

Short note **${}^7\text{Li}$ quasi-free scattering off the α -cluster in ${}^9\text{Be}$ nucleus**N. Soić¹, D. Cali², S. Cherubini^{2a}, E. Costanzo², M. Lattuada², M. Milin¹, Đ. Miljanić¹, S. Romano², C. Spitaleri², M. Zadro¹¹ Ruđer Bošković Institute, Zagreb, Croatia² INFN-Laboratori Nazionali del Sud and Università di Catania, Catania, Italy

Received: 1 June 1998

Communicated by C. Signorini

Abstract. Spectra of coincident charged particles from the reactions induced by a 52 MeV ${}^7\text{Li}$ beam incident on a beryllium target were measured. Strong contributions of the ${}^7\text{Li}$ quasi-free scattering off the α -cluster in ${}^9\text{Be}$ nucleus were observed. This observation supports the conclusions from the study of complete fusion of weakly bound light nuclei at low energies that the “fragility” of the nuclei makes their fusion less probable.

PACS. 25.70.-z Low and intermediate energy heavy-ion reactions – 27.20.+n $6 \leq A \leq 19$

${}^7\text{Li}$ and ${}^9\text{Be}$ nuclei are very deformed, loosely bound systems. In the cluster model their ground states are portrayed as having the α -t and α - ${}^5\text{He}$ cluster structure, respectively. It has been recently found [1], that the cross section for fusion of light, weakly bound nuclei at energies ranging from E_C to $5E_C$ (E_C - Coulomb barrier) is significantly lower than the total reaction cross section and also smaller than the fusion cross section expected from the available systematics. This feature was interpreted to be due to the strong influence of the break-up processes. Among the break-up processes, especially at higher energies, an important role is often played by the quasi-free scattering, a process in which one of the nuclei in collision quasielastically scatters off a cluster and ejects it from the other nucleus. Many different quasi-free processes have been observed and studied with both ${}^7\text{Li}$ and ${}^9\text{Be}$ nuclei - from e.g. (p,p α) and (α ,2 α) reactions on them as target nuclei [2–4] to their direct fragmentation as projectiles in interaction with complex nuclei e.g. [5]. However, as far as we know, there is no information about these processes in reactions between these two “fragile” nuclei. Recently we have studied different many-body exit channels of the ${}^9\text{Be}$ - ${}^7\text{Li}$ reaction at ${}^7\text{Li}$ energy of 52 MeV [6]. This short note is concerned primarily with the observation of strong contributions of the ${}^7\text{Li}$ quasi-free scattering on the α -particle cluster in ${}^9\text{Be}$ nucleus at this relatively low energy.

In the experiment a 52 MeV ${}^7\text{Li}^{+++}$ beam ($I = 60 - 100$ nA) from the SMP Tandem Van de Graaff accelera-

tor (Laboratori Nazionali del Sud) was used to bombard a self-supported beryllium target ($400 \mu\text{g cm}^{-2}$). Outgoing charged particles were detected and identified in several particle telescopes consisting either of silicon surface barrier (ΔE and E) detectors (SDT), or of an ionization chamber (ΔE) and position sensitive silicon detector (E), (ICPSDT). The angular range covered by the ICPSDTs was 8° , while the angular opening of the SDTs was 1° . Coincidence events between any two telescopes of different type were recorded.

Figure 1. shows the ${}^7\text{Li}$ - α coincidence data for the ICPSDT positioned at $\Theta_{7\text{Li}} = 26.8^\circ$ and for the SDT at $\Theta_\alpha = 40.3^\circ$ ($\Delta\Phi_{ij} = 180^\circ$ for all spectra presented here). The axes correspond to the total energies of particles from the reaction. An intense concentration of events can be observed on the boundary corresponding to the undetected α -particle and neutron left in the ${}^5\text{He}$ ground state. Three weaker partially overlapping bands also show through the four-body ($2\alpha + {}^7\text{Li} + n$) continuum. They correspond to different processes in which one of the products (${}^5\text{He}_0$, ${}^8\text{Be}_0$ and ${}^8\text{Li}_2$) decays with small energy and either α or ${}^7\text{Li}$ from the decay are detected. In the insert one can see the same data presented as a Q-value spectrum, which evidently shows that the largest contribution to the ${}^9\text{Be}({}^7\text{Li}, {}^7\text{Li}\alpha)\alpha n$ reaction for this angle pair corresponds to the undetected particles being in the ${}^5\text{He}$ ground state ($Q \approx -2.5$ MeV).

Figure 2. presents the ${}^7\text{Li}$ - α coincident spectra from the ${}^9\text{Be}({}^7\text{Li}, {}^7\text{Li}\alpha)\alpha n$ reaction, measured for $\Theta_\alpha = 40.3^\circ$ and $\Theta_{7\text{Li}} = 29.5^\circ$ and 43.9° , and shown as projections on the α -particle energy axis. These spectra are formed

^a Present address: Institut de Physique Nucléaire, Université Catholique de Louvain, Louvain-la-Neuve, Belgium

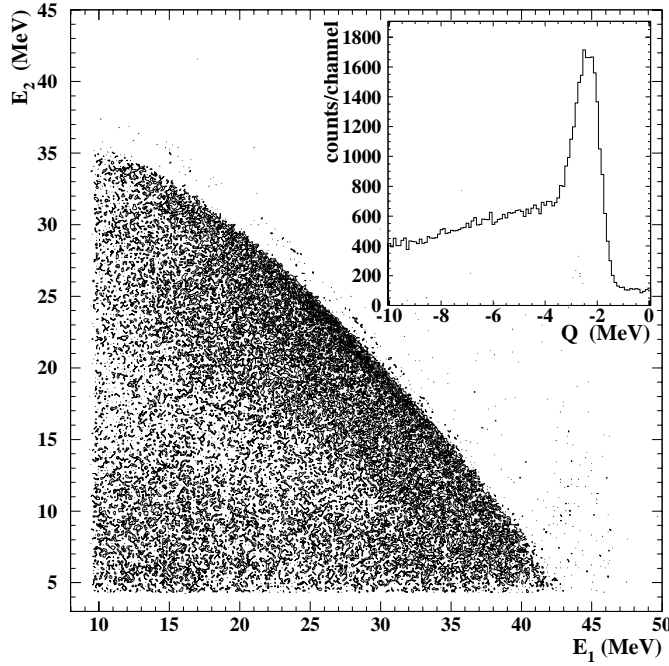


Fig. 1. Two-dimensional E_1 - E_2 plot for the ${}^9\text{Be}({}^7\text{Li}, {}^7\text{Li}\alpha)\alpha n$ events measured at $E_0 = 52$ MeV and for $\bar{\Theta}_{7\text{Li}} = 26.8^\circ$ $\Theta_\alpha = 40.3^\circ$. The Q -value spectrum constructed from these events is shown in the insert

from all those events satisfying the following condition: $Q = (-2.45 \pm 0.55)$ MeV. The curves are the energies of undetected ${}^5\text{He}$ (right scale) and the arrows indicate positions where the contributions from some particle decaying states of ${}^9\text{Be}$ are expected. The prominent peak observed for $\Theta_{7\text{Li}} = 29.5^\circ$ and very low energies of ${}^5\text{He}$ (< 800 keV) is due to the ${}^7\text{Li}$ quasi-free scattering off the α -cluster in ${}^9\text{Be}$. Similar broad peaks are observed for all angle pairs satisfying kinematical conditions for this process ($E_3^L \approx 0$). In these cases they represent a significant fraction of the yield and the only other contribution in the ${}^7\text{Li}$ - α spectra with comparable intensity is due to a sequential process as seen in the spectrum for $\Theta_{7\text{Li}} = 43.9^\circ$. The process is ${}^7\text{Li}$ inelastic scattering on ${}^9\text{Be}$ leading to the $5/2^-$ state, the second member of the ground state rotational band of ${}^9\text{Be}$, which then decays by neutron emission into the tail of the broad first excited state of ${}^8\text{Be}$. Weak contributions from the sequential process through the α - ${}^5\text{He}$ decaying state in ${}^9\text{Be}$ at energies of 6.4 and 11.3 MeV can also be seen.

The quasi-free peaks reflect in a complex way the momentum distributions of the knocked-out clusters in nuclei before the collision. In the factorized distorted-wave impulse approximation (DWIA), the theory most often used in the analysis of the quasi-free reactions, the cross section is essentially a product of two terms (additional terms being spectroscopic and kinematic factors): the so called distorted momentum distribution for the knocked cluster - spectator relative motion and the half-off-shell cross section for the projectile - cluster interaction. The first term in the plane wave limit corresponds to the momen-

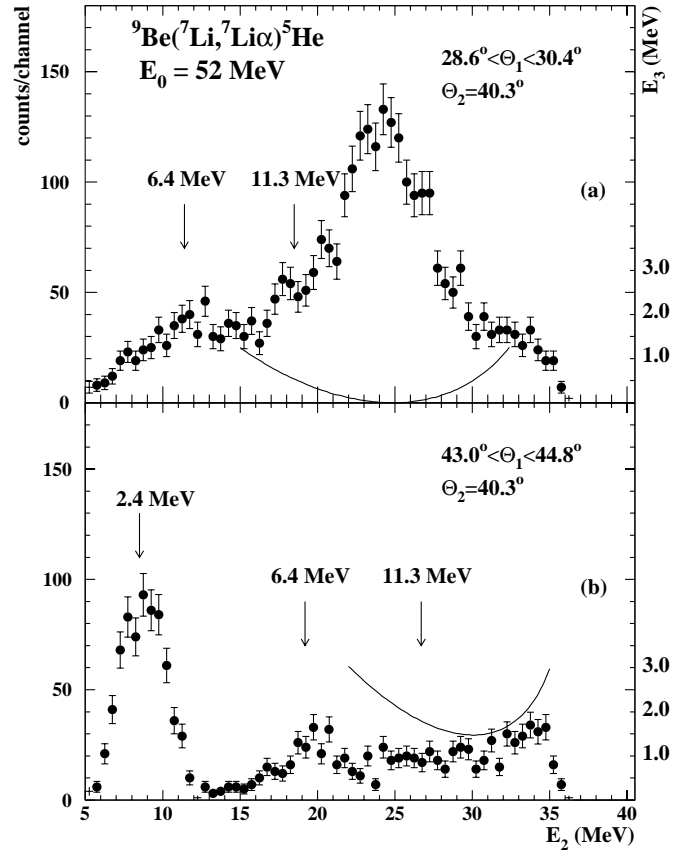


Fig. 2. Projections onto the α -particle energy axis of the ${}^7\text{Li}$ - α coincident spectra for $\Theta_\alpha = 40.3^\circ$ and $\Theta_{7\text{Li}} = 29.5^\circ$ (a) and $\Theta_{7\text{Li}} = 43.9^\circ$ (b). The spectra are constructed from the events having $Q = (-2.45 \pm 0.55)$ MeV. The curves represent energies of undetected ${}^5\text{He}$ nucleus

tum distribution of the cluster in the target nucleus. The half-off-shell cross section is most often replaced by experimental free projectile - cluster scattering cross section. In the present case although there exist some data on ${}^7\text{Li}$ - α scattering [7], they could not be used because they cover an angular range different from the one in the experiment. One can expect that the distortions are severe at these low energies and with complex projectile like ${}^7\text{Li}$. Because of these and other ambiguities it did not seem worthwhile to perform elaborate DWIA calculations. However, for an illustration the ${}^9\text{Be}({}^7\text{Li}, {}^7\text{Li}\alpha)$ reaction cross section data for several angle pairs close to quasi-free scattering conditions, divided by the kinematical factor, are displayed on Fig. 3. as a function of the spectator particle (${}^5\text{He}$) momentum. In the plane wave limit this would correspond to the momentum distribution of α in ${}^9\text{Be}$ if the half-off-shell cross section was constant.

The full width at half maximum of the “momentum distribution” is around 90 MeV/c to be compared with the values extracted from different quasi-free measurements on ${}^9\text{Be}$, ranging from 70 to 130 MeV/c. The maximum of the distribution is shifted with respect to the $p_s = 0$ point. The lower width and the shift could be attributed

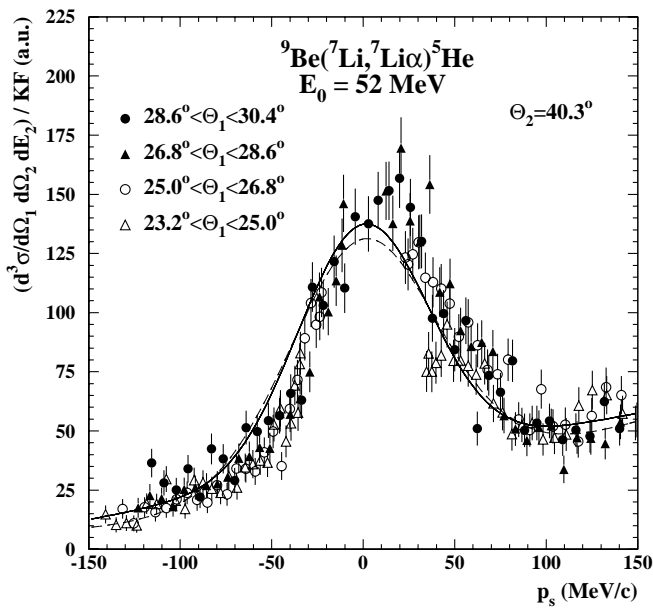


Fig. 3. Plots of $(d^3\sigma / d\Omega_{Li} d\Omega_{\alpha} dE_{\alpha})/KF$ versus ${}^5\text{He}$ momentum with Θ_{α} fixed and four separate ${}^7\text{Li}$ angles. The curves represent PWIA calculations with radial wave functions being a Gaussian (solid line) and Hankel function with $R_c = 4.8$ fm (dotted line)

to strong distortion effects and the variability of the ${}^7\text{Li}$ - α scattering cross section with energy and angle.

For comparison are shown the fits to the data using two radial intercluster (${}^4\text{He}$ - ${}^5\text{He}$) wave functions (Gaussian - solid line, Hankel with a cut-off - dotted line) and with a linear “background” added. The large radial cut-off (4.8 fm), needed to get agreement with the data, can be interpreted, as in other cases before, to be a consequence of the very peripheral nature of this process.

In conclusion, strong contributions of the ${}^7\text{Li}$ - α quasi-free scattering are observed in the ${}^9\text{Be}({}^7\text{Li}, {}^7\text{Li}\alpha){}^5\text{He}$ reaction at center-of-mass energy lower than 4.5 MeV per nucleon. It could be expected that these contributions are present even at lower energies in analogy with the behaviour of some other quasi-free processes like in the ${}^6\text{Li}(d,$

$2d){}^4\text{He}$ [8] and ${}^6\text{Li}({}^6\text{Li}, 2\alpha){}^4\text{He}$ [9] reactions. Similarly, one can expect that other quasi-free scattering contributions, like ${}^7\text{Li}$ - ${}^5\text{He}$, ${}^9\text{Be}$ - α and ${}^9\text{Be}$ - t , play an important role in the ${}^7\text{Li}+{}^9\text{Be}$ collisions, too. These processes together with sequential and other break-up processes then may make a significant part of the total reaction cross section. This is in accordance with the plausible interpretation [1], that the inhibition of the complete fusion in collisions between light weakly bound nuclei at lower energies has its origin in their “fragility”, i.e. high probability of their break-up.

The authors wish to thank Mr. C. Marchetta for target preparation and the staff of the SMP Tandem Van de Graaff accelerator for their efforts during the experiment.

References

1. J. Takahashi, M. Munhoz, E. M. Szanto, N. Carlin, N. Added, A. A. P. Suaide, M. M. de Moura, R. Liguori Neto, A. Szanto de Toledo and L. F. Canto, *Phys. Rev. Lett.* **78**, (1997) 30
2. Mahavir Jain, P. G. Roos, H. G. Pugh and H. D. Holmgeen, *Nucl. Phys.* **A153**, (1970) 49
3. A. Nadasen, N. S. Chant, P. G. Roos, T. A. Carey, R. Cowen, C. Samanta and J. Wesick, *Phys. Rev. C* **22**, (1980) 1394
4. A. A. Cowley, G. F. Steyn, S. V. Förtsch, J. J. Lawrie, J. V. Pilcher, F. D. Smit and D. M. Whittal, *Phys. Rev. C* **50**, (1994) 2449
5. J. Yorkston, A. C. Shotton, T. Davinson, E. W. Macdonald and D. Branford, *Nucl. Phys.* **A524**, (1991) 495
6. N. Soić, D. Cali, S. Cherubini, E. Costanzo, M. Lattuada, Đ. Miljanić, S. Romano, C. Spitaleri and M. Zadro, *Europhys. Lett.* **41**, (1998) 489 and to be published
7. S. Matsuki, S. Yamashita, K. Fukunaga, D. C. Nguyen, N. Fujiwara and T. Yanabu, *J. Phys. Soc. Jap.* **26**, (1969) 1344
8. Đ. Miljanić, J. Hudomalj, G. S. Mutchler, E. Andrade and G. C. Phillips, *Phys. Lett.* **50B**, (1974) 330
9. M. Lattuada, F. Riggi, D. Vinciguerra, C. Spitaleri, G. Vourvopoulos, Đ. Miljanić and E. Norbeck, *Z. Phys. A* **330**, (1988) 183