Vol. 43 (2012) *ACTA PHYSICA POLONICA B* No 2

^{10}Be YIELD FROM ^{11}Be + ^{120}Sn INTERACTION AT THE COULOMB BARRIER[*]

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(Received November 14, 2011)

Experimental data sets of ^{11}Be + ^{120}Sn ($E_{\rm lab} = 32$ MeV) quasielastic scattering and ^{10}Be yield coming from the breakup of the projectile were analyzed by means of the continuum-discretized coupled-channel method. Comparison of the calculations and the experimental data suggests that the root-mean-square radius of the neutron wave function of the ^{11}Be ground state is larger than that deduced previously from a high energy scattering experiment. The largest contribution to the breakup cross-section was found to come form Coulomb breakup, in good agreement with the observed post-acceleration of the detected ^{10}Be. Large Coulomb-nuclear interference effects are found.

DOI:10.5506/APhysPolB.43.233
PACS numbers: 25.45.De, 26.60.–t, 24.10.Eq

1. Introduction

The very low neutron separation energy of the neutron-rich beryllium isotope, ^{11}Be, suggests the dominant role of the couplings with the states from the n+^{10}Be continuum (breakup) in the processes induced by this nucleus. In the IS444 experiment performed at REX-ISOLDE facility, the interaction of ^{11}Be + ^{120}Sn was studied at the beam laboratory energy of

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[*] Presented at the XXXII Mazurian Lakes Conference on Physics, Piaski, Poland, September 11–18, 2011.

32 MeV [1, 2]. The angular distributions of quasielastically scattered ^{11}Be (elastic + inelastic to the 1st excited state of the projectile) and emitted ^{10}Be were measured. The latter could come out from the breakup of the projectile and from the neutron-transfer to the target. A series of test calculations has shown that the neutron transfer reaction would lead to the states from the ^{121}Sn continuum and could contribute to the angular distribution of ^{10}Be at scattering angles around $\theta_{\rm cm} = 60\,$deg. Thus, at forward angles, the emerging ^{10}Be must come from the $^{11}\mathrm{Be} \to {}^{10}\mathrm{Be} + n$ breakup. In order to study this mechanism, continuum-discretized coupled-channel (CDCC) calculations were performed.

2. CDCC calculations

The calculations were performed by means of a widely used binning method. The $^{11}\mathrm{Be} = {}^{10}\mathrm{Be} + n$ continuum above the breakup threshold ($E_x = 0.503$) MeV was divided into bins of equal width in the momentum space. The continuum was truncated at the $^{11}\mathrm{Be} \to {}^{9}\mathrm{Be} + 2n$ breakup threshold ($E_x = 7.316$) MeV. Only states with the orbital angular momentum $L = 0, 1, 2$ were considered. The $5/2^+$ resonant state at $E_x = 1.778$ MeV was included in the calculations. All the diagonal and coupling potentials were derived by means of a cluster-folding technique from the empirical n–^{120}Sn [3] and $^{9}\mathrm{Be} + {}^{120}\mathrm{Sn}$ [4] optical potentials. The ^{9}Be potential was used instead of ^{10}Be as the latter is not known. The deformation of the ^{10}Be core was not taken into account. The calculations were performed using the computer code FRESCO [5].

2.1. Neutron radius of the ^{11}Be ground state

The results of the CDCC calculations depend on the potential binding the neutron to the ^{10}Be core. In the past analyses of ^{11}Be interactions with the different targets and at different energies a few such binding potentials were used. In Fig. 1 we present results of CDCC calculations corresponding to the four binding potentials adopted from the papers [1, 6, 7, 8]. The best description of the experimental data, both quasielastic scattering and breakup, is obtained with the geometry proposed by Cravo *et al.* [7] (solid curves). Calculations with the potential of Acosta *et al.* [1] seriously underestimate the measured ^{10}Be yield. Root-mean-square radius of the neutron wave function of the ^{11}Be ground state calculated within this potential is, however, very close to the value deduced from a high energy experiment [9] ($r = 5.7\,$fm). The radius calculated with the potential of Cravo is much larger, of 7.2 fm.

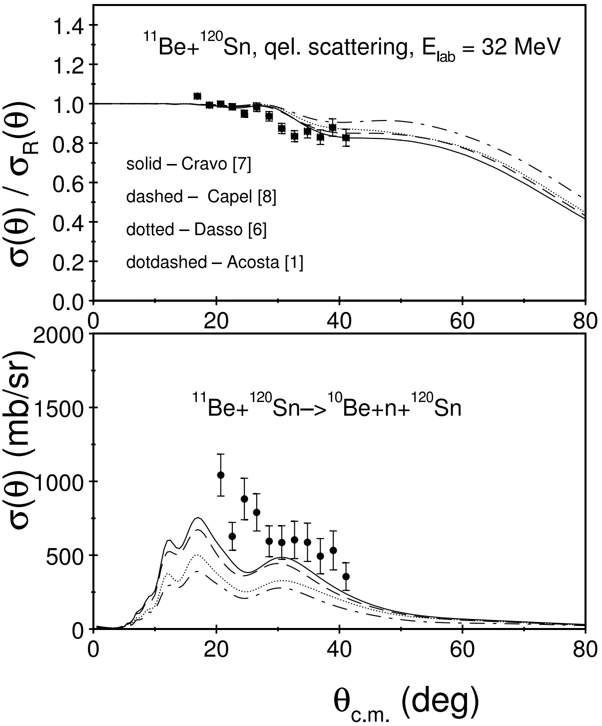

Fig. 1. Comparison of the CDCC calculations, corresponding to the different geometries of the n + ^{10}Be potential, with the experimental data for quasielastic scattering (upper panel) and with the ^{10}Be yield (lower panel). The data sets are from Refs. [1,2].

2.2. Coulomb-nuclear interference effect

The competition of Coulomb and nuclear contributions to the total ^{11}Be breakup cross-section was discussed in a few previous papers. For example, calculations of Dasso *et al.* [6] have shown that for ^{11}Be + ^{208}Pb, at the bombarding energy of 792 MeV, the nuclear contribution is the dominating component while at much higher energy of 520 MeV/u Palit *et al.* [9] has found this component to be much smaller in comparison with the Coulomb.

In order to study this competition at the barrier energy we performed separate calculations, both with the Cravo binding potential, with the pure Coulomb and the pure nuclear couplings. The results are plotted in Fig. 2 with the dashed and the dotted curves, respectively. For comparison, the results of calculation with included couplings (Coulomb and nuclear) only to the first excited state of ^{11}Be are shown by the dot-dashed curve. The calculations presented with the solid curves are the same as in Fig. 1.

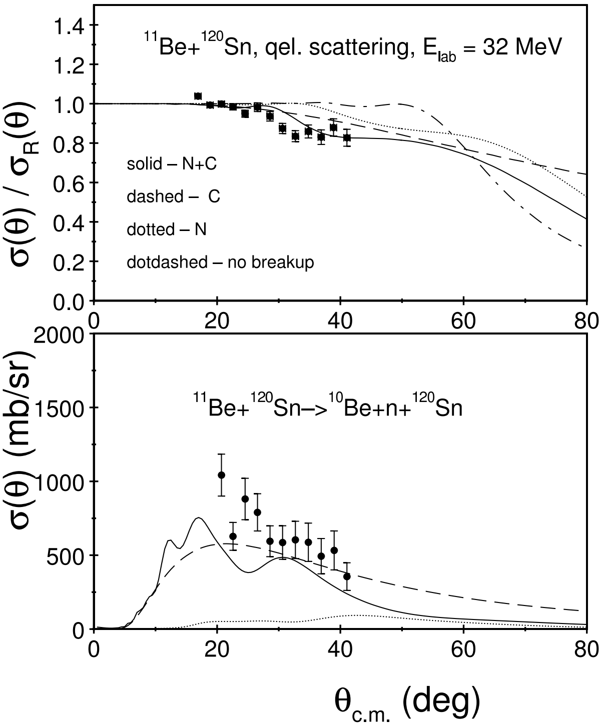

Fig. 2. Contributions of Coulomb (C) and nuclear (N) breakup to the quasielastic scattering (upper panel) and the ^{10}Be yield (lower panel). The data sets are from Refs. [1, 2].

For the ^{10}Be yield, the cross-section calculated with the pure nuclear interactions is negligible in comparison with the cross-section calculated with the Coulomb forces. However, because of the interference effect, the nuclear forces play a very important role in explaining the experimental data. The same holds for the quasielastic scattering, the addition of the nuclear forces significantly modifies the final result.

The effect of the Coulomb — nuclear interference is found to be important not only at the very forward angles. Thus, the results of the calculations suggest a continuation of the IS444 experiment in order to collect some experimental data at the scattering angles larger than 40 deg. This will also help in disentanglement of a contribution due to neutron-transfer.

2.3. Coulomb post-acceleration

Because the projectile breaks into charged ^{10}Be and a neutron, the whole Coulomb potential energy of ^{11}Be is taken by ^{10}Be. Thus, the energy of the detected ^{10}Be is larger than predicted from kinematics. In the present experiment, this energy shift (ΔE) was of about 1.8 MeV. In a very approximate way it could be related to the distance (d) where the breakup occurs

$$\Delta E = \frac{m_1 Z^2 e^2}{m_2 d}\,,$$

where m_1 and m_2 are the masses of the neutron and ^{11}Be, respectively, and Z is the charge number of beryllium. From this relation follows that ^{11}Be breaks at about 14.5 fm from the target, a distance that is larger than the strong absorption radius for the ^{11}Be + ^{120}Sn scattering system. This explains the strong Coulomb component in the breakup cross-section.

3. Conclusions

From the CDCC analysis of the ^{11}Be + ^{120}Sn experimental data taken at 32 MeV of bombarding energy we have learnt that the measured ^{10}Be yield is due to projectile breakup. The calculations suggest that the root-mean-square radius of ^{11}Be ground state wave function is larger than 5.7 fm, the value extracted previously from the high energy experiment of Palit *et al.* [9]. However, the present calculations did not include the effects due to a reported large quadrupole deformation of the ^{10}Be core [10]. The shapes of the calculated angular distributions result from an interference of Coulomb and nuclear contributions. Although the Coulomb contribution is giving much larger cross-section, the nuclear forces contribute very significantly to the final result.

This work was supported by the Grant No. N202 033637 from the Ministry of Science and Higher Education of Poland and the Grant FPA-2010-22131-C02-01 from the Spanish Research Council.

REFERENCES

[1] L. Acosta *et al.*, *Eur. Phys. J.* **A42**, 461 (2009).
[2] L. Acosta *et al.*, *AIP Conf. Proc.* **1165**, 317 (2009).
[3] R.L. Varner, *Phys. Rep.* **201**, 57 (1991).
[4] R. Balzer *et al.*, *Nucl. Phys.* **A293**, 518 (1977).

[5] I.J. Thompson, *Comput. Phys. Rep.* **7**, 167 (1988).
[6] C.H. Dasso, S.M. Lenzi, A. Vitturi, *Phys. Rev.* **C59**, 539 (1999).
[7] E. Cravo *et al.*, *Phys. Rev.* **C79**, 064610 (2009).
[8] P. Capel, G. Goldstein, D. Bye, *Phys. Rev.* **C70**, 064605 (2004).
[9] R. Palit *et al.*, *Phys. Rev.* **C68**, 034318 (2003).
[10] H.G. Bohlen *et al.*, *Phys. Rev.* **C75**, 054604 (2007).