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Nuclear break-up of ^{11}Be

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Abstract

The break-up of ^{11}Be was studied at 41 AMeV using a secondary beam of ^{11}Be from the GANIL facility on a ^{48}Ti target by measuring correlations between the ^{10}Be core, the emitted neutrons and gamma rays. The nuclear break-up leading to the emission of a neutron at large angle in the laboratory frame is identified with the "towing mode" through its characteristic n-fragment correlation. The experimental spectra are compared with a model where the time dependent Schrödinger equation (TDSE) is solved for the neutron initially in the ^{11}Be. A good agreement is found between experiment and theory for the shapes of neutron experimental energies and angular distributions. The spectroscopic factor of the $2s$ orbital is tentatively extracted to be 0.46 ± 0.15. The neutron emission from the $1p$ and $1d$ orbitals is also studied.

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1. Introduction

The investigation of exotic nuclei has strongly developed during the last two decades thanks to the availability of radioactive beams produced by in-flight fragmentation [1–3] and structural properties of a large variety of nuclei far from stability can be accessed. Recent advances have demonstrated the importance of a detailed understanding of nuclear reactions in order to infer properties of nuclei such as nuclear shapes, spectroscopic factors or pairing correlations [4]. Several reaction mechanisms are used: transfer reactions of one or two nucleons [5,6], Coulomb or nuclear break-up reactions [4,7–9], the latter being the focus of this paper.

With exotic nuclei, we have to deal with low intensity beams and we expect an increasing complexity in obtaining nuclear structure information due to the reduction of the binding energy. In addition, modification of two-body correlations like pairing is expected.

In this paper, we will demonstrate that the study of nuclear break-up around the Fermi energy, conjointly with the development of accurate nuclear reaction models [10–13], can provide an alternative path to get information on structural properties in stable and weakly bound exotic nuclei. In this respect, ^{11}Be appears as a good case for study as it is a one-neutron halo nucleus and is abundantly produced. Its ground state is known to be a mixture of a cold ^{10}Be core coupled to a halo neutron in a $2s_{1/2}$ state with an excited ^{10}Be in a 2^+ state coupled to a $1d_{5/2}$ neutron leading to a $1/2$ ground state with a positive parity.

$$|\mathrm{GS}\rangle = \alpha|0^+ \otimes 2s_{1/2}\rangle + \beta|2^+ \otimes 1d_{5/2}\rangle.$$

The determination of the relative importance of these two states was addressed through several experimental and theoretical approaches and is related to the spectroscopic factors $\mathrm{S}_{2s} = \alpha^2$ and $\mathrm{S}_{1d} = \beta^2$. ^{11}Be was extensively studied during the last decade as one of the first observed halo nuclei [1]. It has revealed many of its properties through several different types of reactions such as break-up experiments [7,14–16] or transfer reactions [5]. Coulomb dissociation has been shown to play an important role when ^{11}Be interacts with a heavy target such as Au, as the halo neutron is bound by only 500 keV and easily separates from the core.

For lighter targets such as Be, the nuclear break-up is expected to take over [17]. It has been shown in a time dependent non-perturbative calculation (TDSE) [10,11] that nuclear break-up presents a typical emission pattern, where the neutron and the remnant ^{10}Be core are expected to be emitted in opposite sides of the beam direction. This property has already been observed with stable nuclei and was called "towing mode" [18]. The pattern of this mechanism, leading to the emission of the particle at large angle, is expected to be sensitive to the initial wave function such as its angular momentum and could be used to shed some light on the structure of the nucleus.

In this paper, we will report on an experiment performed at the GANIL facility on the break-up of ^{11}Be where a ^{10}Be fragment was detected in coincidence with a neutron and gamma rays. After a description of the experimental apparatus in section 2 and of the theoretical framework in Section 3, we will present the neutron angular distribution in Section 4.1 and demonstrate the characteristic anti-correlation between the neutron and the ^{10}Be in Section 4.2. The gamma energy distribution will be presented in Section 4.3. Sections 4.4 and 4.5 will be devoted to the neutron energy spectra in two-fold and three-fold events, respectively. By comparing the experimental data with the time dependent Schrödinger calculation described in Section 3, the possible extraction of spectroscopic factors of the ground state of ^{11}Be will be discussed in Section 5.