

Effect of π condensate on the real part of the optical potential in a π -mesic atom

M. A. Troitskiĭ, É. E. Sapershtein, O. A. Markin, and I. N. Mishustin

Physico-chemical Research Institute

(Submitted November 25, 1974)

ZhETF Pis. Red. 21, No. 1, 96-99 (January 5, 1975)

It is shown that the presence of a pion condensate in nuclei leads to an additional repulsion contribution in the P -wave terms of the optical potential in π -mesic atoms.

The possible existence of a pion condensate in atomic nuclei was pointed out by A. B. Migdal in 1972^[1] and was investigated in a number of studies.^[2, 3] We examine in this note how the presence of this condensate affects the optical potential of pions in π -mesic atoms.

An analysis of the position and widths of the energy levels of π -mesic atoms yields interesting information on the properties of the atomic nuclei.^[4] Inasmuch as small momenta K are significant for the pion in the π -mesic atom, it suffices to retain in the optical potential two terms, a local term (independent of K) connected with the S -wave πN scattering, and a term proportional to K^2 and due to P scattering. The parameters of this optical potential can be obtained from experiment with high accuracy.

The optical-potential term V_r due to the short-range part of the P -wave scattering is of the form ($\hbar = m_\pi = c = 1$)

$$2V_\pi = \rho(\omega = 1 + k^2, \mathbf{k}) \quad \text{[diagram: a circle with a vertical line through its center, representing a nucleon hole]} \quad \mathbf{k}, \omega = -4\pi n C_0 (1-a) k^2 \quad (1)$$

$$\approx -1.35 C_0 (1-a) k^2.$$

Here ρ is the polarization operator of the pion in a nucleus with $N=Z$, n is the density of nuclear matter ($n=0.5$ in our units), and C_0 is the arithmetic mean of the scattering lengths of the pion by the proton and neutron in vacuum: $C_0=0.21 \pm 0.007$.^[1] The main contribution to ρ is made by processes with exchange of a Δ resonance and a nucleon hole:

$$(2)$$

The factor $(1 - \alpha)$ in (1) is due to the possible difference between the amplitude for the production of the Δ resonance in the medium (shaded vertex in (2)) and the vacuum amplitude. It is easy to verify that the contribution to the polarization operator from the long-range terms connected with the production of a particle and hole in the intermediate state is strongly suppressed by the Pauli principle and is a small quantity of the order of

$$(v_F/R\omega)^2 = (\epsilon_F/\omega A^{1/3}) \sim 0.1A^{-2/3}.$$

The experimental data on the levels of the π -mesic atoms call for $\alpha=1/3$, i.e., a suppression of the vacuum πN amplitude by a factor 1.5.

This suppression is usually accounted for by introducing the so-called Lorenz-Lorentz (LL) factor. The LL factor was introduced by the Ericsons in^[5] to take into account the nucleon correlations at short distances. Barshay *et al.*^[6] have shown that introduction of the LL factor corresponds to the introduction of a hard repelling core between the nucleon and the Δ resonance. In formula (1), any $N\Delta$ interaction is accounted for by the quantity α .

The parameter α is a constant analogous to the other constants of the Fermi-liquid theory, since the diagrams corresponding to it are irreducible with respect to the production of a particle-hole pair. Its calculation is a complicated many-body problem, and its value can be determined from an analysis of the experimental data.

If it is assumed that the suppression of the optical potential is indeed connected with the factor α , i.e., $\alpha=1/3$, then, as shown by analysis,^[3] it is impossible to explain the experimentally observed enhancement of the λ -forbidden $M1$ transitions of the $S_{1/2} - d_{3/2}$ type, which call for $\alpha < 0.15$. So small a value of α can be reconciled with the data on π -mesic atoms by assuming that pion condensate is present in the nucleus.

In this case, additional terms proportional to K^2 appear in the pion optical potential and are due to the interaction with the condensate field ϕ_0 :

$$(3)$$

The dashed lines in Fig. (3) denote a static condensate field with wave number K_0 . The quantity γ depends on the structure of the pion condensate and on the amplitude ϕ_0 of the condensate field. A simple estimate in perturbation theory in terms of the condensate field yields

$$(4)$$

In formula (4) $p_F=2$ is the Fermi momentum, $m_N=6.7$ is the nucleon mass, $f_\pi=g^2/2m_N \approx 1$, $\omega \approx m_\pi=1$, and the constants of the theory of finite Fermi systems is $g^*=1.6$.^[7] $K_0=2$ is the wave vector of the condensate field.^[1] ϕ_0^2 is the square of the condensate-field amplitude.

It is seen from (3) and (4) that the real part of the optical potential of the π -mesic atom can be reconciled with experiment even at $\alpha=0$, provided that we assume that a pion condensate with amplitude $\phi_0^2 \sim 0.1$ exists in the atomic nucleus. This estimate does not contradict the results of^[2].

In conclusion, we thank A.B. Migdal, V.A. Khodel', and N.I. Chekunov for a useful discussion of the results.

¹⁾We note that the contribution of one-nucleon exchange to C_0 is zero by virtue of isotopic symmetry.

¹A.B. Migdal, Zh. Eksp. Teor. Fiz. 63, 1993 (1972) [Sov. Phys.-JETP 36, 1052 (1973)] A.B. Migdal, O.A. Markin, and I.N. Mishustin, *ibid.* 66, 443 (1974) [39, No. 2 (1974)].

²A.B. Migdal, N.A. Kirichenko, and G.A. Sorokin, Phys. Lett. 50B, 411 (1974).

³E.E. Sapershtein and M.A. Troitskiĭ, Yad. Fiz. [Sov. J. Nuc. Phys.] (in press)

⁴G. Backenstoss, Ann. Rev. Nucl. Sci. 20, 467 (1970).

⁵M. Ericson and T.E.O. Ericson, Ann. of Phys. 36, 323 (1966).

⁶S. Barshay, G.E. Brown, and M. Rho, Phys. Lett. 32B, 787 (1974).

⁷V.M. Osadchiv and M.A. Troitskiĭ, Yad. Fiz. 5, 1001 (1967) [Sov. J. Nuc. Phys. 5, 714 (1967)].