The Effect of the Method of Demagnetization of the Specimen on the Temperature Dependence of the Magnetization of Nickel in Weak Fields

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By two different methods, a study was made of the effect of the method of demagnetization of the specimen on the temperature variation of the intensity of magnetization of nickel in weak magnetic fields.

1. INTRODUCTION

THE temperature dependence of the magnetization of nickel in weak fields depends materially on the method of demagnetization of the specimen before the start of the measurements. Analysis of the works of various investigators[1,4] on the study of magnetic temperature-hysteresis of ferromagnetics, in which the ascending branch of a cycle portrays the temperature variation of the magnetization in weak fields, shows that the demagnetization of the specimen before the measurements was usually carried out with alternating current, gradually decreased to zero.

However, a study of the magnitude of the observed magnetostriction, carried out by Vlasov[5], and the change of shape of the magnetization curve for different methods of demagnetization, studied by Kondorskii[6], suggest that the results of measurements of the temperature dependence of the magnetization of nickel in weak fields may depend on the method of demagnetization of the specimen before the start of the measurements.

In the present work, a study was made of the effect of two methods of demagnetization of the specimen on the temperature variation of magnetization in nickel. One method consisted in heating above the Curie point and then cooling in the absence of a magnetic field. The other was the method of alternating current of diminishing amplitude. at the initial test temperature.

[1] Ia. S. Shur and V. I. Drozhzhina, J. Exper. Theoret. Phys. USSR 17, 607 (1947)

[2] V. I. Drozhzhina and Ia. S. Shur, Izv. Akad. Nauk SSSR, Ser. Fiz. 11, 539 (1947)

[3] Ia. S. Shur, N. A. Baranova and V. A. Zaikova, Dokl. Akad. Nauk SSSR 81, 557 (1951)

[4] Ia. S. Shur and N. A. Baranova, J. Exper. Theoret. Phys. USSR 20, 183 (1950)

[5] A. Ia. Vlasov, Izv. Akad. Nauk SSSR, Ser. Fiz. 16, 680 (1952)

[6] E. I. Kondorskii, J. Exper. Theoret. Phys. USSR 10, 420 (1940)

2. SPECIMENS STUDIED AND METHOD OF MEASUREMENT

The experiments were done on a cylindrical specimen of pure nickel (99.98%), of diameter 1.05 mm and length 100 mm. To relieve the internal stresses, the specimen was annealed in a vacuum for eight hours at 1000° C and then cooled slowly in a magnetic shield. During the measurements, steps were taken to prevent work-hardening or strain of the specimen. The investigations were carried out by two methods: the method of automatic photographic recording on a vertical astatic magnetometer, and the method of counting the discontinuous changes of magnetization on a special amplifier.

The diagram of the vertical astatic magnetometer is shown in Fig. 1. A beam of light, reflected by the mirror of the astatic suspension, fell on the slit of the camera Ф. On this same slit there fell a beam from the mirror of the pyrometer galvanometer G_2, connected in the circuit of a thermocouple; one junction of the thermocouple was in direct contact with the specimen, the other was in a constant-temperature bath of melting ice. The construction of the vertical astatic magnetometer has been described in detail in the literature[1-4]

A novel experimental feature of the present investigation is the simultaneous automatic photographic recording of the intensity of magnetization and of the temperature, in the form of a magnetothermogram. The camera is a cylindrical drum of diameter 6 cm and length 30 cm, inserted in a cylindrical jacket, along a generator of which there runs a narrow slit. To the camera drum is fastened the photographic film, clamped with a special holder. At the time of the measurements the camera drum is rotated about a horizontal axis by

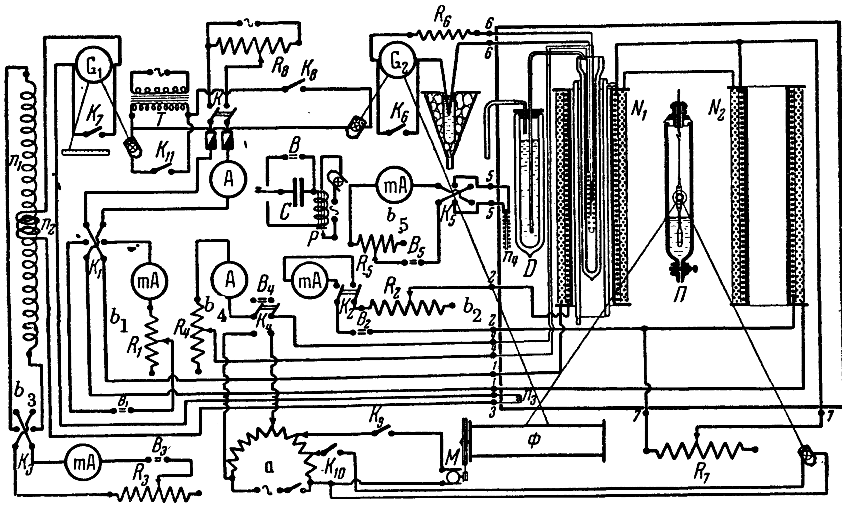

FIG. 1. Diagram of the astatic photographically recording magnetometer. N_1 and N_2, magnetometer coils; П, astatic suspension; D, liquid oxygen system; b_1, magnetizing circuit; consisting of battery B_1, rheostat R_1, milliammeter mA, reversing switch K_1, and magnetizing windings of the magnetometer coils. b_2, compensating circuit, consisting of battery B_2, switch K_2, milliammeter mA, rheostat R_2 and compensating windings on the magnetometer coils. b_3, calibrating circuit consisting of standard solenoid with windings n_1 and n_2, ballistic galvanometer G_1, damping switch K_7, reversing switch K_3, milliammeter mA, battery B_3, rheostat R_3 and calibrating solenoid n_3. b_4, heating circuit, consisting of bifilar furnace winding, supplied with alternating current from autotransformer a or with direct current from battery B_4, selecting switch K_4, ammeter A and rheostat R_4. b_5, means of calibrating camera with respect to magnetization of specimen, consisting of calibrated coil n_4, reversing switch K_5, milliammeter mA, rheostat R_5 and battery B_5. The demagnetizing circuit is connected to potentiometer R_8; it functions when switch K is closed and reversing switch K_1 is open. B, battery for the automatic device for horizontal light marks. C and P, condenser and relay of the automatic marker. G_2, galvanometer; K_6, damping switch; R_6, thermocouple resistance; T, lamp transformer; K_{10} and K_{11}, lamp switches; K_9, switch for motor M; Φ, camera; R_7, shunt; Z, magnetic shield.

the Warren motor M. The speed of rotation of the drum is 1 revolution per hour.

By means of an automatic marking device, there are produced on the magnetothermogram marks of equal width, which simultaneously determine a magnetization and a temperature of the specimen. The calibration of the camera scale for intensity of magnetization is accomplished by means of the calibrating solenoid n_3*, inserted in place of the specimen, on the basis of the current through its winding[7].

Translator's note: From the context, this appears to be an error for "calibrated coil n_4".

[7] I. V. Antik, E. I. Kondorskii et al, Magnetic Measurements (State Institute of Technology, 1939), p. 29

Before the start of the measurements, the specimen was heated to 400° C and cooled in a magnetic shield to − 183° C. During this step, the vertical component of the earth's magnetic field and of other extraneous parasitic fields was compensated with the single-layer compensating winding of the magnetometer. During the cooling, the magnetometer mirror remained steadily at the zero position.

A magnetizing field of strictly constant magnitude was applied, and the specimen was heated to 400° C. During the heating of the specimen, the camera operated, and the variation of the temperature and magnetization of the specimen was recorded on the film. After this the camera was

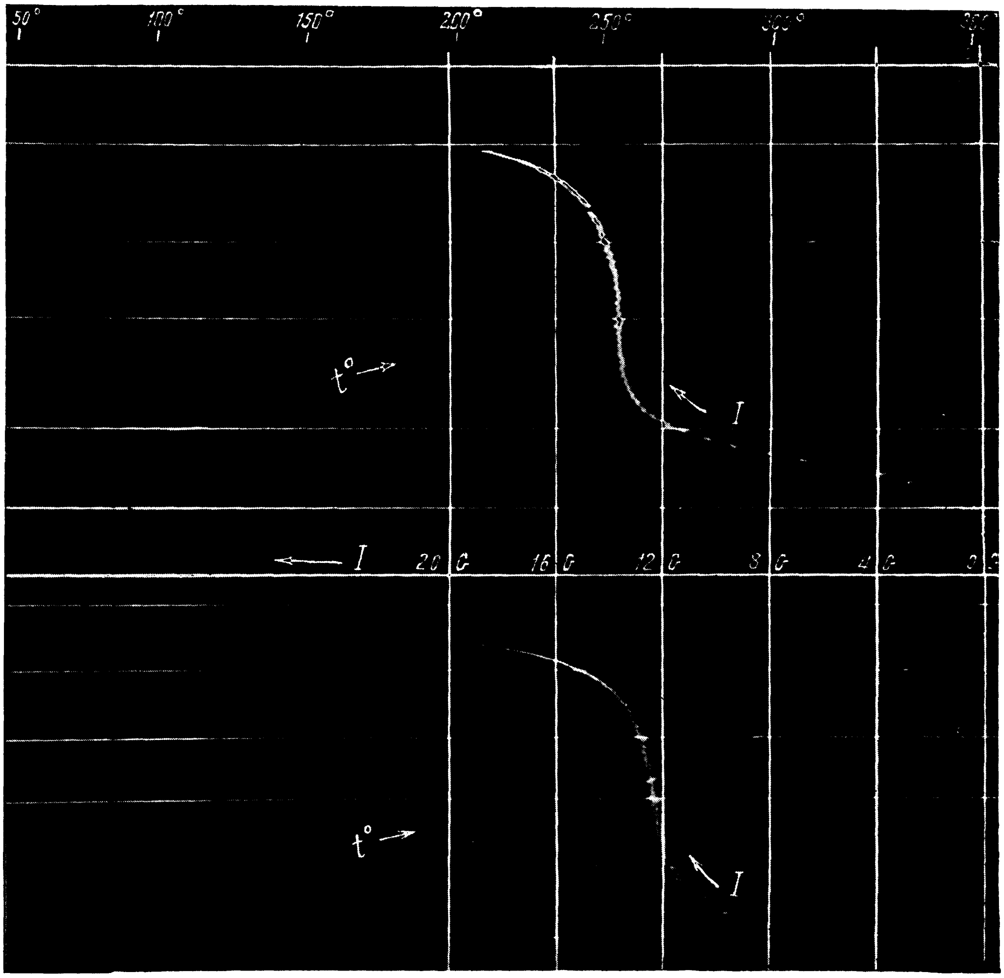

FIG. 2. Magnetothermograms. $t^0 \rightarrow$ variation of the temperature of the specimen, $I \rightarrow$ resulting variation of the intensity of magnetization of the specimen. *a*, specimen demagnetized in the initial state with alternating current, gradually diminished to zero; *b*, specimen demagnetized by heating to 400° C and cooling in a magnetic shield to the initial state (-183° C). The variation of the temperature from -183 to 50° is suppressed.

closed and stopped. The magnetizing field was removed, and the specimen was cooled to - 183° C. The specimen was demagnetized with alternating current, whose amplitude was gradually diminished to zero by means of the potentiometer R_8.

Then the same magnetizing field was applied, the camera slit was opened, the camera motor was connected and the specimen was heated to 400° C.

The experiment was carried out in various fields; and consistent differences were observed, in the temperature behavior of the curves of intensity of magnetization, between the two methods of demagnetizing the specimen. The differences were more noticeable, however, in weak fields than in fields of order 2 to 3 oersteds and higher. For illustration, Fig. 2 shows a magnetothermogram taken in a field of 0.39 oersted.

In the investigation by the method of counting discontinuous changes of magnetization, apparatus was used whose measurement principle has been described in detail in the literature[8,9]. A somewhat modified, improved scheme is depicted in Fig. 3.

The same specimen was used in this investigation as in the first case. The specimen with a thermocouple was placed inside a bifilarly wound furnace,

[8] B. F. Tsomakion and V. F. Ivlev, Dokl. Akad. Nauk SSSR 76, 205 (1951)

[9] V. F. Ivlev, Izv. Akad. Nauk SSSR, Ser. Fiz. 16, 664 (1952)

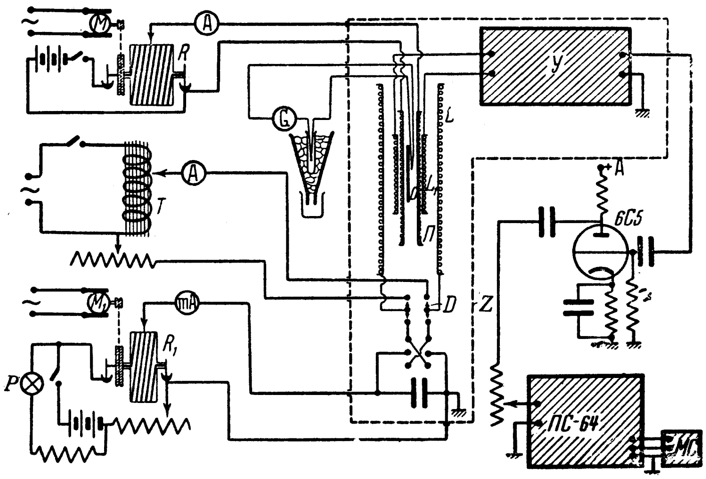

FIG. 3. Schematic diagram of the apparatus. R and R_1, rotating rheostats; M and M_1, Warren motors; T, autotransformer; y, amplifier; L, magnetizing coil; L_1, test coil; П, furnace; 0, specimen; ПС-64 (PS-64), counter circuit; MC, mechanical counters; D, reversing switch; Z, magnetic shield; P, pilot lamp; G, pyrometer; A, ammeter; mA, milliammeter.

which was inside a test coil L_1. The test coil was connected to the input terminals of a three-stage amplifier. A gradual change of temperature was produced by variation of the furnace current by means of a rotating rheostat R. Upon change of the temperature of the specimen---which was in a constant magnetic field, produced by the magnetizing coil L---, there occurred at the terminals of the test coil short-time voltage impulses, caused by Barkhausen jumps. These impulses indicated changes of magnetization; they were picked up by the amplifier and entered the input terminals of a counter circuit, type PS-64. The number of discontinuous changes of magnetization was registered on mechanical counters, type SB-1 M/100.

Before the start of the measurements, the specimen was demagnetized with alternating current of diminishing amplitude at temperature -183° C. The magnitude of the alternating current in the coil 1 (Fig. 3) was gradually decreased to zero by means of the rheostat and autotransformer T. The magnetizing field was applied with reversing switch D, and the specimen was slowly heated to 400° C. The discontinuous changes of magnetization upon heating of the specimen were registered on the mechanical counters. The number of jumps was recorded in each of the temperature intervals - 183 to 0, 0 to 150, 150 to 300 and 300 to 360° C.

Separate counters registered discontinuities of different volumes.. Then the specimen was demagnetized by heating to 400° C and cooling in a magnetic shield to - 183° C. The magnetizing field and the measuring apparatus were again connected, and the specimen was heated to 400° C.

The mechanical counters registered the discontinuous changes of magnetization during the heating.

3. RESULTS OF THE MEASUREMENTS

The data from the magnetothermogram of Fig. 2 are plotted in Fig. 4. It is evident that when the specimen was demagnetized by heating to 400° C and then cooling in a magnetic shield, heating in a field of 0.39 oersted produced an increase in the intensity of magnetization (Curve 1). At 180° C the rate of increase slowed down, and at 250° C there was a point of inflection; this corresponded to intensity of magnetization 12.3 gauss. Further heating of the specimen again speeds up the increase of the intensity of magnetization; near the Curie point (360° C) the intensity of magnetization reaches a maximum value of 19.2 gauss (Hopkinson's maximum)[10] and then drops to zero.

Demagnetization of the specimen in the initial thermal state, with alternating current of diminishing amplitude, and subsequent heating in a field of 0.39 oersted, give qualitatively the same

[10] J. Hopkinson, Trans. Roy. Soc. (London) **153**, 443 (1885)

picture; but the curve of intensity of magnetization, in every section of the temperature range studied, is higher (Curve *2*), and the point of inflection occurs at temperature 200° C, which corresponds to intensity of magnetization 13.3 gauss. The magnitude of Hopkinson's maximum remains the same.

The investigations by counting discontinuous changes of magnetization showed that the number of these jumps also depends on the method of demagnetizing the specimen. Demagnetization of the specimen in the initial state, with alternating current of diminishing amplitude, produces consistently more discontinuous changes of magnetization than does demagnetization of the specimen by heating and then cooling in a magnetic shield.

In Tables I and II are presented the data taken with the counters on heating the specimen in the same field of 0.39 oersted. In fields of other magnitudes, the same relation was observed.

These Tables show the dependence of the number of discontinuities of different magnitudes (volumes)[8] on temperature.

The apparatus permitted detection of discontinuous changes of magnetization of regions whose dimensions exceeded 2×10^{-9} cm^3. In the temperature interval 300-360° C (near the Curie point), the jumps were not detected by the apparatus because of the small volumes of the reversing

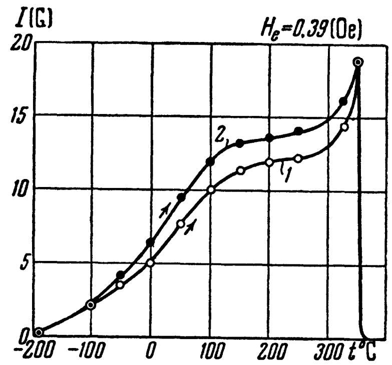

FIG. 4. Effect of the method of demagnetization of the specimen on the temperature variation of the intensity of magnetization of nickel in a field of 0.39 oersted. *1*, specimen demagnetized by heating to 400° C and cooling in a magnetic shield to -183° C; *2*, specimen demagnetized in the initial state with alternating current, gradually decreased to zero.

TABLE I

Specimen demagnetized by heating to 400° C

t °C	$V \times 10^9$ cm^3						Combined number of jumps
	2,5	3.5	4,5	5,5	6.5	7.5	
	Number of jumps, registered by separate counters						
—183—0	5	3	0	0	1	1	10
0—150	6	2	0	1	0	1	10
150—300	3	0	0	0	0	0	3
300—360	0	0	0	0	0	0	0

TABLE II

Specimen demagnetized by alternating current with amplitude diminishing to zero

t °C	$V \times 10^9$ cm^3						Combined number of jumps
	2,5	3.5	4.5	5,5	6,5	7,5	
	Number of jumps, registered by separate counters						
—183—0	18	4	3	3	1	2	31
0—150	13	8	4	4	1	2	32
150—300	4	0	0	1	0	0	5
300—360	0	0	0	0	0	0	0

regions. From the data of Tables I and II, Table III has been constructed; here is shown the dependence of the combined volume of all the reversing regions on the temperature.

TABLE III

t° C	Method of demagnetization	
	demagnetization by heating	demagnetization by alternating current
	Volume $\times 10^9$ cm^3	
—183—0	37	110.5
0—150	35	122
150—300	7.5	15.5
300—360	0	0

4. ANALYSIS OF RESULTS AND CONCLUSIONS

Upon demagnetization of the specimen with alternating current, gradually diminished to zero, there is created a definite texture of antiparallel orientations of spin moments, which we must suppose also causes differences in the temperature variation of the intensity of magnetization of nickel. Such a texture insures principally longitudinal inversions, which occur in weaker fields than do transverse inversions.

Heating of the specimen in a constant field, after its demagnetization with diminishing alternating current, causes a more abrupt rise of the intensity of magnetization than in the case of demagnetization of the specimen by heating to the Curie point and then cooling in a magnetic shield to -183° C. The formation of such a texture is also indicated by the investigations conducted on discontinuous changes of magnetization. The number of jumps after demagnetization of the specimen by alternating current is greater than the number after demagnetization by heating above the Curie point and then cooling in a magnetic shield; this can be explained by the fact that in demagnetization of the specimen by alternating current, an antiparallel texture is created, and heating of the specimen in a field causes reorientation of domains of magnetic reversal along new directions of easy magnetization, and then along the field. In the case of demagnetization by heating above the Curie point, there is a random distribution of domains of magnetization, and heating in the field causes only reorientation along the field.

Since the temperature variation of the intensity of magnetization of the specimen forms the ascending branch of the magnetic temperature-hysteresis curve, it follows that in studies of magnetic temperature hysteresis, the specimen must be demagnetized by heating; for demagnetization with alternating current leads to production of a magnetic texture.

In conclusion, we remark that in order to obtain not merely qualitative but also quantitative demonstrations of the inferences from the present investigation, it is desirable to conduct, in parallel, measurements of the temperature variation of the intensity of magnetization and of the magnetostriction or electrical resistivity of the specimen in the field under study.

The conduct of such an investigation involves well-known technical and experimental difficulties. Nevertheless, the authors are setting themselves the task of accomplishing such an investigation in the future.

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