Study of the $^4\text{He}(e, e'd)pn$ Reaction*

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Abstract. The cross section for the $^4\text{He}(e, e'd)pn$ reaction has been measured in parallel and in $(q, \omega)$-constant kinematics for values of the three-momentum transfer of 406, 495 and 595 MeV/c, and for a range in missing momentum. Just above threshold this reaction can be characterized as a spin/isospin flip transition of the involved $pn$ pair. By using two electron energies (576 and 370 MeV) the longitudinal and transverse structure functions could be separated. The cross sections turn out to be purely transverse, as expected for a spin/isospin flip transition. The data are well described by new covariant and current-conserving calculations that include the major final-state interaction effects.

1 Introduction

Professor Arenhövel has devoted a large part of his professional life to the study of the proton-neutron ($pn$) system, both its bound configuration, the deuteron, with spin $S = 1$ and isospin $T = 0$, as well as the $pn$ continuum, which at low energy is characterized by an almost bound state, sometimes indicated by $d^*$, with spin $S = 0$ and isospin $T = 1$.

It is highly interesting to investigate the properties of a $pn$ system, in both spin/isospin configurations, when it is embedded in a nucleus. In principle the $(e, e'pn)$ reaction is the most appropriate one for studying such correlated $pn$ pairs. The (virtual) photon can transfer zero or one unit of isospin ($\Delta T = 0$ or $\Delta T = 1$ transitions). However, since in the $(e, e'pn)$ reaction the isospin of the final $pn$ system is not known, this reaction does not discriminate between isoscalar and isovector transitions. This is different in the $(e, e'd)$ reaction. Because the deuteron has isospin zero and since possible hadronic interactions in the final state (FSI) conserve isospin, the $(e, e'd)$ reaction works as an isospin filter. If the initial nucleus has $T = 0$, states in the final nucleus with $T = 0$ select isoscalar transitions, whereas final states with $T = 1$ are reached by isovector transitions.

* Dedicated to Prof. H. Arenhövel on the occasion of his 60th birthday
Both types of transitions have been observed in the $^{12}\text{C}(e,e'd)$ reaction [1]. In a direct-reaction description, in which the final nucleus (apart from possible elastic rescattering of the produced deuteron) is a spectator, the mechanism of the isoscalar transition is similar to elastic scattering from the deuteron (although the internal wave function of the $pn$ system in the initial nucleus most probably will differ from that of a free deuteron), while the isovector transition is similar to the inverse of the threshold electrodisintegration of the deuteron ("deuteron reintegration"), i.e., a spin/isospin flip transition, in which an $S = 0, T = 1$ $pn$ system is transformed into an $S = 1, T = 0$ deuteron. Because of the spin-flip character such a transition should be purely transverse. Indeed, the transition to the $T = 1$ state at 0.72 MeV in $^{10}\text{B}$ in the $^{12}\text{C}(e,e'd)$ reaction had no longitudinal component, in contrast to the transitions to the $T = 0$ states. Also the dependence of the cross section on the value of the transferred momentum $q$ was consistent with a "deuteron reintegration" mechanism [1, 2].

However, the nuclear structure in the case of the $^{12}\text{C}(e,e'd)$ reaction is not too well under control. In that respect few-body systems offer much better perspectives, since realistic wave functions for the initial and final states are available. For that reason the $(e,e'd)$ reaction has been studied both on $^{3}\text{He}$ [3–5] and on $^{4}\text{He}$ [6]. The $^{4}\text{He}$ nucleus provides an especially interesting case. Since $^{4}\text{He}$ has isospin zero, the $^{4}\text{He}(e,e'd)d$ reaction probes $T = 0$ proton-neutron correlations in $^{4}\text{He}$, while the $^{4}\text{He}(e,e'd)pn$ reaction just above the break-up threshold, where the final $pn$ system is dominantly of $S = 0, T = 1$ character, probes initial $T = 1$ correlations. Furthermore $^{4}\text{He}$ has a rather high density, so that proton-neutron correlations are enhanced. In this paper, which we dedicate to Professor Arenhövel, we will discuss the results of a $^{4}\text{He}(e,e'd)pn$ study, which can be considered as the inverse of the threshold electrodisintegration of a deuteron within a nucleus.

There are three important aspects one wants to study when investigating the $(e,e'd)$ reaction: the dependence of the cross section on the missing momentum $p_m$, its dependence on the (three-)momentum transfer $q$, and the longitudinal/transverse character of the transition. In a semi-microscopic factorized PWIA approach [2] the first one depends on the centre-of-mass motion of the $pn$ pair, while the second one reflects the relative $pn$ motion (c.q. wave function) inside the nucleus. All three aspects have been investigated.

2 Experiment

The experiment was performed with the extracted electron beam from the pulse-stretcher ring AmPS [7] at NIKHEF. In order to perform an $L/T$ separation incident energies of 370 and 576 MeV were used. The current extracted from the ring was about 6 μA and had a duty factor of about 30%. The scattered electrons were detected with the QDD spectrometer and the knocked-out deuterons with the QDQ spectrometer [8].

A cryogenic gas target [9] operating at 20 K and 1.5 MPa was used, which was filled with a mixture (2:1 in volume) of $^{3}\text{He}$ and $^{4}\text{He}$ gases. The helium gas was contained in a cylinder with its axis aligned along the beam. At both ends the cylinder is closed by 75 μm copper foils. The sides, through which the knocked-out particles pass into the direction of the spectrometers, are made of 25 μm nickel-