$H'_{c1} = H_c/\sqrt{2}\kappa$ and smaller than the lower limit for the vortical state H_{c1}. A second-order phase transition takes place at the points H'_{c1} and H_{c2}.

This raises the question of how the magnetic field penetrates into the bulky sample when the external field changes. This proceeds, apparently, via formation of a nucleus near the surface, with a transverse dimension on the order of the characteristic dimension of (11), i.e., $(c/eH)^{1/2}$. When $H_0 \to H'_{c1}$ the dimension of the nucleus is large, since $H \to 0$. A homogeneous mixed state can therefore hardly be realized in a bulky cylinder, except in the vicinity of H_{c2}.

The question of penetration of the field does not arise in the case of a thin plate transverse to the field (the plate dimension along the field is small compared with the remaining dimensions, since the external field is not screened, $H = H_0$. A homogeneous state should therefore be realized here, rather than a vortical one (in the case of a plate, the energy of the vortical plate (10) increases also as a result, say, of the field inhomogeneity near the plate surface). This is the most suitable object for an experimental verification of the theory.

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[1] V.L. Ginzburg and L.D. Landau, Zh. Eksp. Teor. Fiz. 20, 1064 (1950).
[2] E.G. Batyev, A.Z. Patashinskii, and V.L. Pokrovskii, ibid. 46, 2093 (1964) [Sov. Phys.-JETP 19, 1412 (1964).
[3] A.A. Abrikosov, ibid. 32, 1442 (1957) [5, 1174 (1967)].
[4] W.H. Kleiner, L.M. Roth, and S.H. Autler, Phys. Rev. A133, 1226 (1964).

PROTON-NEUTRON CORRELATIONS IN MEDIUM AND HEAVY NUCLEI

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It is well known (cf., e.g., [1]) that it follows from a comparison of data on hadron and lepton scattering that the radius R_Z of the charge distribution in the nucleus is smaller than the radius R_A of mass distribution. As noted recently in [2], the corresponding experimental data fit the formula

$$R_z = r_0 (2z)^{1/3}; \qquad R_A = r_0 A^{1/3}, \tag{1}$$

where $r_0 = (5/3)^{1/2}$F. According to (1), the densities and hence the chemical potentials of the proton and neutron distributions are equal (but not the radii of these distributions). Apparently, the fact whether relation (1) is satisfied or not should strongly influence certain conclusions of the superconducting model of the nucleus.

The point is that in the analysis of medium and heavy nuclei it is customary to start with the model of two superconducting liquids (neutron and proton). This is connected with the fact that if the difference between the radii of the neutron and proton distribution radii is not taken into account, then the difference of the chemical potentials of the neutrons and protons turns out to be $\Delta\zeta \sim 5 - 10$ MeV. This is larger than the expected energy gap in the spectrum, $2\Delta \sim 2 - 3$ MeV, and is usually the justification for not taking into account the possible pairing of the protons and neutrons [3].

In light of the possible equality of the chemical potentials of the neutrons and protons, it is of interest to consider the consequence ensuing from a possible proton-neutron (pn) pairing[1]. We shall show in this paper that such a pairing alters appreciably (compared with the usual pp and nn pairing) the isotropic structure of the correlation functions of the nucleons in the nucleus.

We start for simplicity with the Hamiltonian

$$H' = -\sum I a^{i_1 +}_{p_1 s_1} a^{-i_1 +}_{-p_1 s_1} a^{-i_2}_{-p_2 s_2} a^{i_2}_{p_2 s_2}, \tag{2}$$

where a^{i}_{ps} and a^{i+}_{ps} are the operators for the annihilation and creation of a nucleon with momentum $\vec{p}$, spin projections s, and isospin projection i; I is the interaction potential, which differs from zero in a narrow energy region near the Fermi energy.

The Hamiltonian is chosen in the simplest form, in which the equality of the chemical potentials of the protons and neutrons should become most strongly pronounced, namely, it is obvious that at large $\Delta\zeta$ the Hamiltonian (2) does not lead to superfluidity at all.

The Hamiltonian (2) takes into account only the interaction of pairs of nucleons in the state with S = 1 and T = 0 (quasideuteron). In this state, the attraction between the nucleons is maximal, and therefore the quasideuteron pairing model should determine correctly the ground state of the nucleon system at $\Delta\zeta = 0$.

Following further the usual method of superconductivity theory, we can obtain the following expressions for the Fourier components of the correlation functions of the nucleon density ($\Phi^{(0)}$) and of the isospin density ($\Phi^{(i)}$)

$$\Phi^{(0)}(q, \omega) = \int \frac{d^3 p}{(2\pi)^3} \left(1 + \frac{\Delta^2}{E_p E_{p-q}}\right) \delta(\omega - E_p - E_{p-q}), \tag{3}$$

$$\Phi^{(i)}(q, \omega) = \int \frac{d^3 p}{(2\pi)^3} \left(1 - \frac{\Delta^2}{E_p E_{p-q}}\right) \delta(\omega - E_p - E_{p-q}), \tag{4}$$

where $E_p = (\Delta^2 + \xi_p^2)^{1/2}$, Δ is the gap in the energy spectrum and is connected with the interaction potential by the usual relation $I\sum E_p^{-1} = 1$, and ξ_p is the energy reckoned from the Fermi surface.

The isotopic structure of the correlation functions (3) and (4) differs significantly from the isotopic structure of the correlation function in the usual (two-fluid) superconducting models of the nucleus, in which the correlations of the superconducting type take place only between particles of the same kind [5].

This difference between the two-fluid and quasideuteron models of the nucleus should become strongly manifest in a large number of interactions between the particles and the nuclei. In particular, for the processes of scattering of slow pions with charge exchange, based on the known Hamiltonian [6]

[1] The possibility of such a pairing is duscussed in a number of papers, see [4].

$$H_{int} = 4\pi \sum_{\ell} (B_0 + B_1 \vec{\tau}_\ell \vec{\tau}_\pi)\, \delta(r - r_\ell), \tag{5}$$

where r_ℓ and $(1/2)\vec{\tau}_\ell$ are the coordinate and isospin of the ℓ-th nucleon of the nucleus and $\vec{\tau}_\pi$ is the isospin of the pion, we obtain [7]

$$\frac{d\sigma}{d\Omega\, d\omega} = \frac{4|B_1|^2}{\rho_0} \frac{v_2 \varepsilon_2^2}{v_1} \Phi^{(1)}(q, \omega), \tag{6}$$

where $\vec{k}_1$, ε_1, v_1, and $\vec{k}_2$, ε_2, and v_2 are the momenta, energies, and velocities of the incident and scattered pion, $\vec{q} = \vec{k}_1 - \vec{k}_2$, $\omega = \varepsilon_1 - \varepsilon_2$, $d\Omega$ is the solid-angle element of the vector $\vec{k}_2$, and ρ_0 is the equilibrium density of the nucleus.

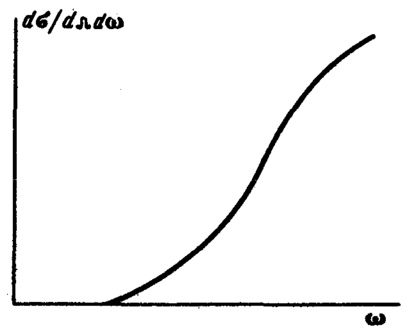

Fig. 1

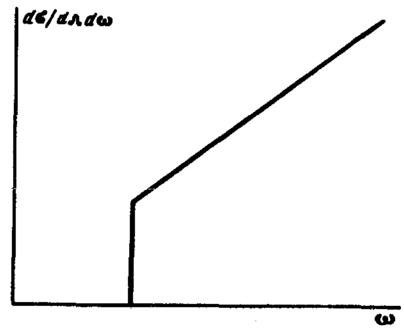

Fig. 2

We see that in the case of pairing of the quasideuteron type (Fig. 1) the scattering cross section has an essentially different character than in the case of pairing of the two-fluid type (Fig. 2).

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[1] A.S. Davydov, Teoriya atomnogo yadra (Theory of Atomic Nucleus), Fizmatgiz, 1958.
[2] N.G. Afanas'ev, I.G. Shevchenko, G.A. Savitskii, I.S. Gul'karov, and V.N. Khvastunov, Yad. Fiz. 8, 1112 (1968) [Sov. U. Nuc. Phys. 8, 646 (1969)].
[3] V.G. Solov'ev, Vliyanie parnykh korrelyatsii sverkhprovodyashchego tipa na svoistva atomnykh yader (Influence of Pair Correlations of the Superconducting Type on the Properties of Atomic Nuclei), Gosatomizdat, 1953.
[4] A.M. Lane, Nuclear Theory, Benjamin, 1964.
[5] A.G. Sitenko and I.V. Simenog, Nucl. Phys. 70, 535 (1965).
[6] T.E.O. Ericson, Pion Interaction with Nuclei, Preprint, TH-716, 1966.
[7] A.I. Akhiezer and I.A. Akhiezer, Yad. Fiz. 8, 1029 (1968) [Sov. J. Nuc. Phys. 8, 598 (1969)].