A study of pion absorption by $^{16}$O using realistic interactions—I. Two-nucleon emission following bound-pion absorption

U N L MATHUR* and Y R WAGHMARE

Department of Physics, Indian Institute of Technology, Kanpur 208 016, India
* Permanent address: Department of Physics, Science College, Patna University, Patna, India

Abstract. Matrix element of the Galilean invariant non-relativistic reduction of the pseudoscalar-pseudovector interaction has been calculated assuming the reaction to be a direct process with bound $\pi^-$ being absorbed by a correlated pair of nucleons. The Hartree-Fock wavefunctions obtained with the unitary-model-operator approach starting with the realistic nucleon-nucleon interaction have been used for $\pi$-capturing nucleon pair in the initial state. The calculations have been done with and without antisymmetrising the initial state wavefunction of the pion absorbing pair. For the final state nucleon-nucleon interaction has been taken into account. The strong $\pi$-nucleus interaction together with the Coulomb interaction with the finite nuclear size on the bound pion wavefunction are taken into account. Angular distributions of the emitted nucleon-pair, the branching ratios and the total absorption rates are calculated for $^{16}$O with and without antisymmetrisation effect. The calculated results are compared with the experimental and other theoretical work.

Keywords. Bound-pion absorption; Hartree-Fock wavefunctions; absorption by nucleon pair; pion-nucleon interaction; antisymmetric wavefunctions; initial state pion wavefunctions; final state pion wavefunctions.

1. Introduction

The process of bound pion absorption by a pair of nucleons has been studied for more than twenty years. When a negative bound pion is captured by a nucleus, the final state is produced such that the two nucleons emerge from the nucleus in a more or less back-to-back direction. This is essentially due to the fact that the bound pion absorption introduces a great deal of energy equivalent to its rest mass energy of 140 MeV into the nucleus, but transfers no momentum and therefore the most probable emission mechanism is that in which two nucleons come out back-to-back. The two-nucleon absorption mode involves a final state of high energy, but small total momentum. This process also has a very high relative momentum of about 300 MeV/c for the two nucleons. It thus probes very small separation distance of the order of 0.67 fm for the relative wavefunction of the two-nucleon system. This yields information on nucleon-nucleon correlations in the ground state wavefunction for the nucleus. In recent years a number of theoretical (Eisenberg and Le Tourneux 1967; Guy et al 1968; Kaushal and Waghmare 1970; Jain 1972; Bhalerao et al 1978; Shimlzer 1978) and experimental investigations (Lee et al 1972; Barrett et al 1973; Bassaleck et al 1976, 1980) have been conducted on the ($\pi^-, NN$) reactions. The experimental results indicate that the angular distributions are strongly peaked for an opening angle between the two nucleons of about 180°. This confirms the hypothesis of back-to-back emission of the two nucleons. The two-hole state excitations, short-range pair correlations and the nucleon-nucleon pair momentum distributions in the initial-state wavefunctions have
also been studied (Bhalerao et al 1978) in the two nucleons absorption mechanism. The essential requirements of an experiment on the ($\pi^-$, $NN$) reaction are that the final state be determined completely, i.e. the particles emitted in the reaction must be identified and the energies of both the emitted particles and the opening angle between them must be measured. The early experiments (Nordberg et al 1968; Ozaki et al 1960) measured the $w(nn)/w(np)$ branching ratio and the angular distributions of the emitted pairs only. The later experiments (Castleberry et al 1970) revealed that deuterons and tritons as well as protons are also emitted. The experiments of Lee et al identified the emitted charged particles and showed that even with coincident neutrons, there is considerable emission of deuterons and tritons. The experiment of Nordberg et al (1968) shows that the branching ratio for $^{16}$O nucleus is 3.9 ± 1.0. While the theoretical branching ratio for $^{16}$O was less than one by Guy et al (1968) the calculations of Shimizu and Faessler (1978) shows that the branching ratio changes from 3.5 to 6.8 in their model. The theoretical difficulties in the study of the process of ($\pi^-$, $NN$) reactions are due to the uncertainties in the exact nature of the initial correlated state, the three-body final state composed of the two outgoing nucleons and the residual nucleus, the precise form of the $\pi$-absorption vertex and the rescattering process which takes into account the scattering of a negative pion on one of the nucleons of the pair with its subsequent absorption by the second pair. In this context, it is seen that several methods have been used to introduce short-range correlations. In most of the above calculations the antisymmetrisation of the wavefunctions has not been taken into account.

2. Theory

In the present work we have calculated angular distribution for the emitted pair in the $^{16}$O ($\pi^-$, $NN$) reaction. The branching ratio and total absorption rate have been evaluated and compared with experimental results available. The total angular distributions for the pion absorption by the pair of nucleons have also been compared with the experimental data of Nordberg et al (1968). The calculation has been done with and without antisymmetrisation of the wavefunction of the pion absorbing pair. We use the 1N-model for pion absorption and neglect rescattering of pion before its absorption. We use a nonrelativistic pseudoscalar-pseudovector pion-nucleon interaction for simplicity. A modified pion wavefunction has been used which takes into account the strong interaction with the nucleus and also the finite size of the nucleus. We also consider the final state interaction between the emitted nucleon pairs in the asymptotic form by knowing the nucleon-nucleon phase shift. The short range correlations (SRC) have been introduced in the framework of unitary-model-operator approach (UMO) (Shakin and Waghmare 1966; Shakin et al 1967a, b). The UMO approach incorporates SRC and generates the effective interaction which is in turn used to generate the radial HF wavefunction. The radial HF wavefunction has been used for the pion absorbing pair. We have considered these pairs to be lying in $(os_{1/2})^2$, $(op_{3/2})^2$ and $(op_{1/2})^2$ configuration. The total angular momentum ($J$) and the isospin ($T$) of the pion absorbing pair in the form of $J^T(T)$ is given by $0^+(1)$, $2^+(1)$ for $pp$ pair and $0^+(1)$, $1^+(0)$, $2^+(1)$ and $3^+(0)$ for $pn$ pair (table 1). We have evaluated the angular distribution for these possible $J^T(T)$ states in the above mentioned configurations. We have assumed that the two outgoing nucleons may have unequal energies. The excitation energy of the residual nucleus has been calculated in the independent particle model (IPM).