Eur. Phys. J. A **25**, s01, 299–301 (2005)
DOI: 10.1140/epjad/i2005-06-066-4

EPJ A direct
electronic only

Entrance channel dependence in compound nuclear reactions with loosely bound nuclei[*]

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Received: 15 April 2004 /

Abstract. The measurement of light charged particles evaporated from the reaction ^{6,7}Li + ^{6}Li has been carried out at extreme backward angle in the energy range 14–20 MeV. Calculations from the code ALICE91 show that the symmetry of the target-projectile combination and the choice of level density parameter play important roles in explaining the evaporation spectra for these light particle systems. In the above barrier energy region the fusion cross-section is not suppressed for these loosely bound nuclei.

PACS. 25.70.Gh Compound nucleus – 25.70.-z Low and intermediate energy heavy-ion reactions

1 Introduction

Study of fusion reactions with loosely bound stable nuclei like ^{6,7}Li, ^{9}Be etc. have gained importance in recent times as they provide a good analogue to investigations with halo nuclei. The effect of low break-up threshold of loosely bound nuclei on fusion reactions are not well understood [1,2,3,4]. Most of the recent experiments with loosely bound nuclei investigate the behaviour of fusion excitation functions both in the above and below barrier regions. There are however fewer attempts to study the evaporation of light charged particles involving the reaction of such nuclei [5,6]. In this work we report the inclusive measurement of α-particles emitted in the reactions of ^{6,7}Li projectile on ^{6}Li target at extreme backward angle for a range of energies above the Coulomb barrier. Statistical model calculations reproduce the experimental α-spectra (from other published works) nicely when emitted from a compound nucleus (CN) formed from an asymmetric target projectile combination. However in our case where the target-projectile combination is nearly symmetric, a large deformation (in terms of the rotating liquid drop model [7]) along with a structure-dependent level density parameter is required to properly explain the observed spectra.

2 Experiment

The experiment was performed using ^{6,7}Li beams from the 14UD BARC-TIFR Pelletron Accelerator Facility at Mumbai, in the laboratory energy range 14 to 20 MeV. A 4 mg/cm^2 thick rolled ^{6}Li target was used. Only light charged particles were detected. For particle identification standard two element ΔE-E telescopes with silicon surface barrier ($\Delta E = 10\,\mu$m) and Si(Li) detectors ($E = 300\,\mu$m) were used. This telescope was placed at 175° to detect α-particles. The beam current was kept between 1–20 nA. Standard electronics and CAMAC based data acquisition system were used. Energy calibration was done using ^{7}Li elastic scattering data on Au and mylar targets each of thickness 500 μg/cm^2.

3 Results and discussions

Figures 1(a) and (b) show the inclusive α-spectrum measured at 175° from the reaction ^{7}Li + ^{6}Li at energies $E(^{7}\mathrm{Li}) = 14$ and 16 MeV, respectively. The experimental spectra in general consists of a continuum part followed by some discrete peaks at higher energy. The discrete peaks are identified as due to α emission from ^{13}C and ^{23}Na (formed due to oxidation of ^{6}Li target) compound nuclei. As ^{6,7}Li are loosely bound nuclei, the continuum part may contain contributions from both break-up and compound nuclear reactions. However, the contribution of α emission from break-up process at this extreme

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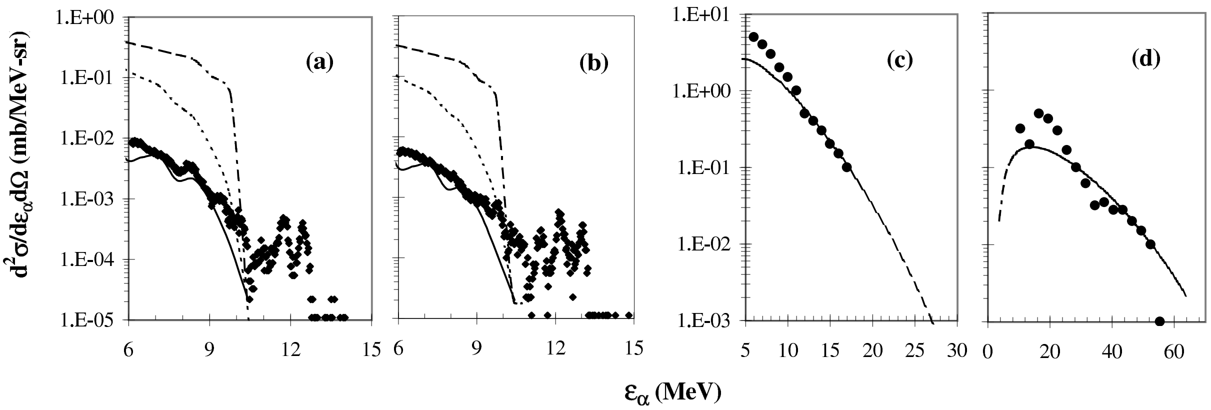

Fig. 1. (a), (b) Inclusive α-spectrum measured at 175° from the reaction ^{7}Li + ^{6}Li at energies $E(^7\mathrm{Li}) = 14$ and 16 MeV, respectively. Inclusive α-spectrum from (c) ^{28}Si + ^{6}Li scattering at $E(^6\mathrm{Li}) = 36$ MeV, $\theta = 155°$ and (d) n + ^{12}C scattering at $E(\mathrm{n}) = 72.8$ MeV, $\theta = 40°$. Calculations (solid, dashed and dotted lines) are explained in the text.

backward angle is expected to be negligible. To evaluate the continuum part we use the statistical model code ALICE91 [8]. The dashed lines in fig. 1 indicate calculations with the Fermi gas level density parameter ($a = A/9$) assuming a spherical compound nucleus. As can be seen, the calculations grossly overpredict the experimental data. It is well known that the level density parameter a strongly influences the level density and hence the higher energy part of the evaporation spectra. We have found that in our case arbitrary change of a parameter does not help to improve the spectra, except for some change in slope. Instead of resorting to arbitrary adjustment of the parameters in the statistical model we try to consider a deformation in the excited CN as in the works [9,10] for reactions with heavier nuclei. The dotted lines show the results of this calculation with the same level density parameter. The rotational energy is evaluated in terms of the Rotating Liquid Drop Model deformations [7]. These new calculations are now much reduced in comparison to the calculations assuming a spherical CN but they still overpredict the data. In the Fermi gas model a/A is simply a constant. However there are shell effects in a especially near the magic nucleon numbers. Therefore, instead of trying to adjust the parameter a, we now adopt the Gilbert Cameron prescription [11] for the shell-dependent level density parameter. The solid lines are calculations using shell corrected Gilbert-Cameron level density parameter and a deformed CN. This calculation agrees with the experimental data more satisfactorily. Similar results were observed for the reactions with ^{6}Li beam which will be discussed elsewhere. In order to verify the effect of target-projectile symmetry on the statistical calculations we have reanalyzed the published experimental data for $^{12}\mathrm{C}(\mathrm{n},\alpha)$ [12] and $^{28}\mathrm{Si}(^6\mathrm{Li},\alpha)$ [6] shown in figs. 1(c) and (d). In the reaction $^{12}\mathrm{C}(\mathrm{n},\alpha)$ the compound nucleus is ^{13}C, which is same as in our experiment but populated by an asymmetric combination of target and projectile. However, the excitation energy is much higher (72.15 MeV) (lower energy data is not available for this system). In case of $^{28}\mathrm{Si}(^6\mathrm{Li},\alpha)$ the α-particles were detected at backward angle (155°) and the excitation of the compound nucleus was 46.68 MeV. The excitation of the compound nucleus in our case is close to this value (32.34 to 35.1 MeV). ALICE91 calculations (dotted line) using Fermi gas level density parameter ($a = A/9$) in the Weisskopf-Ewing approximation (without any deformation) and comparison to the observed data is shown in figs. 1(c) and (d). The calculation reproduces the experimental data satisfactorily considering a spherical compound nucleus.

In summary, the measurement of light charged particles evaporated from ^{6,7}Li + ^{6}Li has been carried out at extreme backward angle in the energy range 14–20 MeV. Calculations considering a deformed compound nucleus and shell-corrected Gilbert-Cameron level density parameter agree well with the experimental data. Interestingly, statistical model calculations require the excited compound nucleus to be deformed for ^{6,7}Li + ^{6}Li reaction, but spherical for asymmetric n + ^{12}C target-projectile combination. This indicates some target-projectile dependence for the light particle evaporation spectra. This phenomenon though known for heavier systems has not been reported earlier for such light loosely bound nuclei. For further verification of this phenomenon, additional experimental data leading to the same compound nucleus, excitation energy and angular momentum are needed in both the symmetric and asymmetric channels.

Authors thank V. Tripathi, K. Mahata, K. Ramachandran and Pelletron personnel for their generous help during experiment and grant No. 2000/37/30/BRNS for funding.

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