magnetic field. To determine the magnetic susceptibility it is necessary to evaluate the current density which in the case of the relativistic electron gas is of the form

$$\mathbf{j} = ec \int d\mathbf{p}\,(\boldsymbol{\alpha}_{\alpha\beta} f_{\alpha\beta}). \qquad (2)$$

The magnetic susceptibility of the gas χ* is determined using a solution of the stationary linearized equation (1) as follows: $\mathbf{j}_k = ck^2\chi\mathbf{A}_k$, where $\mathbf{j}_k$ and $\mathbf{A}_k$ are the Fourier components of the current and the vector potential. After simple calculations we find the magnetic susceptibility of a relativistic electron gas

$$\chi = \pi e^2\hbar^2 \left\{1 - \frac{1}{3}\right\} \int_0^\infty \frac{f_0(p)}{E_p}\,dp, \qquad E_p = \sqrt{c^2p^2 + \mu^2}, \qquad (3)$$

where $f_0(p)$ is the equilibrium momentum distribution function of the electrons normalized to the total number of electrons per unit volume. The one in the curly brackets in (3) is caused by the electron spins and corresponds to the spin paramagnetism of the electron gas, while the second term $1/3$ corresponds to the diamagnetism of the free electrons. The diamagnetism of a relativistic, as of a non-relativistic, electron gas is thus equal to one third of its spin paramagnetism. In the nonrelativistic limit $E_p = \mu = mc^2$ and Eq. (3) goes over into Landau's well-known expression.

For a relativistic degenerate electron gas a simple evaluation of the integral in (3) gives

$$\chi_\Phi = \left(\frac{e\hbar}{2mc}\right)^2 \frac{m^2c}{\pi^2\hbar^3}\left\{1 - \frac{1}{3}\right\} \ln\frac{p_0 + \sqrt{p_0^2 + m^2c^2}}{mc}, \qquad (4)$$

where $p_0 = \hbar(3\pi^2N)^{1/3}$. In the ultrarelativistic limit, $p_0 \gg mc$, we get from Eq. (4)

$$\chi_\Phi = \left(\frac{e\hbar}{2mc}\right)^2 \frac{m^2c}{\pi^2\hbar^3}\left\{1 - \frac{1}{3}\right\}\left[\ln\frac{2\hbar(3\pi^2N)^{1/3}}{mc} + \frac{m^2c^2}{4\hbar^2(3\pi^2N)^{2/3}}\right]. \qquad (5)$$

It follows from Eq. (5) that the magnetic susceptibility of an ultrarelativistic degenerate electron gas increases logarithmically with increasing density

$$\chi_\Phi \approx 0.5 \cdot 10^{-3} \ln(2\hbar(3\pi^2N)^{1/3}/mc).$$

In real cases $\chi_\Phi \ll 1$.

For an ultrarelativistic Boltzmann electron gas ($\kappa T \gg mc^2$) Eq. (3) goes over into the following expression for the magnetic susceptibility

$$\chi_B = \left(\frac{e\hbar}{2mc}\right)^2 \frac{N}{2\kappa T}\left(\frac{mc^2}{\kappa T}\right)^2\left\{1 - \frac{1}{3}\right\}\left[\ln\frac{\kappa T}{mc^2} + 0.116\right]. \qquad (6)$$

In the equilibrium state of the system the number of electron-positron pairs formed through collisions is for $\kappa T \gg mc^2$ equal to[4] $N^+ = N^- = 0.183\,(\kappa T/\hbar c)^3$. Taking this into account in Eq. (6) we conclude that the magnetic susceptibility of the system increases logarithmically with increasing temperature, $\chi_B \approx 10^{-4} \ln(\kappa T/mc^2)$. In real systems $\chi_B \ll 1$.

We express our gratitude to V. L. Ginzburg for his interest and for discussions of this paper.

*We emphasize that we are dealing with the susceptibility of an electron gas in a thermodynamic equilibrium state. The magnetic moment of the system may in a non-equilibrium state be appreciably higher.

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ELECTRICAL RESISTANCE MAXIMUM FOR FERROMAGNETS AT THEIR CURIE POINTS AT LOW TEMPERATURES

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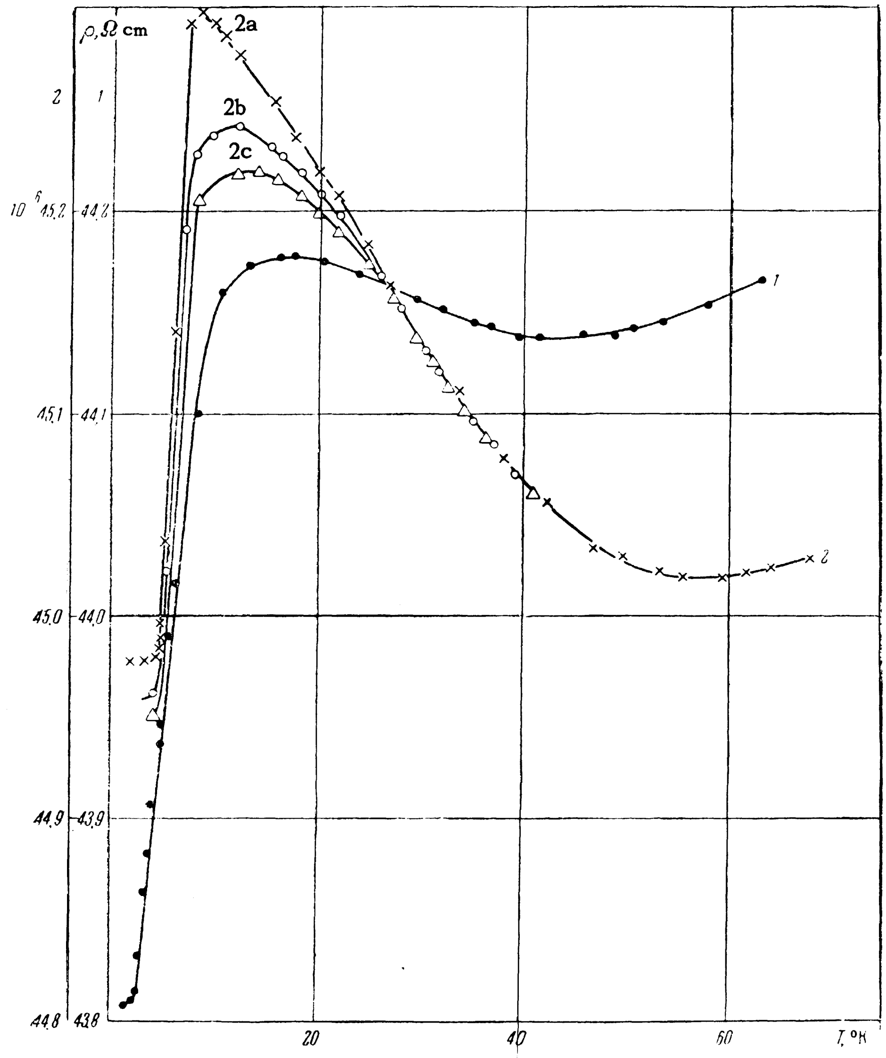
WE showed earlier[1] that for nickel the ratio $\Delta\rho/\Delta I$ (where $\Delta\rho$ is the change of electrical resistivity for a change in magnetization of ΔI produced by a magnetic field, in the region of magnetic saturation) is approximately equal to the ratio $(\rho_T - \rho_0)/(I_0 - I_T)$, where ρ_T and I_T are the specific resistivity and saturation magnetization at temperatures $T < 20°K$, ρ_0 is the residual resistivity and I_0 is the saturation magnetization derived by extrapolation to absolute zero. It was also established that at hydrogen temperatures and below, the law $\rho_T - \rho_0 = aT^{3/2}$ holds for iron and nickel, where a is the constant of proportionality, and that above hydrogen temperatures the difference $\rho_T - \rho_0 - aT^{3/2}$ is roughly proportional to T^5. From this it was deduced that at hydrogen and he-



Dependence of electrical resistivity of copper-nickel alloys on temperature. Curve 1 – alloy with 58% copper; H = 0; 2a – 59.25% Cu, H = 0; 2b – 59.25% Cu, H = 1540 oe; 2c – 59.25% Cu, H = 2310 oe.

lium temperatures, the main cause of the increase in resistivity with temperature for ferromagnetic metals is the increase in disorder of the magnetic moment of the lattice (the increase in the number of ferromagnons, which scatter conduction electrons), and above hydrogen temperatures it is due to the greater intensity of lattice vibrations (the increase in the number of phonons).

In the region of the Curie point, where fluctuations in the magnetic ordering occur, a maximum in the resistivity could be expected. This maximum should be most marked when the Curie point lies at hydrogen or helium temperatures, where the phonon part of the resistivity is small.

The first indication of the existence of such a maximum occurred in the work of Krivoglaz and Rybak,[2] where the effect of various kinds of static disorder of the lattice was examined, and a theoretical study made of the influence of fluctuations in the magnetic moment on the conductivity of ferromagnetic semiconductors. It follows from equations (43), (44), and (54) of that paper that the mean free path and mobility of the electrons due to scattering by the fluctuations of magnetic moment increases on application of a magnetic field which reduces these fluctuations.

The purpose of the present work was an experimental verification of the existence of the resistivity maximum in the region of magnetic saturation for ferromagnets with low transition temperatures. The specimens used were copper-nickel alloys with 58 and 59.25% copper, for which the Curie points lie below 20°K. The resistivity was determined by the method described previously.[1]

The figure shows the dependence of resistivity on temperature. There are maxima in the region of the magnetic transition, and that for the 59.25% Cu specimen with a Curie point near to helium temperatures is especially marked. These maxima are smoothed out when a magnetic field is applied. At the maximum of the 59.25% Cu specimen the value of $\rho - \rho_0$ is 0.7% of the residual resistivity and agrees with the calculation given by Krivoglaz and Rybak.[2] We should point out that this calculation was made for semiconductors, whereas our result is for a metal, so that a quantitative comparison is hardly possible. Nevertheless the existence of a resistivity maximum in the region of the magnetic transition of metals confirms the theory and the deductions made from our previous work about the effect of disorder of the magnetic moment on the electrical resistivity of ferromagnets at low temperatures.

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POSSIBILITY OF AN EXPERIMENTAL TEST FOR FORM FACTORS IN THE THEORY OF THE UNIVERSAL FERMI INTERACTION

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THERE is great interest at present in a test of the form factors in the theory of the weak interaction. These form factors are commonly expressed by "weak magnetism" terms and by pseudoscalar interaction terms.[1] Unfortunately, however, this effect is small in beta decay, is difficult to examine, and up to now has not been observed.[2] In the present note we calculate the process of μ capture by spin-$1/2$ nuclei without emission of neutrons and protons, supposing that after the capture the nucleus makes a transition from the spin-$1/2$ state to the spin-$3/2$ state. The density matrix of the initial state has the form[3]

$$\frac{1}{4}(1 + \sigma_p \xi_p + \sigma_\mu \xi_\mu + \varepsilon\sigma_p \sigma_\mu), \tag{1}$$

ξ_p and ξ_μ are the polarizations of the nucleus and the muon; they are equal to each other for the triplet state and equal to zero for the singlet state; $\epsilon = 1/3$ for the triplet state and $\epsilon = -1$ for the singlet state. The density matrix can also be written in an analytic form for a mixed state. Here ϵ takes on values between -1 and $1/3$ and characterizes the distribution of muons between the singlet and triplet states. We will take as the nuclear matrix element that of Chou Kuang-Chao and Maevskiĭ.[4] We neglect the momenta of the proton and muon in the initial state. After calculation we get the probability for the transition of the nucleus from spin-$1/2$ to spin-$3/2$ in the form

$$W = (G^2Z^3/2\pi^2a_\mu^3)\, N_0\, |M_{G.T.}|^2 q^2 (1 - q/Am_p),$$
$$N_0 = (1+\varepsilon)\Big[\lambda^2 + \frac{\lambda\beta}{3}(2\mu + 2 - f + \lambda) - \frac{\beta^2}{12}(\mu+1)(2f - 2\lambda - \mu + 1)\Big] + \frac{\beta^2}{12}(\mu + f + 1 - \lambda)^2. \tag{2}$$

Here G is the Fermi constant; a_μ is the muon Bohr-orbit radius; q is the neutrino energy, λ is the ratio of the Gamow-Teller and Fermi constants, equal to 1.25 for beta decay; μ is the anomalous gyromagnetic ratio which characterizes "weak magnetism" and is equal to 3.7; f is the pseudoscalar coupling constant, equal to about 8λ for muon capture by protons; $\beta = q/m_p$; A is the atomic number; $|M_{GT}|^2$ is the square of the matrix element for Gamow-Teller transitions, which, as Ioffe showed,[5] is equal to

$$|M_{GT}|^2 = |M_{GT}^\beta|^2 (1 - {}^1/_3 q^2 \langle r^2\rangle_A), \tag{3}$$

where M_{GT}^β is the matrix element for the corresponding beta decay, $\langle r^2 \rangle_A$ is the mean square charge radius, corresponding to the axial vector transition and equal to the square of the radius obtained from the transition of nuclei related to a single isotopic multiplet.

We see from (2) that if the muon is captured by a nucleus in the singlet state, that is, $\epsilon = -1$, and if the process is considered without form factors, then $\mu = f = 0$ and $\lambda = 1$, and this process is completely forbidden in our approximation. But if a form factor exists, then this transition is possible and its probability is on the order of $1/8$ of the ordinary transition. In such a way, an experiment on capture in the singlet state can serve as a criterion for the presence of form factors.

The result obtained is connected with the fact that in the transition considered the neutrino is always in the $J = 1/2$ state if the muon and nucleus are in the singlet state, and conservation of angular momentum completely forbids this process, except when the neutrino carries away orbital momentum. As is well known, a form factor is always tied up with $l = 0$. Therefore, if the number of neutrinos with $J = 1/2$ is small, the contribution from the form factors is comparable to that from other terms which we neglect. An analogous situation exists in nuclei with spin greater than $1/2$.