Role of pion rescattering and nucleon exchange in the final state in the (π^-, nn) reaction

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Using ^{4}He as an example, it is shown that in the reaction (π^-, nn) the pion rescattering effect plays a decisive role at small momentum transfers, while the effective exchange between all nucleons in the final state plays a major role at large transfers. This leads to the appearance of corresponding two maxima, in agreement with the recently obtained experimental data.[10]

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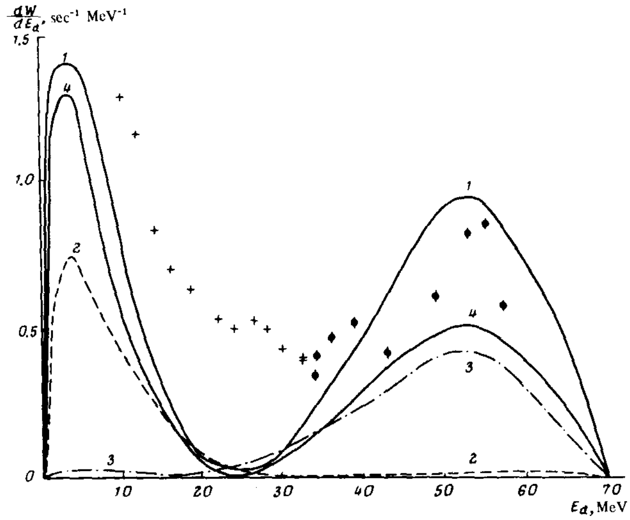
At the present state of the theory of $\pi^\pm$-meson absorption by nuclei, the reactions ($\pi^\pm$,NN) are regarded as direct reactions that proceed via a two-particle absorption mechanism.[1] In the Schrödinger approach, this mechanism presupposes that the t matrix corresponding to the reaction ($\pi^\pm$,NN) can be represented as a sum of operators for absorption by arbitrary pairs, which are chosen in the form of operators for the absorption of a



Distribution with respect to the deuteron recoil energy in the reaction ^{4}He(π^-, nn)d. Curves 1, 2, 3 correspond to the functions Φ_n, and curve 4 corresponds to the function Φ_v. Curve 1—with allowance for effects of rescattering and exchange, 2—with allowance for rescattering only, curves 3—with allowance for exchange only. The experiment points[10] are in arbitrary units.

pion by an isolated pair of nucleons. The direct character of the reaction presupposes that the exchange of the emitted nucleons with the nucleons of the residual nucleus can be neglected in the reaction amplitude. These approximations, generally speaking, are valid at small momentum transfers, or else in the high-energy part of the emitted-nucleon spectrum, and therefore all the fundamental results obtained so far are valid in this region of the kinematic variables.

The two-particle absorption matrix in the "microscopic" approach is constructed within the framework of the meson theory with allowance for the experimental data on πN interaction and takes the form[2-4]

$$T_{12} = t^0_{12} + t'_{12},$$

where t^0_{12} is the sum of the single-particle absorption-operators, and t'_{12} is an exclusively two-particle operator that takes into account the scattering of the meson by one nucleon of the pair prior to its absorption by the second (the rescattering effect).

The rescattering effect was investigated in a number of studies[2,3,5,6] for the case of stopped π^- mesons in (π^-, nn) reactions. The analysis was carried out in this case at small momentum transfers, and it turned out that allowance for the rescattering effect leads as a rule to an increase, by approximately one order of magnitude, in the probability of the (π^-, NN) reaction. This raises the natural question of ascertaining the role of the rescattering effect at large momentum transfers. In the region of kinematic variables, the energies of the nucleons emitted in the reaction become comparable with the energies for the separation of the nucleons, and therefore the exchange effects between the emitted nucleons and the residual-nucleus nucleons can no longer be neglected and must be taken into account. We investigate these problems in the present paper using as an example the reactions ^{4}He(π^-, nn)d.

The choice of this example is dictated by the fact that, first, for the ^{4}He nucleus there exist wave functions that take into account the correlations, including the short-range pair correlations, and give the correct value for the binding energy and the dimensions of the nucleus; recently there were reported experiments,[9,10] in which the probability of this reaction was measured as a function of the deuteron recoil energy at high energies, up to the maximum corresponding to large momentum transfers.

As the wave functions of the ^{4}He nucleus, we chose variational wave functions obtained in[7]. One of these functions corresponds to the NN-interaction potential with a rigid repelling core Φ_h, and the second corresponds to a velocity-dependent potential Φ_v. These functions were used by us earlier in calculations of the reactions (π^-, nn) and (γ, np) on ^{4}He.[8] It was shown there that if rescattering is neglected, the interaction in the final state between the emitting nucleons does not play an important role in the value of the probability, although it does alter somewhat the form of the distribution with respect to its relative energies of the emitted nucleons. Therefore, when ascertaining the relative role of rescattering and exchange between all the nucleons in the final states, we neglect the interaction between the emitted nucleons as well as the interaction of the emitted nucleons with the residual deuteron. The wave function of the deuteron is chosen in the form of a Gaussian function whose parameters were determined from the dimensions of the deuteron. For the operator T_{12} we have chosen the expression obtained in[3], which takes into account the rescattering of the S-wave pion by a nucleon and correspond to absorption of a pion from the 1S orbit of the mesic atom.

The results of the calculations of the probability as a function of the deuteron recoil energy are plotted in the figure. We note that in this paper, just as in[8], when deriving the reaction probability we took into account the number of np pairs absorbing the pion, which is equal to four. We present here also experimental data taken from[10]. As seen from the figure, the rescattering effect is significant at small momentum transfers and is negligible at large momentum transfers. The exchange effect, as expected is significant precisely in the large momentum region. We find as a result that allowance for the rescattering effect increases the total absorption probability effect only by a factor of two. This result is important from the point of view of the question of the convergence of the multiple-scattering series in the absorption of a pion by a pair of nucleons in the reaction (π^-, nn), since it indicates that inclusion of the next rescattering term in T_{12} should not lead to significant increase in the total reaction probability obtained above. On the other hand, if the convergence in this series is assessed from the results obtained in[3] in the case of the ^{4}He(π^-, nn)d reaction on the role of the rescattering effect at small momentum transfer only, then an impression may be gained that the multiple-scattering series will not converge, since allowance for rescattering in first order increases the probability by approximately one order of magnitude. It is also seen from the figures that simultaneous allowance for the rescattering and the nucleon exchange in the final states explains the presence of two maxima in the experimental distribution with respect to the recoil energies[10] and explains the values of the probability ratio at the maxima. Calculations have shown that the reaction probability turns out to be practically independent of allowance for the motion of the pair mass center in the absorption operator T_{12}, something not obvious beforehand at large momentum transfers.

As seen from the figure, the wave functions of the ^{4}He nucleus corresponding to an *NN* interaction potential with a hard repelling core and a velocity-dependent potential lead to somewhat different results for the probability distribution with respect to the deuteron recoil energy. Preference should be given to the first of these functions.

The foregoing results lead to the conclusion that the rescattering effect plays an essential role in the reaction (π^-, nn) only at small momentum transfers, and that allowance for the exchange effect in the final state leads to an increase of the reaction probability at large momentum transfers.

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