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Elastic and break-up of the 1n-halo ^{11}Be nucleus

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Abstract. The elastic and break-up angular distributions of the ^{10,11}Be+^{64}Zn reactions measured at $E_{c.m.} \approx 1.4\ V_C$ have been analysed within the CCDC and O.M. frameworks. The suppression of the Coulomb-nuclear interference, observed in the ^{11}Be scattering case with respect to the ^{10}Be, has been interpreted as due to a long range absorption owing to the coupling with the break-up (Coulomb and nuclear) channels. The presence of ^{10}Be events on the ^{11}Be experiment data have been explained as due mainly to break-up processes.

1 Introduction

Nuclear halo arises from the very weak binding of the last valence nucleon(s) which decouples from an inert core [1]. The single-particle wave function of the valence nucleons in halo nuclei has a long tail, which extends mostly outside the potential well. Over the years, a lot of experiments have been performed in order to investigate this peculiar structure also in the attempt to understand how it affects the reaction processes (see e.g. [2–5]).
Elastic scattering, being a peripheral process, can be used to probe the tail of the wave function

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thus allowing to learn about the surface properties of these nuclei. The observed striking shape of the elastic scattering angular distribution for halo nuclei, required to introduce in the calculations the explicit inclusion of coupling effects between relative motion and internal degrees of freedom. In particular, the coupling not only to bound and unbound excited states but also to the continuum (break-up) is needed (see e.g. [6–9]).
A common feature observed in the low-energy halo-induced elastic scattering, on medium mass and heavy targets, is a reduction of the Coulomb-nuclear interference peak (e.g. [4, 10]). This suppression seems to be attributed to long range absorption which smooths the surface-jump of the scattering matrix $|S(l)|$. A further consequence of this suppression is a much larger total-reaction cross-section with respect to the one measured in reactions induced by the corresponding non-halo isotope (e.g. [10, 11]).
Moreover, weakly bound halo systems are characterized by a low-lying large dipole strength just above the break-up threshold, it has been found that coupling with this B(E1) strength is important in collisions with heavy targets where, in turn, this strength is also responsible for the presence of a very large break-up cross-section which is partially responsible of the large total reaction cross-section that has been found in these collisions.
In this paper, will be summarised the results concerning elastic scattering and break-up in the collision ^{11}Be+^{64}Zn performed at REX-Isolde at energies around the Coulomb barrier.

2 Elastic scattering

The ^{11}Be+^{64}Zn experiment was performed at the REX-ISOLDE facility of CERN at $E_{c.m.}$ ≈24.5 MeV. The detection system used consisted of an array of Si-detector telescopes which were placed very close to the target allowing for a large angular and solid angle coverage [9, 10]. In the same experiment the elastic-scattering angular distribution for ^{10}Be+^{64}Zn was also measured. The beam energy resolution was insufficient to separate ^{11}Be elastic from the inelastic scattering of the ^{11}Be 1^{st} excited state at E_x=320 keV therefore, in this case, the quasi-elastic angular distribution was measured and it is shown in Fig. 1 in linear scale. However, the contribution of inelastic scattering on the quasi-elastic angular distribution was found to be small [9, 10].

As shown in Fig. 1, a strong reduction of the cross-section in the Coulomb-nuclear interference region is observed for the ^{11}Be+^{64}Zn collision, much stronger than in the ^{6}He case [11, 12]. In the same figure, the ^{10}Be+^{64}Zn elastic scattering angular distribution is also shown; this last angular distribution presents the typical Fresnel diffraction pattern. The total-reaction cross-sections have been extracted via O.M. analysis of the elastic angular distribution. It was found that in the ^{11}Be case (σ=2.73 b) this is ≈ 2.2 times larger than for the ^{10}Be one (σ=1.26 b).
The optical potential deduced from the ^{10}Be+^{64}Zn analysis was used as bare potential for the ^{11}Be+^{64}Zn calculations.
In the Optical Model (O.M.) analysis of ^{11}Be+^{64}Zn, in addition to the bare potential, two types of Dynamic Polarization potentials (DPP) were used. 1) A phenomenological DPP having the shape of a Woods-Saxon derivative; 2) a DPP potential derived from the semiclassical theory of Alder and Winter for Coulomb excitation which takes into account the effect of the coupling to the inelastic and break-up channels due to the dipole Coulomb interaction. In the first case a good fit of the data was obtained with a DPP having a very large diffuseness of 3.5 fm, in agreement with what found by [13]. In the second case, adding the DPP to the bare potential produced a strong reduction of the elastic cross-section in the Coulomb-nuclear interference region; however, this reduction is not sufficient to reproduce the measured data showing that other processes, not included in the calculations must be contributing.

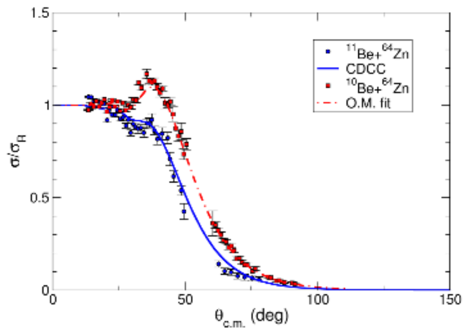

Figure 1. (color online). Elastic scattering angular distribution of ^{10}Be+^{64}Zn (red squares) and ^{11}Be+^{64}Zn (blue circle) at c.m. energy of ≈ 24.5 MeV. The full line represent the CDCC calculations for the elastic-scattering ^{11}Be+^{64}Zn while the dot-dashed line represent O.M. calculations for the scattering ^{10}Be+^{64}Zn. See text for details.

The scattering angular distribution for the ^{11}Be case was also compared with CDCC calculations. In these calculations the ^{11}Be+^{64}Zn reaction is treated within an effective three-body model, ^{10}Be+n+^{64}Zn, and coupling to break-up channels is explicitly taken into account. The calculations show that the suppression of the Coulomb-nuclear interference peak observed in the angular distribution is due to a combined effect of Coulomb and nuclear couplings to break-up channels, although they act in very different way. Coulomb coupling gives a large contribution to the break-up cross section and therefore produces an increase of the reaction cross section; nuclear coupling has a large effect on the elastic phase-shift which becomes almost real, thus affecting the shape of the elastic angular distribution but not so much the break-up cross section [9]. The results of all these calculations are also shown in Fig. 1.

3 Break-up

In the ^{11}Be+^{64}Zn data, it was possible to identify, along with the scattered ^{11}Be events also ^{10}Be events having an energy close to the quasi-elastic peak. These events correspond to transfer or breakup processes. However, DWBA calculations predict very low cross-section for the transfer process, therefore mainly break-up contributes to the ^{10}Be production.

The break-up angular distribution was extracted and it is shown in Fig 2. For the largest measured angles the thickness of the ΔE detector was too large to allow ^{10}Be particles to punch through and being identified. Therefore the break-up angular distribution was extracted only in a limited angular range. The integrated cross-section is σ=1.10±0.15 b.

The measured angular distribution was compared with the CDCC calculations described in the previous section. In the calculations it was approximated that the angle of the outgoing ^{10}Be fragment is the same as that of ^{11}Be* in the laboratory frame as for the data. The CDCC calculations underestimate the measured cross-section. The CDCC calculations provide only the elastic break-up cross-section i.e. neither the core nor the target are excited. Moreover, core excitation effects are expected to be non-negligible [14] and by introducing them in the calculations the agreement with the data could improve. The 1n-trasfer contribution is also not included in the CDCC calculations.

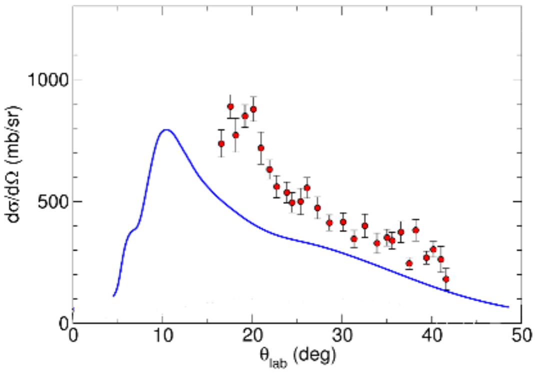

Figure 2. (color online). Beak-up angular distribution of ^{11}Be+^{64}Zn. The full line represent the CDCC calculations for the break-up process. See text for details.

4 Summary

The collision induced by the ^{11}Be halo nucleus on a ^{64}Zn target has been investigated. The quasi-elastic scattering angular distribution shows that the peak due to Coulomb-nuclear interference disappears, being the indication that long-range absorption occurs. The long-range absorption is due to the combined effects of Coulomb and nuclear couplings to the continuum. The Coulomb break-up is also responsible for the large break-up cross-section observed.

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