Few-Body Syst (2011) 50: 319–321
DOI 10.1007/s00601-010-0178-5

R. G. Pizzone · C. Spitaleri · A. M. Mukhamedzhanov · L. D. Blokhintsev · C. A. Bertulani · B. F. Irgaziev · M. La Cognata · L. Lamia · S. Romano

Distortion Effects on Trojan Horse Applications

Received: 29 October 2010 / Accepted: 29 November 2010 / Published online: 14 December 2010

Abstract The widths of the spectator momentum distributions in several nuclei, which have been used as Trojan Horses, have been obtained as a function of the transferred momentum. Applications of Trojan Horse method will also be discussed.

The study of processes relevant for astrophysics involving light nuclei has increased in the last decades due to the development of indirect methods. These latter try to measure bare nucleus cross sections at astrophysically relevant energies [1,2]. Among them we cite Coulomb dissociation [3], the ANC [4–7] and the Trojan Horse Method (THM). The main features of this latter method are extensively discussed elsewhere [8–14,21–23]. The method was used both for charged particle induced reactions as well as for neutron induced ones [19].

The present paper will also help to point out the distortion effects which arise at low energies in the study of three-body processes and will suggest some way to by-pass them in THM applications.

The results of the work [15] have been recently updated and extended to many other light nuclei [16,17] because of the importance of weakly bound nuclei in the framework of the THM and its application to the nuclear astrophysics. Since the extraction of the bare-nucleus S(E) factor uses the momentum distribution of the spectator cluster inside the TH nucleus, it is important to evaluate the impact of the uncertainty of the momentum distribution width on the final result. The goal of this paper is to compare the experimental momentum distribution of the spectator in the bound state $a = (sx)$ extracted from the $2 \to 3$ particles (breakup, or breakup with rearrangement) reactions with the theoretical one. The theoretical momentum distribution has been calculated for the target $a = (sx)$ using the Hulthen potential for $a = d$ and Woods-Saxon one with the standard geometrical parameters, radius $r_0 = 1.25$ fm and diffuseness $a = 0.65$ fm, for other nuclei.

In previous works [15,16] it has been shown that the full width at half maximum, $W(q_t)$, (e.g for the α−d momentum distribution in ^{6}Li) slowly increases with increasing mean transferred momentum. In the most

Presented at the 21st European Conference on Few-Body Problems in Physics, Salamanca, Spain, 30 August–3 September 2010.

R. G. Pizzone (✉) · C. Spitaleri · M. La Cognata · L. Lamia · S. Romano
INFN—LNS, Universitá di Catania, Catania, Italy
E-mail: rgpizzone@lns.infn.it

A. M. Mukhamedzhanov
Cyclotron Institute Texas A&M University, College Station, USA

L. D. Blokhintsev
Moscow State University, Moscow, Russia

C. A. Bertulani
Physics Department, Texas A&M University, Commerce, USA

B. F. Irgaziev
GIK Institute of Engineering Sciences and Technology, Topi, District Swabi, N. W. F. P., Pakistan

general case the 3-body reaction used for achieving information on some astrophysically relevant binary one can be expressed as $A+a \to s+c+C$, where particle s is then considered to be spectator to the $A+x \to c+C$ binary reaction and the Trojan Horse nucleus a is described in terms of a cluster structure $a = (sx)$.

In the case of transferred momentum from the projectile A to the center-of-mass of the final system $B = C + c$, the latter can be written as the Galilean invariant quantity:

$$\mathbf{q}_t = \left(\frac{m_B}{m_A}\right)^{1/2} \mathbf{p}_A - \left(\frac{m_A}{m_B}\right)^{1/2} \mathbf{p}_B. \tag{1}$$

The experimental momentum distribution FWHM $W(q_t)$, extracted from several experiments, are measured in the case of different Trojan Horse ^{2}H,^{3} He,^{6} Li,^{9} Be at different beam energies and kinematic conditions (see ref. [16,17] for further details). This allows us to explore a wide range of the transferred momentum and made it possible to explore the correlation between the momentum distribution width and the transferred momentum. This is extensively reported in [16,17]. What is clear for all isotopes is that at low q_t, the W_t smoothly increases until the predicted PWIA asymptotic value (which varies for the different studied isotopes) is reached in the region where q_t is large. These data strongly confirm the behaviour already discussed in [15,16] for the $\alpha - d$ case in ^{6}Li. This experimental behaviour was fitted, in all the cited cases, by using the following empirical function, as in [16,17], $W(q_t) = f_0(1 - \exp(-q_t/q_0))$, with f_0 the asymptotic width of momentum distribution and q_0 a coefficient which takes into account the distortion present at low transferred momenta. We found that the deviation of the theoretical momentum distributions from the experimental ones is correlated with the transfer momentum from the projectile to the ejectiles. When the average transferred momentum is large compared to κ, where $\kappa_{sx} = \sqrt{2 \cdot \mu\, \varepsilon_{sx}} \varepsilon_{sx}$ being the binding energy of the fragments x and s in the bound state $a = (sx)$ and μ is their reduced mass, the experimental FWHM reaches the theoretical one (the plateau is reached at $q_t \sim$ (5–6)κ_{sx}).

Thus at higher relative $C - s$ and $c - s$ kinetic energies and higher q_t the final-state ejectile-spectator effects are negligible and the reaction is an "ideal" quasi-free reaction. But as soon as the relative $C - s$ and $c - s$ kinetic energies decrease or the transferred momentum becomes comparable with κ_{sx} the momentum distribution shape changes and its width becomes smaller. This behaviour appears for all the examined nuclei, ^{2}H, ^{3}He, ^{6}Li, ^{3}H and ^{9}Be. The application of the THM to these cases should take into account these distortions by adopting the "distorted" FWHM extracted from the experimental data instead of the theoretical one. In Fig. 1 the behaviour of FWHM for the different examined isotopes is reported. In order to do this the $W(q)$ is normalized to f_0 for each isotope while the transferred momentum is expressed in units of κ_{sx}. Again the saturation effect is clear as well as the distortion at small transferred momentum for both the examined isotopes (^{6}Li and ^{2}H). The same behaviour was evident for all the other examined isotopes as discussed in [17].

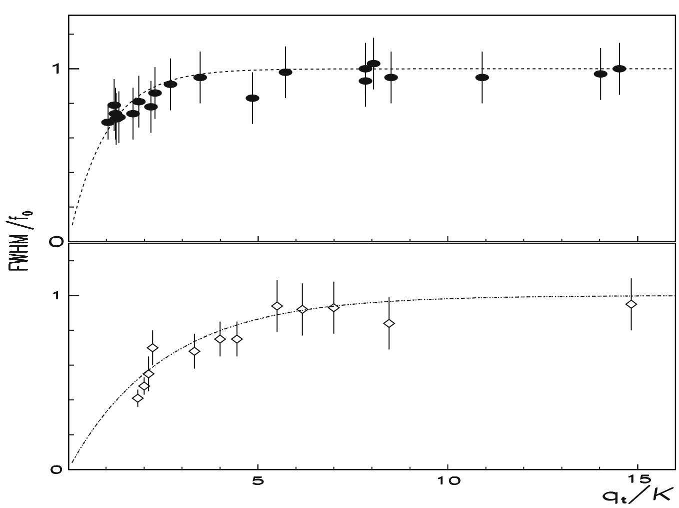

Fig. 1 FWHM (normalized to f_0 for each isotope) as a function of transferred momentum expressed in units of κ_{sx}. On *top* the case of deuterium is reported, on *bottom* the ^{6}Li one. The experimental fit (*line*) is discussed in the text

References

1. Pizzone, R.G., et al.: Proton-induced lithium destruction cross-section and its astrophysical implication. A. & A. **398**, 423–427 (2003)
2. Pizzone, R.G., et al.: Bare astrophysical S(E)-factor for the $^{6}Li(d,\alpha)^{4}$He and $^{7}Li(p,\alpha)^{4}$He reactions at astrophysical energies. A & A **438**, 779 (2005)
3. Baur, G., Bertulani, C.A., Rebel, H.: Coulomb dissociation as a source of information on radiative capture processes of astrophysical interest. Nucl. Phys. A **458**, 188 (1986)
4. Tang, X.D., et al.: ANC method applied to nuclear astrophysics. Phys. Rev. C **67**, 015804 (2003)
5. Mukhamedzhanov, A.M., et al.: New astrophysical S factor for the $^{15}N(p,\gamma)^{16}$O reaction via the asymptotic normalization coefficient (ANC) method. Phys. Rev. **78**, 015804 (2008)
6. Azhari, A., et al.: Asymptotic Normalization Coefficients for p $+^{7}$Be $\rightarrow^{8}$B and the Direct $^{7}Be(p,\gamma)^{8}$B Astrophysical S Factors at Solar Energies. Phys. Rev. C **63**, 055803 (2001)
7. Mukhamedzhanov, A.M., Tribble, R.E.: Connection between asymptotic normalization coefficients, subthreshold bound states, and resonances. Phys. Rev. C **59**, 3418 (1999)
8. Cherubini, S., et al.: Indirect investigation of the d+Li-6 reaction at low energies relevant for nuclear astrophysics. Ap. J. **457**, 855 (1996)
9. Spitaleri, C., et al.: "Trojan horse" method applied to ^{2}H(^{6}Li, α)^{4}He at astrophysical energies. Phys. Rev. C **63**, 055801 (2001)
10. Lattuada, M., et al.: The bare astrophysical S(E) factor of the ^{7}Li(p, α)α reaction. Ap. J. **562**, 1076 (2001)
11. Spitaleri, C., et al.: The Trojan Horse Method in nuclear astrophysics. Nucl. Phys. A **719**, 99C–106C (2003)
12. Spitaleri, C., et al.: Indirect $^{7}Li(p,\alpha)^{4}$He reaction at astrophysical energies. Phys. Rev. C **60**, 055802 (1999)
13. Tumino, A. et al.: Validity test of the "Trojan horse" method applied to the ^{6}Li(p, α)^{4}He reaction. Phys. Rev. C **67**, 065803 (2003)
14. Spitaleri, C., et al.: The ^{11}B(p, α_0)^{8}Be reaction at sub-Coulomb energies via the Trojan-horse method. Phys. Rev. C **69**, 055806 (2004)
15. Barbarino, S., et al.: Impulse distribution of the ?-d motion in 6Li. Phys. Rev. C **21**, 1104 (1980)
16. Pizzone, R.G., et al.: Influence of the alpha-d motion in Li-6 on Trojan horse applications. Phys. Rev. C **71**, 058801 (2005)
17. Pizzone, R.G., et al.: Effects of distortion of the intercluster motion in H-2, He-3, H-3, Li-6, and Be-9 on Trojan horse applications. Phys. Rev. C **80**, 025807 (2009)
18. Baur, G.,: The theory of the trojan horse method. Phys. Lett. B **178**, 135 (1986)
19. Tumino, A., et al.: Quasi-free $^{6}Li(n,\alpha)^{3}$H reaction at low energy from ^{2}H break-up. Eur. Phys. J. A **25**, 649 (2005)
20. La Cognata, M., et al.: Astrophysical S(E) factor of the ^{15}N(p, α)^{12}C reaction at sub-Coulomb energies via the Trojan horse method. Phys. Rev. C **76**, 065804 (2007)
21. Tumino, A., et al.: Suppression of the Coulomb interaction in the off-energy-shell p-p scattering from the p + d $\rightarrow$ p + p + n reaction. Phys. Rev. Lett. **98**, 252502 (2007)
22. La Cognata, M., et al.: Measurement of the 20 and 90 keV Resonances in the ^{18}O(p, α)^{15}N Reaction via the Trojan Horse Method. Phys. Rev. Lett. **101**, 152501 (2008)
23. Lamia, L., et al.: Boron depletion: indirect measurement of the $^{10}B(p,\alpha)^{7}$Be S(E)-factor. Nucl. Phys. A **787**, 309C–314C (2007)