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Trojan Horse particle invariance for ^{2}H(d,p)^{3}H reaction: a detailed study

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Abstract. In the last decades the Trojan Horse method has played a crucial role for the measurement of several charged particle induced reactions cross sections of astrophysical interest. To better understand its cornerstones and its applications to physical cases many tests were performed to verify all its properties and the possible future perspectives. The Trojan Horse nucleus invariance for the binary d(d,p)t reaction was therefore tested using the quasi free ^{2}H(^{6}Li, pt)^{4}He and ^{2}H(^{3}He,pt)H reactions after ^{6}Li and ^{3}He break-up, respectively. The astrophysical S(E)-factor for the d(d,p)t binary process was then extracted in the framework of the Plane Wave Approximation applied to the two different break-up schemes. The obtained results are compared with direct data as well as with previous indirect investigations. The very good agreement confirms the applicability of the plane wave approximation and suggests the independence of binary indirect cross section on the chosen Trojan Horse nucleus also for the present case.

1 Introduction

Nuclear reactions induced by charged particles at astrophysical energies are extremely difficult to study, mainly for the presence of the Coulomb barrier and the electron screening effect. In the last decades strong efforts were devoted to the development and application of indirect methods in nuclear astrophysics. Among them an important role is played by the Trojan Horse Method (THM) which has been applied to several reactions in the past decade [1–21] at the energies relevant for astrophysics (typically smaller than few hundred keV's), which usually are far below the Coulomb barrier, of the order of MeV's. THM allows one to extract the low energy behavior of a binary reaction by applying the well known theoretical formalism of the Quasi-Free (QF) process. The basic idea of the THM is to extract the cross section in the low-energy region of a two-body reaction with significant astrophysical impact:

$$a + x \rightarrow c + C \tag{1}$$

from a suitable QF break-up of the so called Trojan Horse nucleus, e.g. $A = x \oplus s$ where usually x is referred to as the *participant* and s as the *spectator* particle. We refer to previous papers and references therein for an extensive discussion on THM and its theoretical formalism [18].

Many tests have been made to fully explore the potentiality of the method and extend as much as possible its applications: the target/projectile break-up invariance [22], the spectator invariance [23, 24] and the possible use of virtual neutron beams [26, 27]. In recent works [23, 24] the spectator invariance was extensively examined for the ^{6}Li(^{6}Li,$\alpha\alpha$)^{4}He and the ^{6}Li(^{3}He,$\alpha\alpha$)H case as well as the ^{7}Li(d,$\alpha\alpha$)n and ^{7}Li(^{3}He,$\alpha\alpha$)^{2}H reactions, thus comparing results arising from ^{6}Li and ^{3}He and deuteron and ^{3}He break-up respectively [24]. Agreement between the sets of data was found below and above the Coulomb barrier. The idea of the present paper is to see whether the same can hold also for the d(d,p)t binary reaction, studied via the quasi free ^{2}H(^{6}Li, pt)^{4}He and ^{2}H(^{3}He,pt)H reactions after ^{6}Li and ^{3}He break-up, respectively.

In Fig. 1, the different break-up schemes of interest are depicted. On the left side we report the QF process which proceeds through ^{6}Li break-up while on the right the one which goes through ^{3}He.

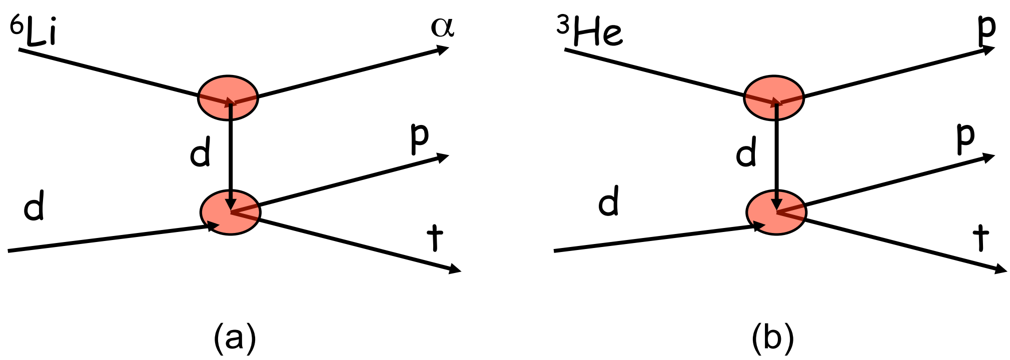

Figure 1. Sketch of the processes discussed in the text. Left (a): the quasi-free reaction involving the ^{6}Li break-up is shown. Right (b): the ^{3}He break-up is reported.

2 Results and discussion

The two experiments are discussed extensively elsewhere, in particular the ^{2}H(^{6}Li, pt)^{4}He reaction in [25, 29] and the ^{2}H(^{3}He,pt)H in [34]. In both cases the standard prescriptions of the THM, as discussed in [18, 28], to extract the energy trend of the S(E)-factor were applied. Therefore the binary cross section is extracted from the measured three-body one, in both experiments. The momentum distributions adopted for the data extractions were treated as prescribed in [30, 31] and fitted with a Hänckel function for the ^{6}Li break-up and with the Eckart function for the ^{3}He case.

The averaged results for the d(d,p)t reaction after ^{6}Li break-up (black dots, see [25] for details) are then compared with the ones extracted from ^{3}He break-up (see [34], triangles). We can point out that the errors in the ^{6}Li break-up case are much larger than in the case of ^{3}He breakup. This is mainly

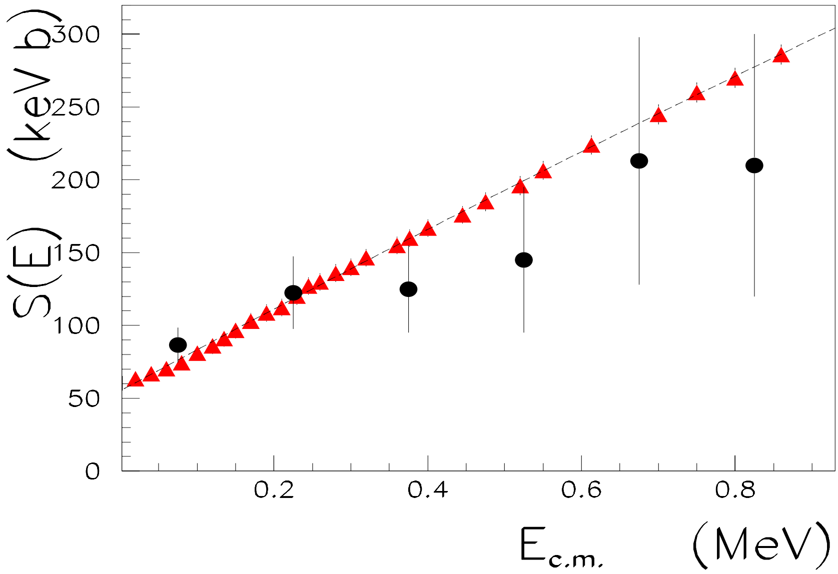

Figure 2. Averaged astrophysical S(E)-factor for the d(d,p)t reaction measured via THM after ^{6}Li break-up (black dots) and after ^{3}He break-up(red points), extracted from [34] clearly showing the Trojan Horse particle invariance. The polynomial fit to data from [34] is reported for comparison as a solid line.

due to the presence of the sequential mechanism in ^{7}Li, already discussed in [29] that decreases the number of the QF events. Also the normalization errors and errors connected to the penetrability factor are fully included in the error bar shown in the pictures. Polynomial fits were then performed on the data giving S_0= 75 ±21 keV·b in the case of the ^{6}Li break-up, while for ^{3}He one obtains S_0= 58 ±2 keV·b. The results are in agreement, within the experimental errors, also with previous direct measurements [32, 33]. Coherent results from both the considered break-up schemes (as in figure 1) are achieved, not only in terms of the S(E)-factors but also for the electron screening effect.

In such a way we find that, also in the present case, data extracted via the THM applied to the ^{6}Li and ^{3}He break-up are comparable among themselves and that the THM shows spectator particle invariance also in the case of the d(d,p)t reactions. This confirms in an additional and independent case what was already observed in [24] for the $^{6}Li(d,\alpha)^{4}He$ and the $^{7}Li(p,\alpha)^{4}He$ reactions and strengthen the understanding and reliability of the method and its theoretical formalism.

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