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Quasi-free scattering with ^{6,8}He beams

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Abstract

This paper presents the results of experimental investigations of (p, pn), $(p, p\alpha)$ and $(p, p\,^6\mathrm{He})$ reactions with relativistic ^{6}He and ^{8}He beams impinging on a hydrogen target. Information on the structure of extremely neutron-rich nuclei was obtained by using the unique characteristic of quasi-free scattering processes and inverse kinematics. For the first time, momentum distributions of complex clusters inside ^{6}He and ^{8}He were measured. Spectroscopic factors for valence neutrons, α- and ^{6}He clusters were deduced from the experimental data. They demonstrate that the filling of the

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$p_{\frac{1}{2}}$ shell is the essential feature of the ^{8}He structure. It is shown that the ^{8}He cluster structure can be considered as a ^{6}He core plus two valence neutrons.

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1. Introduction

Studies of quasi-free scattering (QFS) reactions provide quite precise information concerning clustering effects in nuclei. In QFS, a probe particle scatters off a bound cluster inside a nucleus. The process leads to a separation of the cluster from the nucleus, the rest of the nucleus acts as a spectator. The transition amplitude may be separated into a reaction term and a nuclear structure term, this property is a prerequisite for nuclear-structure investigations.

Experimental investigations of QFS of the type (a, ax) with $a, x = p, n, d, t$, ^{3}He or α, due to the simplicity of the reaction mechanism and due to the presence of three bodies in the final state is a unique and easy way to understand the nuclear structure. In the past, QFS studies have provided a wealth of nuclear structure information for stable nuclei [1–4]. The application of this method to experiments with radioactive beams is very promising. The QFS method has been used in investigations of the cluster structure of drip-line nuclei (for example, see Refs. [5,6] and references therein). However, these experiments were restricted mainly to the valence-neutron knockout by a complex particle (^{9}Be or ^{12}C). Moreover, the recoil nucleus and the knocked-out neutron usually were not detected in these experiments and relative contributions from the different reaction channels were not determined experimentally.

Here we present first investigations of valence-neutron and charged-cluster knockout from ^{6,8}He by protons making use of the specific kinematics of QFS. In order to disentangle different reaction channels, we propose an effective method based on reaction kinematics. The validity of the assumed QFS mechanism is proven by angular and energy correlations and by the dependence of the differential cross sections on the momentum transfer. The spectroscopic factors for valence neutrons, α and ^{6}He clusters, and the momentum distributions of knocked-out particles and of the spectators are among the main results of the present experiment.

The lighter isotope, ^{6}He, a Borromean two-neutron halo system, has been studied in a large number of different experiments (see reviews [5,6]). Its structure is well understood and the ground state is to more than 90% a pure $(0p_{3/2})^2$ state. The relatively simple structure of ^{6}He makes it a bench-mark nucleus. ^{8}He is an extreme example, thought to consist of an α-core surrounded by a halo of four additional neutrons [7]. Besides, interactions of the valence neutrons with the core could also lead to configurations $^6\mathrm{He}(0^+) + 2n$ and $^6\mathrm{He}(2^+) + 2n$ [8,9].

The data obtained in this experiment agree well with the known features of the ^{6}He structure, but indicate new and unexpected features of the ^{8}He structure. The α-particle