressure. In this case the dependence of the specific spontaneous magnetization σ_s on pressure for $T \neq 0$ is attributed to the influence of the pressure on the exchange integral, and through it on the Curie temperature.

In that theory of metallic ferromagnetics that takes account of interaction between the valence electrons and the conduction electrons (the s-d exchange model of Vonsovskii[2] and the Zener model[3]), the possibility of an influence of pressure upon σ_0 is not excluded; for in this case one considers changes in the values of exchange integrals that affect the resultant magnetic moment, equal to the sum of the magnetic moments of the lattice and of the conduction electrons. There are other cases, also, in which an influence of pressure on the specific magnetization at absolute zero is obviously not excluded — cases in which there are several magnetic subsystems, in particular compounds or alloys in which there are magnetic sublattices.

In band theory, the value of σ_0 is connected with the distribution of electrons among shells (in metals of the iron group, the 3d and 4s shells). Under the influence of pressure, this distribution can change, and a simultaneous change should occur in σ_0 and in the electric resistivity ρ. However, ρ can change also if the change of σ_0 is caused only by changes of the exchange integrals, since magnetic inhomogeneities have an influence on the movement of conduction electrons.

Until recently, the investigation of the influence of pressure on the saturation magnetization of ferromagnetic metals was carried out at or above room temperature.[4] The influence of uniaxial tension on saturation magnetization has been investigated from nitrogen temperatures to the Curie point.[5] The observed changes were interpreted as an indirect effect, caused by a shift of the Curie point under pressure.

The present work was undertaken for the purpose of studying the effect of pressure and field on the saturation magnetization and electrical resistance of ferromagnetic metals and alloys at low (hydrogen and helium) temperatures, and of estimating the influence of these factors on the saturation magnetization at absolute zero. In this article we present results obtained in a study of binary iron-nickel alloys containing 38 and 45% nickel. These alloys were chosen for the reason that iron-nickel alloys of such compositions exhibit, at high temperatures, a larger number of

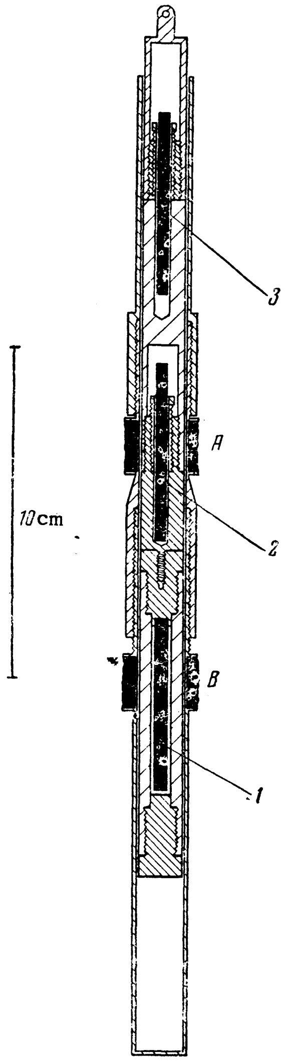

FIG. 1. Arrangement of specimens and coils for measurement of the effect of pressure on the magnetic flux through a specimen.

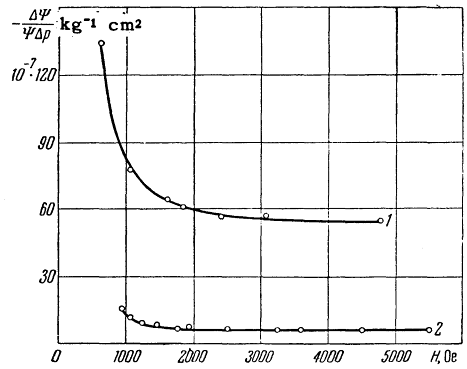

FIG. 2. Relative change or magnetic flux under the influence of pressure at various fields, for iron-nickel alloys: 1) 38% nickel; 2) 45% nickel (T = 20.4°K).

interesting effects than do ferromagnetic metals, and become magnetized to saturation in comparatively small fields; this is convenient for investigations at elevated pressures.

SPECIMENS AND METHOD OF MEASUREMENT

For the measurements of the change of saturation magnetization and electrical resistance under the influence of pressure, the specimens used were cylinders with length $l = 55$ mm and diameters from 3 to 3.5 mm. The differential magnetic susceptibility was measured on cylindrical specimens with $l = 200$ mm and d = 8 mm. Before the measurements, the specimens were annealed in vacuum at 1000° for a period of 6 to 8 hours, with subsequent slow cooling in the furnace.

Pressures from 1700 to 1900 kg/cm^2 were produced with a bomb of beryllium bronze, by the freezing of water, in accordance with the method proposed by Lazarev and Kan.[6] The magnitude of the pressure was controlled with the aid of a resistance strain gauge, on the basis of the elastic change of external diameter in the middle part of the bomb. What was measured was the relative change of resistance of the gauge upon freezing of the water. The precision of measurement of the magnitude of the pressure by this method is 3%.

The change of magnetic flux through the test coils was recorded with a photoelectric fluxmeter, constructed according to a system like that described in reference 7. A 15-maxwell change of magnetic flux in the specimen produced a deflection of one division on the scale of the instrument (the critical resistance of the fluxmeter system was 10,000 ohms).

Figure 1 shows the arrangement of the specimens and test coils. Three identical specimens, rigidly fastened to one another, are capable of displacement along the axis of coils A and B, which have 2400 turns apiece and are connected in series. If the system of specimens is so displaced that specimen 2 takes the place of specimen 1 and that specimen 3 takes the place of specimen 2, the magnetic flux through the test coils does not change. If specimen 1 is subjected to pressure, then in such a displacement of the system a change of magnetic flux will be recorded.

The differential susceptibility κ was measured by the following method: to a specimen in a constant magnetic field there was applied an additional magnetic field ΔH, of order 100 Oe, from a special "submagnetizing" coil, which was wound on the outside surface of the liquid-helium dewar; the latter was placed inside the liquid-nitrogen dewar. The test coil consisted of two coaxially arranged sections, connected in series in such a way that in the absence of a specimen, the signals from the two sections upon application of ΔH canceled each other. The magnitude of the observed effect was proportional to the difference between the numbers

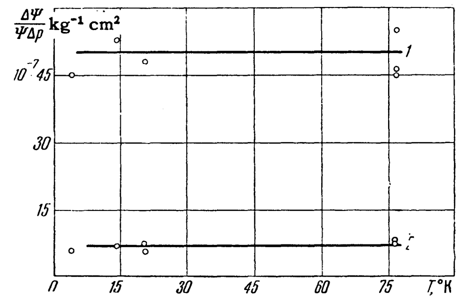

FIG. 3. Relative change of magnetic flux at saturation under the influence of pressure, for iron-nickel alloys of compositions: 1) 38% nickel; 2) 45% nickel; H = 4500 Oe.

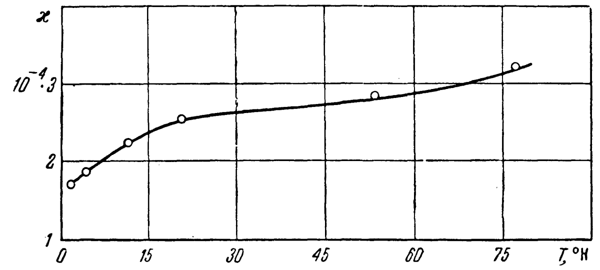

FIG. 5. Dependence of the differential magnetic susceptibility on temperature for an iron-nickel alloy with 38% nickel; H = 6700 Oe.

of turns of the inside and outside sections, which in our case was 6300 turns.

The measurement of the electrical resistance under pressure was carried out by the method described in reference 6. The magnitude of the pressure in this case was determined from the shift of of the transition temperature of tin in the superconducting state.

The properties mentioned above were determined for temperatures from 1.7 to 77°K. Magnetic fields up to 7000 Oe were obtained with a solenoid with water cooling. In the middle part of the solenoid, the change of field over a distance of 80 mm along the axis did not exceed 1%.

RESULTS OF THE MEASUREMENTS

In Figs. 2 and 3 are shown curves that describe the variation of $\Delta\Psi/\Psi\Delta p$ with field at 20.4°K, and with temperature at field $H = 4500$ Oe, respectively; here $\Delta\Psi$ is the magnitude of the change of magnetic flux Ψ in the specimen upon change of the pressure by amount Δp. Within the precision of the measurements, $\Delta\Psi/\Psi\Delta p$ does not vary with temperature over the range 4.2 to 77°K; it does not approach zero as $T \to 0$.

The values of $\Delta\Psi/\Psi\Delta p$ are related to the values

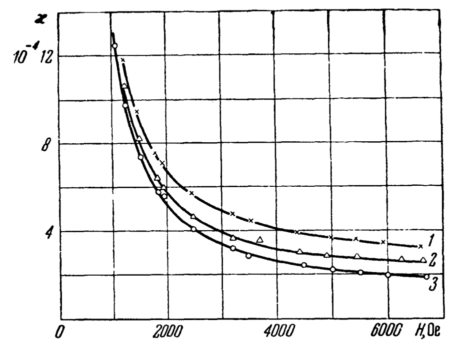

FIG. 4. Dependence of the differential magnetic susceptibility in strong fields upon the field intensity at various temperatures, for a nickel-iron alloy 38% nickel. 1) T = 77°; 2) T = 20.4°; 3) T = 4.2°K.

of interest to us, namely the values of $\Delta\sigma/\sigma\Delta p$, where $\Delta\sigma$ is the change of specific magnetization σ upon change of the pressure by Δp. The relation is

$$\frac{\Delta\Psi}{\Psi\Delta p} = \frac{\Delta\sigma}{\sigma\Delta p} - \frac{1}{3V}\frac{\Delta V}{\Delta p}. \tag{1}$$

For the alloy studied, the coefficient of compressibility $\frac{1}{V}\frac{\Delta V}{\Delta p} = -12 \times 10^{-7}$ cm²/kg; thus the second term in the right member of (1) has a sign opposite to that of the observed value of $\Delta\Psi/\Psi\Delta p$ in both alloys. It follows from this that the value of $\Delta\sigma/\sigma\Delta p$ also does not approach zero as $T \to 0$; consequently, the value of σ_0, for the alloy studied, changes under the influence of pressure.

In Fig. 4 are shown curves that describe the variation with field of the magnitude of the differential susceptibility $\kappa = \Delta I/\Delta H$ in strong fields at various temperatures. The dependence of κ on temperature at $H = 6700$ Oe is described by the curve shown in Fig. 5; from the course of the curve it is clear that κ does not approach zero as $T \to 0$. Hence, as will be shown below, it can be concluded that the value of σ_0, for the alloy studied, changes not only under the influence of pressure, but also under the action of a magnetic field.

In Figs. 6 and 7 are shown curves that describe the variation with temperature of the values of $\Delta R/R_0\Delta p$ and $\Delta R/R_0\Delta H$, respectively. Here ΔR is the change of electrical resistance, in the strong magnetic field region, upon change of pressure by amount Δp or of field by amount ΔH; R_0 is the electrical resistance at normal pressure and at

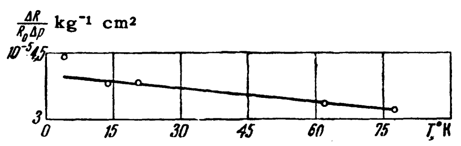

FIG. 6. Dependence on temperature of the relative change of electrical resistance of iron-nickel alloys with 38% nickel under the influence of pressure.

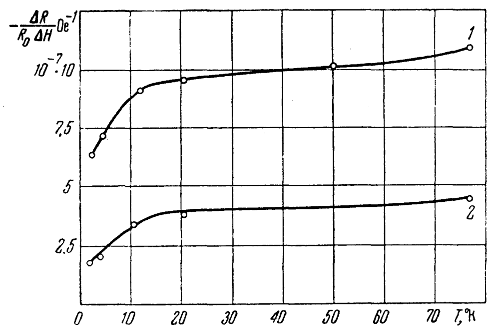

FIG. 7. Dependence on temperature of the relative change of electrical resistance of an iron-nickel alloy [composition: 1) 38% nickel; 2) 45% nickel], for small increments of the magnetic field at strong magnetic fields (in the range of the paraprocess).

4.2°K. From the course of the curves in Figs. 6 and 7 it is clear that the quantities $\Delta R/R_0\Delta p$ and $\Delta R/R_0\Delta H$ do not approach zero as $T \to 0$. The existence at $T \to 0$ of residual values of one of these quantities ($\Delta R/R_0\Delta H$) had already been established.[8,9]

Table I gives numerical values of some of the measured quantities. Table II gives their limiting values, obtained by linear extrapolation to T = 0 of the part of the corresponding curves belonging to the interval 1.7 to 4.2°K; the values $(\Delta I/\Delta H)^*_{p0}$ and $(\Delta R/R\Delta H)^*_{p0}$ were obtained by linear extrapolation to zero of the part lying in the interval 20.4 to 53°K (cf. Figs. 5 and 7).

DISCUSSION OF RESULTS

We shall first show that the existence of residual values of κ and $\Delta R/R_0\Delta H$ at $T \to 0$ cannot be considered a consequence of the change of volume of the lattice under the action of the magnetic field. The latter possibility is not excluded, since for the alloy studied $(\Delta V/V\Delta H)_{T=0} = -(\delta\Delta\sigma/\Delta p)_{T=0} \neq 0$ (δ is the value of the density). The differential susceptibility is

$$\varkappa = \left(\frac{\partial I}{\partial H}\right)_p = \delta\left(\frac{\partial \sigma}{\partial H}\right)_p - \frac{1}{V}\left(\frac{\partial V}{\partial H}\right)_p I = \delta\left[\left(\frac{\partial \sigma}{\partial H}\right)_p + \left(\frac{\partial \sigma}{\partial p}\right)_H I\right] \tag{2}$$

With the aid of known thermodynamic relations, it is easy to obtain

$$\left(\frac{\partial \sigma}{\partial H}\right)_p = \left(\frac{\partial \sigma}{\partial H}\right)_V - \delta\left(\frac{\partial \sigma}{\partial p}\right)_H^2 \Big/ \frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_H . \tag{3}$$

By substituting (3) in (2), we get

$$\varkappa = \delta\left(\frac{\partial \sigma}{\partial H}\right)_V - \left[\delta^2\left(\frac{\partial \sigma}{\partial p}\right)_H^2 \Big/ \frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_H\right] + \delta\left(\frac{\partial \sigma}{\partial p}\right)_H I. \tag{4}$$

TABLE I

Ni content in the alloy specimens	T,°K	$\frac{1}{\Psi}\left(\frac{\Delta\Psi}{\Delta p}\right)_H\cdot 10^7$, kg^{-1} cm^2	$\left(\frac{\Delta I}{\Delta H}\right)_p\cdot 10^4$, G·Oe^{-1}	$\frac{1}{R_0}\left(\frac{\Delta R}{\Delta p}\right)_H\cdot 10^5$, kg^{-1} cm^2	$\frac{1}{R_0}\left(\frac{\Delta R}{\Delta H}\right)_p\cdot 10^7$, Oe^{-1}
38%	1.7	—	1.71±0.07	—	— 6.6±0.35
	4.2	—50±8	1.88±0.07	4.5 ±0.3	— 7.3±0.35
	11.3	—	2.25±0.1	—	— 9.1±0.35
	14.5	—50±8	—	3.7 ±0.2	—
	20.4	—50±8	2.5 ±0.1	3.8 ±0.2	— 9.6±0.35
	53	—	2.8 ±0.1	3.5 ±0.2	—10.2±0.5
	77	—50±8	3.2 ±0.1	3.2 ±0.2	—10.9±0.5
	293	—	11.7 ±0.3	—	—
45%	1.7	—	—	—	— 1.8±0.2
	4.2	— 7±1.5	—	1.35±0.2	— 2.15±0.2
	11.3	—	—	1.4 ±0.2	— 3.5±0.2
	14.5	— 7±1.5	—	—	—
	20.4	— 7±1.5	—	1.4 ±0.2	— 3.85±0.2
	53	—	—	—	—
	77	— 7±1.5	—	—	— 4.5±0.5

TABLE II

	For alloy Ni content			For alloy Ni content	
	38%	45%		38%	45%
$\delta\sigma_0$, G	1370	1380	$\left(\frac{\Delta I}{\Delta H}\right)^*_{p0}\cdot 10^4$, G·Oe^{-1}	2.33	—
$R_0\cdot 10^4$, Ω	3,12	1,88	$\frac{1}{R_0}\left(\frac{\Delta R}{\Delta p}\right)_0\cdot 10^5$, kg^{-1} cm^2	4.0	1,35
$\frac{1}{\Psi}\left(\frac{\Delta\Psi}{\Delta p}\right)_0 10^7$ kg^{-1} cm^2	—50	—7	$\frac{1}{R_0}\left(\frac{\Delta R}{\Delta H}\right)_{p0}\cdot 10^7$, Oe^{-1}	—6,20	—1.4
$\left(\frac{\Delta I}{\Delta H}\right)_{p0} 10^4$ G·Oe^{-1}	1,62	—	$\frac{1}{R_0}\left(\frac{\Delta R}{\Delta H}\right)^*_{p0}\cdot 10^7$, Oe^{-1}	—9.1	—

The first term in parentheses describes the changes of specific magnetization σ (in strong fields) that are connected with orientation of the spins (paraprocess) and with increase of the number of electrons contributing to ferromagnetism, purely as a result of the action of the field (at constant volume). The second term describes the changes of σ that are connected with an increase of the number of electrons contributing to ferromagnetism, or with their orientation, in consequence of a change of volume of the lattice. The third term, which is equal to the second term of (2), describes a trivial change of the magnetic moment density that is connected with a change of volume of the body in consequence of magnetostriction. By inserting in (4) the values of $\delta\partial\sigma/\partial p$ obtained from our measurements and the value of $\partial V/V\partial p$, we can estimate the influence of volume magnetostriction on κ. The calculation gives, for the alloy with 38% nickel, the value 0.46×10^{-4} for the second term and -0.1×10^{-4} for the third in formula (4). Both terms together amount to about 20% of the value of κ at 4.2°. Thus the main part of κ at $T \to 0$ is determined by a direct and not an indirect effect of the field on σ_0.

The relative change of electrical resistance under the influence of pressure is

$$\frac{\Delta R}{R\Delta p} = \frac{\Delta\rho}{\rho\Delta p} - \frac{1}{3}\frac{\Delta V}{V\Delta p}. \tag{5}$$

Here $\Delta\rho$ is the change of specific electrical resistance upon change of the pressure by Δp. The second term, for the alloy studied, amounts to 4×10^{-7} cm^{2}kg^{-1}, i.e., about 1% of the measured value of $\Delta R/R\Delta p$ at $T = 4.2$°K.

The relative change of electrical resistance in strong magnetic fields (in the paraprocess region) under the action of the field is

$$\left(\frac{\Delta R}{R\Delta H}\right)_p = \frac{1}{\rho}\left(\frac{\Delta\rho}{\Delta H}\right)_V + \left[\frac{1}{\rho}\left(\frac{\Delta\rho}{\Delta p}\right)_H\left(\frac{\Delta V}{\Delta H}\right)_p \Big/ \left(\frac{\Delta V}{\Delta p}\right)_H\right] - \frac{1}{3V}\left(\frac{\Delta V}{\Delta H}\right)_p. \tag{6}$$

The second term in this expression is analogous to the second term in (4) and represents the change of specific electrical resistance connected with a change of volume of the lattice on magnetization. By inserting values of $\frac{1}{V}\left(\frac{\Delta V}{\Delta H}\right)_p = -\delta\left(\frac{\Delta\sigma}{\Delta p}\right)_H$ and of $\frac{1}{V}\left(\frac{\Delta V}{\Delta p}\right)_H$, it is easy to estimate the magnitude of the second and third terms. The calculation gives, for the alloy with 38% nickel, the value -2.5×10^{-7} Oe^{-1} for the second term and -2×10^{9} Oe^{-1} for the third. The larger of these values amounts to about 40% of the value of $(\Delta R/R\Delta H)_p$ at $T = 4.2$°K. For the alloy with 45% nickel, we find correspondingly -0.16×10^{-7} and -0.5×10^{-9}. Thus the ultimate changes of electrical resistance with increase of field at strong fields, as $T \to 0$, cannot be explained entirely on the basis of the effect of volume magnetostriction. With the aid of formulas (1) and (4) to (6) and of the data obtained in the experiment, it is easy to find the limiting values at $T \to 0$ of the quantities of interest to us: $\frac{1}{\sigma_0}\left(\frac{\Delta\sigma}{\Delta p}\right)_0$, $\frac{1}{\rho_0}\left(\frac{\Delta\rho}{\Delta p}\right)_0$, $\delta\left(\frac{\Delta\sigma}{\Delta H}\right)_{V0}$, and $\frac{1}{\rho_0}\left(\frac{\Delta\rho}{\Delta H}\right)_{V0}$. These values are given in Table III. The values of $\delta\left(\frac{\Delta\sigma}{\Delta H}\right)_{V0}$ and $\frac{1}{\rho_0}\left(\frac{\Delta\rho}{\Delta H}\right)_{V0}$ are calculated by formulas (4) and (6); $\delta\left(\frac{\Delta\sigma}{\Delta H}\right)^*_{V0}$ and $\frac{1}{\rho_0}\left(\frac{\Delta\rho}{\Delta H}\right)^*_{V0}$ are obtained if in these formulas we insert, instead of $\left(\frac{\Delta I}{\Delta H}\right)_{p0}$ and $\frac{1}{R_0}\left(\frac{\Delta R}{\Delta H}\right)_{p0}$, $\left(\frac{\Delta I}{\Delta H}\right)^*_{p0}$ and $\frac{1}{R_0}\left(\frac{\Delta R}{\Delta H}\right)^*_{p0}$ from Table II. Also given in Table III are the ratios of the limiting values mentioned; and in the last line, for comparison, is given the ratio $\left(\frac{R_{20} - R_0}{R_0}\right) \Big/ \left(\frac{I_{20} - I_0}{I_0}\right)$, which describes the relation between the changes of electrical resistance and of saturation magnetization upon change of temperature in the hydrogen temperature range.[10]

With the aid of the values of $(\Delta\sigma/\sigma\Delta p)_0$ and $(1/\rho_0)(\Delta\rho/\Delta p)_0$ given in Table III, it is possible to estimate the values of the dimensionless quantities $n_\sigma = \left(\frac{\Delta\sigma}{\sigma}\right)_0 \Big/ \frac{\Delta a}{a}$ and $n_\rho = \left(\frac{\Delta\rho}{\rho}\right)_0 \Big/ \frac{\Delta a}{a}$, where $\Delta a/a$ is the fractional change of the lattice constant of the alloy under the influence of pressure Δp; $\Delta a/a \approx \frac{1}{3}\Delta V/V$. For the alloys under consideration, $\Delta a/a \approx 4 \times 10^{-7}\Delta p$. By use of the values of quantities given in Table III, we get for the alloy with 38% nickel, $n_\sigma \approx 15$ and $n_\rho \approx 100$; and for the alloy with 45% nickel, $n_\sigma \approx 2.5$ and $n_\rho \approx 30$.

From a consideration of the quantities given in Table III it is clear that whether it is a pressure or a field that is acting, an increase of σ_0 is accompanied by a decrease of ρ_0 and vice versa. The values of the ratios $\left(\frac{\Delta\rho}{\rho\Delta p}\right)_0 \Big/ \left(\frac{\Delta\sigma}{\sigma\Delta p}\right)_0$, $\left(\frac{\Delta\rho}{\rho\Delta H}\right)_{V0} \Big/ \left(\frac{\Delta\sigma}{\sigma\Delta H}\right)_{V0}$, and $\frac{R_{20} - R_0}{R_0} \Big/ \frac{I_{20} - I_0}{I_0}$ are of a single order and close to one another; this

TABLE III

	For alloy Ni content			For alloy Ni content	
	38%	45%		38%	45%
$\left(\frac{\Delta\sigma}{\sigma\Delta p}\right)_0 \cdot 10^7$, $kg^{-1}\ cm^2$	—54	—11	$\frac{1}{\rho_0}\left(\frac{\Delta\rho}{\Delta H}\right)^*_{V0} \cdot 10^7$, Oe^{-1}	—6.62	—
$\delta\left(\frac{\Delta\sigma}{\Delta H}\right)_{V0} \cdot 10^4$, $G \cdot Oe^{-1}$	1.26	—	$\left(\frac{\Delta\rho}{\rho\Delta p}\right)_0 \Big/ \left(\frac{\Delta\sigma}{\sigma\Delta p}\right)_0$	—7.4	—11.8
$\delta\left(\frac{\Delta\sigma}{\Delta H}\right)^*_{V0} \cdot 10^4$, $G \cdot Oe^{-1}$	2.0	—	$\left(\frac{\Delta\rho}{\rho\Delta H}\right)_{V0} \Big/ \left(\frac{\Delta\sigma}{\sigma\Delta H}\right)_{V0}$	—4.1	—
$\frac{1}{\rho_0}\left(\frac{\Delta\rho}{\Delta p}\right)_0 \cdot 10^5$, $kg^{-1}\ cm^2$	4.0	1.3	$\left(\frac{\Delta\rho}{\rho\Delta H}\right)^*_{V0} \Big/ \left(\frac{\Delta\sigma}{\sigma\Delta H}\right)^*_{V0}$	—4.6	—
$\frac{1}{\rho_0}\left(\frac{\Delta\rho}{\Delta H}\right)_{V0} \cdot 10^7$, Oe^{-1}	—3.7	—1.3	$\frac{(R_{20}-R_0)}{R_0} \Big/ \frac{(I_{20}-I_0)}{I_0}$	—5.45	—6.7

points to the existence of a close connection between the changes of σ_0 and of ρ_0. We note that at fields of 6000 to 7000 Oe, the differential susceptibility κ decreases with increase of field somewhat faster than does $\Delta\Psi/\Psi\Delta p$ (cf. Figs. 2 and 4), and therefore in stronger fields the ratios mentioned should become even closer.

The existence of a connection between the changes of σ_0 and of ρ_0 under the influence of pressure and field indicates that the value of σ_0, like that of ρ_0, depends on the state of the conduction electrons. Changes of σ_0 and ρ_0 may be caused by: (1) transitions of electrons from the s to the d shell on compression of the lattice, or contrary transitions on increase of magnetic field; (2) change of the spontaneous magnetization of the d electrons as a result of the influence of pressure or field on the magnitude of the d-d exchange integrals, when there is uncompensated antiferromagnetism in the alloy and some of the exchange integrals (d_{Ni}-d_{Fe} or d_{Ni}-d_{Ni} and d_{Fe}-d_{Fe}) are negative; (3) change of the spontaneous magnetization of the s electrons as a result of the influence of pressure or field on the magnitude of the s-d exchange integral.

In the first case the observed signs of the changes in σ_0 and ρ_0 receive a simple explanation;* however, the reason for the large effect of pressure on σ_0 in the 38% alloy remains an open question. It also remains an open question why, in the alloys with 30 to 40% nickel (which according to our data show the largest changes of σ_0 under the influence of pressure), there are also observed appreciable changes of the spontaneous magnetization under uniaxial tension in the vicinity of the Curie point.[5] In the second case there is an explanation for the connection that exists between the change of σ_0 and the shift of the Curie point under the influence of pressure; however, it is more difficult to explain the connection between the changes of σ_0 and of ρ in this case. The possibility is not excluded that in the changes of σ_0 and ρ_0 under the influence of pressure and field, all the causes indicated above play a role.

*We note that if the changes of σ_0 and ρ_0 under the influence of pressure are mainly due to the first cause, there arises a possibility of using the values of the ratio $(\Delta\rho/\rho\Delta p)_0/(\Delta\sigma/\sigma\Delta p)_0$ for a rough estimate of the number x of conduction electrons belonging to one atom of the alloy. This estimate gives, for the alloy with 38% nickel, the value

$$x \approx \frac{\rho_0}{\mu N} \frac{\Delta\sigma_0}{\Delta\rho_0}(0.62\, A_{Fe} + 0.38\, A_{Ni}) \approx 0.2.$$

[1] F. Bloch, Z. Physik **74**, 295 (1932); C. Møller, Z. Physik **82**, 559 (1933); T. Holstein and H. Primakoff, Phys. Rev. **58**, 1098 (1940).

[2] S. V. Vonsovskii and Ia. S. Shur, Ферромагнетизм (Ferromagnetism), OGIZ, 1948.

[3] C. Zener, Phys. Rev. **81**, 440 (1951); **82**, 403 (1951); **83**, 299 (1951); **85**, 324 (1952).

[4] M. Ebert and A. Kussman, Physik. Z. **38**, 437 (1937); K. H. v. Klitzing and J. Gielessen, Z. Physik **146**, 59 (1956).

[5] K. P. Belov, J. Tech, Phys. (U.S.S.R.) **19**, 1032 (1949); Izv. Akad. Nauk SSSR, Ser. Fiz., **16**, 420 (1952); Физика металлов и металловедение (Physics of Metals and Metal Research) **2**, 447 (1956).

[6] B. G. Lazarev and L. S. Kan, J. Exptl. Theoret. Phys. (U.S.S.R.) **14**, 439 (1944).

[7] S. P. Kapitza, J. Tech. Phys. (U.S.S.R.) **25**, 1307 (1955).

[8] J. Smit, Physica **17**, 612 (1951).

[9] K. P. Belov and A. V. Ped'ko, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 815 (1957), Soviet Phys. JETP **6**, 628 (1958).

[10] Kondorskii, Galkina, and Chernikova, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 1070 (1958), Soviet Phys. JETP **7**, 741 (1958).

Translated by W. F. Brown, Jr.
183