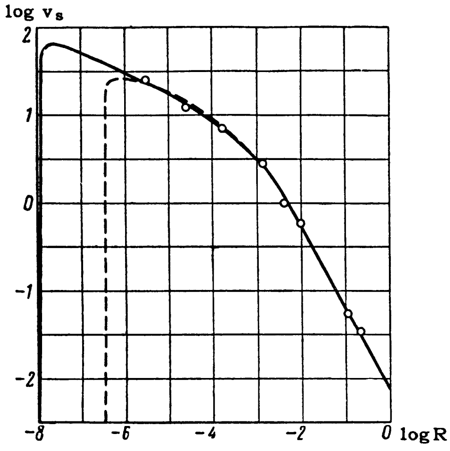

dashed curve, with a = 3 × 10^{-7} cm, τ = 2 × 10^{-4} sec, and α = 0.116.

The appearance of a trans-critical regime in the capillary under conditions of slight supercriticality is represented in the following form: At certain points in the capillary, due to nonuniformity of its walls, there will exist more suitable conditions for the formation of a ring vortex. When the vortex has moved along the capillary, another vortex arises at the same point, but with two vortices present near one another one vortex begins to move into the other. After a third vortex has formed, it too begins to take part in the collective vortex motion. Thus, the vortices forming at individual points due to slight supercriticalities begin gradually to fill the capillary, through an extremely complex collective motion. In the presence of a thermal current along the capillary the vortices existing therein increase the thermal resistance; the gradual filling of the capillary with vortices is therefore accompanied by a real, experimentally observable, slow (e.g., 0.2 cm/sec) advance of a front of increased thermal gradient. This pattern has been observed by Mendelssohn and Steele.[8] The vortices formed are more stable when their momenta are in the direction of motion of the normal component than when they are oppositely directed; when trans-critical regimes are present in capillaries, therefore, a velocity distribution is established which is similar to that proposed by Gorter and Mellink,[9] wherein the difference $v_s - v_n$ remains constant over the entire cross-section of the capillary.

[1] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. **A170**, 423, 439 (1939).

[2] J. F. Allen and A. D. Misener, Proc. Roy. Soc. **A172**, 467 (1939).

[3] P. L. Kapitza, JETP **11**, 581 (1941).

[4] L. D. Landau, JETP **11**, 592 (1941).

[5] R. P. Feynman, Progr. in Low Temp. Phys. **1**, Amsterdam, 1955, p. 17.

[6] K. R. Atkins, Liquid Helium, Cambridge, 1959.

[7] H. E. Hall, Proc. Roy. Soc. **A245**, 546 (1958).

[8] K. Mendelssohn and W. A. Steele, Proc. Phys. Soc. **73**, 144 (1959).

[9] C. J. Gorter and J. H. Mellink, Physica **15**, 285 (1949).

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ORIGINS OF THE NERNST EFFECT IN FERROMAGNETIC METALS

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THIS article treats a relativistic effect connected with the movement of current carriers that possess a nonvanishing mean magnetization. An estimate of the transverse electric field intensity connected with this effect shows that it needs to be taken into account in the theory of the Nernst effect in ferromagnetic metals. It is shown that from the sign of the Nernst field one can determine how the magnetization of the current carriers is directed with respect to the resultant spontaneous magnetization of the metal.

In the existing theories, the fractional values of the magnetic moments of ferromagnetic metals are explained[1] on the basis of the assumption that the current carriers possess a magnetization directed parallel or antiparallel to the magnetization of the metal.

Let us consider the simplest possible model, in which the current carriers are free electrons with mean magnetization $I_e = a_e I_z$, where a_e is a positive or negative coefficient and I_z is the magnetization. Under the influence of an electric field E_x, there is excited an electric current of density $j_x = env_x = -enuE_x$, where u is the mobility. It is known that if a system possessing magnetic moment **I** moves with velocity **v**, a stationary observer records in it an electric polarization **P** and an electric field $\mathbf{E} = -4\pi\mathbf{P} = -(4\pi/c)\mathbf{v}\times\mathbf{I}$. In the case being considered, this field is directed along the y axis and is equal to $E = (a_e v_x/c) 4\pi I_z$. Therefore the Lorentz force is $F_y = e(E - v_x B_z/c)$, and the Hall current density is $j_y = -(\sigma v_x/c)(B_z - a_e \cdot 4\pi I_z)$. This current vanishes after appearance of surface charges that produce an electric field $E_{H1} = j_y/\sigma$. The Hall field intensity is $E_{Hy} = E_{H1} + E = v_x B_z/c$, whence $R_0 = 1/cne$. Thus in the case of free electrons possessing magnetization, the Hall constant remains the same as if the whole magnetization were produced exclusively by bound electrons. In this case the derivation given differs from the usual one only in the treatment of the physical interpretation of the terms that enter E_{Hy}.

The effect considered plays an essential role in the Nernst effect, where because of the electrical polarization connected with current carriers that possess a magnetization, there can arise a field, two orders of magnitude larger than the usual Nernst field, which is produced by the difference of speeds of electrons moving toward the hot and the cold ends of the conductor.

Current carriers of any type moving toward the hot end of the metal have a larger mean magnetization than carriers that are moving in the opposite direction. Therefore when a heat current flows along the conductor, there is a transfer not only of energy but also of magnetic moment. As a result, in this case also there is produced an electric polarization, which leads to the appearance of a transverse electric field. Calculation of the part Q_{se} of the ferromagnetic Nernst constant Q_s that is due to the effect under consideration leads to the expression

$$Q_{se} = \frac{2\tau(\eta)\eta a_e}{3cm^* I_s}\frac{\partial I_s}{\partial T}\cdot 300 = \frac{K a_e}{c C_0 I_s}\frac{\partial I_s}{\partial T}\cdot 300 \text{ [v/deg-gauss]}. \quad (1)$$

Here $\tau(\eta)$ is the relaxation time, η is the Fermi energy, K is the thermal conductivity, C_0 is the electronic heat capacity, and I_s is the spontaneous magnetization. It is easily demonstrated that at temperatures near the Curie point and for $|a_e| \geq 0.1$, we have $Q_{se} \gg Q_s'$, where Q_s' is the usual Nernst constant.

In the Nernst field there is also included a field connected with spin-orbit interaction of the current carriers with the ions. If in first approximation, as was done by Karplus and Luttinger,[2-3] we describe the spin-orbit interaction by means of an effective field $H_{eff} = H_{spo} I_e/I_s$, then we can derive a formula for the part of the Nernst constant connected with this interaction; it will differ from (1) only by a positive multiplier. Comparison with experimental data[4-5] on nickel and on iron-nickel alloys shows that (1) describes well the temperature dependence of Q_s from room temperature to the Curie point and gives the right order of magnitude for the value of Q_s.

It follows from (1) that, independently of the type of current carrier, the coefficient Q_s is positive if the magnetization of the carriers is directed opposite to the spontaneous magnetization of the metal, and is negative if both magnetizations are parallel. Thus from the sign of Q_s it is possible to determine the signs of the magnetizations of the current carriers. As Smith's[4] experimental data show, Q_s is negative in iron and positive in nickel and cobalt. Consequently, the magnetization of the current carriers is directed along the spontaneous magnetization in iron and opposite to it in cobalt and in nickel.

[1] S. V. Vonsovskiĭ, Современное учение о магнетизме (Modern Theories of Magnetism), Gostekhizdat, 1953, pp. 224-227.

[2] R. Karplus and J. M. Luttinger, Phys. Rev. **95**, 1154 (1954).

[3] J. M. Luttinger, Phys. Rev. **112**, 739 (1958).

[4] A. Smith, Phys. Rev. **33**, 295 (1911); **17**, 23 (1921).

[5] R. P. Ivanova, Физика металлов и металловедение (Phys. of Metals and Metallography) **8**, 851 (1959).

Translated by W. F. Brown, Jr.
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CORRECTION TO THE ARTICLE BY D. P. GRECHUKHIN 'SOME EXPERIMENTAL POSSIBILITIES FOR VERIFICATION OF THE MODEL OF NONAXIAL NUCLEI WITH A ROTATIONAL SPECTRUM'

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THROUGH an oversight on the part of the author, the coefficient of the third term of Eq. (4) is in error. The rigorously correct formula is

$$\langle r^2\rangle_{DF} = \frac{3}{5} Z R_0^2 \Big\{1 + \frac{5}{4\pi}\beta^2 + \frac{25}{12\pi}\cdot\sqrt{\frac{5}{4\pi}}\,(C_{2020}^{20})^2 \beta^3 \cos\gamma\,[1 - 4\sin^2\gamma]\Big\}.$$

Recognizing that $(C_{2020}^{20})^2 = 2/7$ and $(50)/21)\sqrt{5/\pi} \approx 3.004$, we obtain, with sufficient accuracy

$$\langle r^2\rangle_{DF} = \frac{3}{5} Z R_0^2 \Big\{1 + \frac{5}{4\pi}\beta^2 + \frac{3}{8\pi}\beta^2 \cos\gamma\,[1 - 4\sin^2\gamma]\Big\}.$$

The author is deeply grateful to É. E. Fradkin for calling his attention to the error and for undertaking the recalculation of $\langle r^2\rangle_{DF}$.