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Quasi-free ^{6}Li(n, α)^{3}H reaction at low energy from ^{2}H break-up

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Abstract. The ^{6}Li + d reaction was studied in order to investigate the quasi-free ^{6}Li(n, α)^{3}H reaction, off the proton in ^{2}H. A kinematically complete experiment was performed at a beam energy of 14 MeV. Coincidence spectra show the contribution of the quasi-free n+^{6}Li reaction in the relative energy range from 1.5 MeV down to zero. The extracted ^{6}Li(n, α)^{3}H quasi-free cross-section was compared with the behavior of direct data throughout the investigated energy range. No penetrability corrections were introduced on the quasi-free data, being the ^{6}Li(n, α)^{3}H direct reaction free of Coulomb suppression.

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1 Introduction

Quasi-free (QF) scattering and reactions have been extensively studied in the past in order to investigate the cluster structure of light nuclei [1,2,3]. A number of theoretical approaches based on the Impulse Approximation were developed [4,5], which describe a quasi free $A+a \to c+C+s$ reaction (a having a strong $x-s$ cluster structure) by a Pseudo Feynman diagram where only the first term of the Feynman series is retained. A pole of the diagram describes the break-up of the target nucleus a into the clusters x and s, and the other one contains the information on the virtual $A+x \to c+C$ two-body process, which leaves the cluster s as spectator (see ref. [6]). Recently the QF mechanism was successfully applied in the framework of the known Trojan Horse Method (THM) [6,7,8,9] to study charged particle two-body reactions relevant for astrophysics, free of Coulomb suppression and screening effects. The present paper describes an original application of the QF mechanism to the neutron capture ^{6}Li(n, α)^{3}H reaction, selected from the ^{6}Li + d interaction leaving the proton as spectator. Its importance relies on the chance to investigate possible off-energy-shell effects on the QF data in a situation where the Coulomb barrier is absent. This represents an important test for the Trojan Horse Method, also in view of further applications to key astrophysical reactions using deuterons as source of a neutron beam.

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2 The experiment

The ^{2}H(^{6}Li, α^3H)^{1}H experiment was performed at the Laboratori Nazionali del Sud in Catania. The SMP Tandem Van de Graaf accelerator delivered a 14 MeV ^{6}Li beam onto a CD_2 target of about 150 μg/cm^2. Two silicon ΔE-E telescopes, consisting of 20 μm ΔE- and 1000 μm position-sensitive E-detector, were placed on opposite sides with respect to the beam direction covering the laboratory angles 18° to 28° and 43° to 53°. The angular ranges were chosen in order to cover momentum values p_s of the undetected proton ranging from about −100 MeV/c to about 100 MeV/c when α and ^{3}H are detected within 18°–28° and 43°–53°, respectively. This assures that the bulk of the QF contributions for the break-up process of interest falls inside the investigated regions, allowing also to cross check the method outside the relevant phase-space regions. The trigger for the event acquisition was given by the coincidences between the two telescopes.

3 Data analysis and results

The identification of the $\alpha + {}^3$H + p channel of interest was achieved by selecting α and ^{3}H loci in the ΔE-E two-dimensional plots and the kinematics were reconstructed under the assumption of a proton as third particle.

Sequential processes through the ground state of ^{5}Li or excited states of ^{4}He or ^{7}Li can also feed this channel. A way to investigate the reaction mechanism involved and to disentangle QF coincidence events from others, is to examine the shape of the experimental momentum

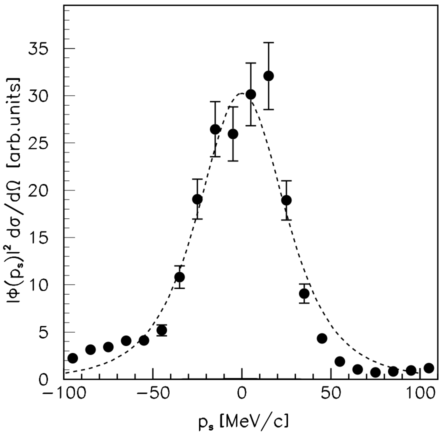

Fig. 1. Experimental proton momentum distribution. The dashed line represents the shape of the theoretical Hulthén function in momentum space.

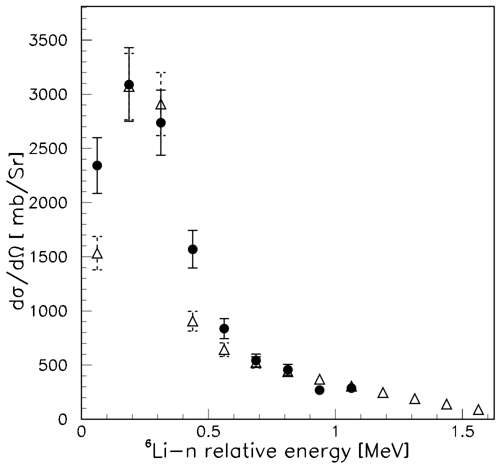

Fig. 2. Comparison between QF data (full dots) and direct cross-section (open triangles) from [11].

distribution for the proton. This observable was reconstructed in plane wave impulse approximation (PWIA) by applying the energy sharing method [2] to our coincidence data. The ^{6}Li-n relative energy was calculated in post collision prescription in the standard way (for details see refs. [6,7,8,9]) and windows of 100 keV were selected. In PWIA the three-body cross-section is factorized into two terms, corresponding to the two poles mentioned in the introduction:

$$\frac{\mathrm{d}^3\sigma}{\mathrm{d}E_c\,\mathrm{d}\Omega_c\,\mathrm{d}\Omega_C} \propto KF\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)\cdot|\Phi(\boldsymbol{p}_s)|^2, \qquad (1)$$

where $(\mathrm{d}\sigma/\mathrm{d}\Omega)$ is the off-energy-shell differential cross-section for the $^6\mathrm{Li}(\mathrm{n},\alpha)^3\mathrm{H}$ two-body reaction, KF is a kinematical factor depending on masses, momenta and angles of the outgoing particles refs. [6,7,8,9], and $\Phi(\boldsymbol{p}_s)$ is the Fourier transform of the radial wave function for the p-n intercluster motion inside the deuteron, described in terms of a Hulthén function [9]. Dividing the three-body coincidence yield by KF, we are left with a quantity reflecting the behaviour of the experimental momentum distribution in arbitrary units. Indeed within relative energy ranges of 100 keV, $[(\mathrm{d}\sigma/\mathrm{d}\Omega)_{A-x}]$ is about constant. The result is reported in fig. 1. The dashed line superimposed on the data gives the shape of the theoretical Hulthén function in momentum space, normalized to the experimental maximum. A quite good agreement shows up, making us confident that in the chosen kinematical region, the QF mechanism gives the main contribution to the $^6\mathrm{Li}+\mathrm{d}$ reaction and it can be selected without significant interference with contaminant sequential decay processes. The further analysis was performed by considering coincidence events with a neutron momentum ranging between -40 and 40 MeV/c. Following the PWIA approach, a Monte Carlo calculation provided kinematical factors and momentum distribution in the factorization of the cross-section. Then the two-body cross-section was derived dividing the selected three-body coincidence yield by the result of the Monte Carlo calculation. An error calculation for the ^{6}Li-n relative energy provides a value ranging from 80 to 120 keV, the minimum estimate corresponding to the phase space region where the lens effect is more efficient [10]. The extracted off-energy shell ^{6}Li-n two-body cross-section was then compared with direct data integrated over the same $\theta_{\mathrm{c.m.}} = 40°$–$70°$ angular region, $\theta_{\mathrm{c.m.}}$ being the emission angle for the outgoing a particle in the ^{3}H-α center-of-mass system [6,7,8,9]. Since the ^{6}Li-n direct data are not affected at low energy by Coulomb suppression, the comparison with our indirect cross-section could be performed throughout the investigated energy range without any further correction. The normalization to the direct behaviour was performed at the top of the resonance, around $E_{^6\mathrm{Li\text{-}n}} = 210$ keV. The comparison is shown in fig. 2, where full dots represent present data while open triangles are direct data from [11], both sets averaged out at the same energy bin of 120 keV comparable with the uncertainty.

The two data sets agree quite well throughout the investigated range, including the resonant region. The good agreement validates the pole approximation for this experiment. Importantly, the present results seem to exclude off-energy shell effects on the QF cross-section other than the lack of the Coulomb suppression at sub-Coulomb energies for reactions involving charged particles.

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