Eurasian Journal of Physics and Functional Materials
2017, **1**(1), 30-34

Fusion and breakup fusion of ^{6}Li with ^{194}Pt at energies around coulomb barrier

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Received 25.10.2017

Results for fusion and breakup fusion reaction (^{6}Li+ ^{194}Pt) are presented and compared with other experimental data and model calculations. A strong isotopic effect is observed when comparing our data with results from (^{6}Li+ ^{198}Pt)

Keywords: fusion and breakup fusion; weakly bound projectile with cluster structure.

Introduction and motivation

In the approach phase of the two nuclei that are going to fuse, couplings appear between the relative motion and the intrinsic structure of the two colliding nuclei. These aspects have been extensively investigated from both theoretical and experimental point of view (see for example the paper [1] and the references therein). In the data analysis on fusion reaction, often reduction procedures are applied. These reductions have the role to bring to a common denominator data with various (but close) partners and energies such as to make appear what are the relevant differences in the parameters describing the fusion process [2]. A well known example is the strong isotopic effect observed in the sub barrier fusion of ^{16}O with various Sm isotopes [3,4]: the heavy isotope, ^{154}Sm, shows an important enhancement of the fusion cross section at sub barrier energies, in contrast to the lighter isotope ^{144}Sm. This effect is explained by the different collection of barriers appearing in the fusion process due to the coupling of the relative motion with various states in the target nuclei. An interesting aspect revealed by the treatment of fusion at near/below barrier energies as a quantum diffusion process is that some nuclei (in this particular case ^{154}Sm), in the approach phase can change their deformation from oblate to prolate, with the consequence of an enhancement of fusion at these energies. The experiment described below refers to the fusion of ^{6}Li with ^{194}Pt at energies around/below the Coulomb barrier. ^{6}Li is a weakly bound projectile with cluster structure (1.45 MeV binding energy against the decay into a deuteron and an alpha particle). For such projectiles sometimes an *enhancement* of the fusion cross section appears at energies below the barrier while at energies above the barrier *a decrease* of the fusion cross section is observed. The position of ^{194}Pt in the Chart of Nuclides is such that an activation experiment is feasible (most fusion-evaporation channels lead to radioactive Tl isotopes with lifetimes in the hours range). Besides, good experimental data exist for the reaction (^{6}Li+^{198}Pt) [6] and also for the reaction (^{7}Li+^{198}Pt) [7]. After a description of the experiment, the main results are presented together with model calculations using the coupled channel program CCFULL [8].

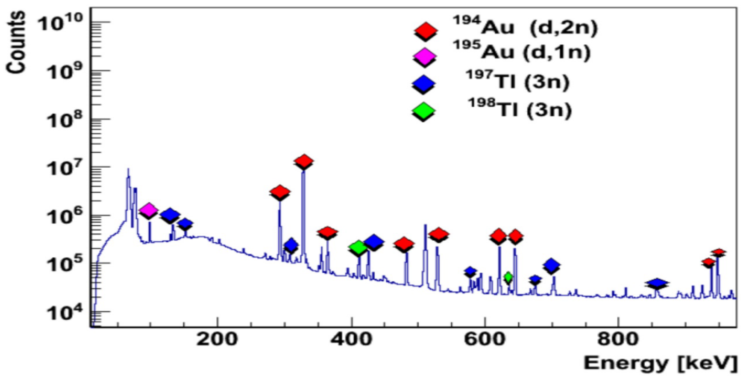

Figure 1. Gamma spectrum measured for activation at 28 MeV, the peaks of the most important channels both for the fusion evaporation channels (Tl isotopes) and for incomplete fusion with deuterium after the ^{6}Li breakup (Au isotopes) are marked with different symbols.

The experiment

*T*he reaction (^{6}Li+^{194}Pt) has been studied at the 9 MV Tandem accelerator of IFIN-HH-Bucharest. Platinum targets (6 pieces, 96.5% enrichment, 3 μm thickness) with a 3.7 μm Al backing (for collecting fusion products recoiling out of the target) were irradiated in a dedicated reaction chamber. The ^{6}Li energies were: 24.4, 26, 28, 30, 32 and 34 MeV, respectively. The beam monitoring was done by a Faraday cup with guard ring tested and calibrated in many previous experiments of such type. The integrated current was recorded by a digitizer (TNT card [9]) allowing a precise reconstruction of the irradiation history. The target uniformity was checked by the transmission method using a ^{241}Am alpha source and compared with SRIM simulations. The results of this test indicated anon-uniformity $\leq 3\,\%$ for all used targets.

The detection setup for activation measurements consisted of two HPGe detectors (100 % relative efficiency) placed in front of each other and shielded with lead bricks with a total thickness of minimum 10 cm. Two different geometries were used corresponding to the irradiated sample - detector distance of 10 and respectively 1 cm, respectively. Efficiency calibrations were done in both geometries. The two geometries were used in the case of high counting rates (detectors far from each other) obtained after irradiation at high energies and low counting rates (close geometry). The intermediate energies were measured in both geometries to check the consistency. Summing effects and dead time corrections were applied when necessary. Two data acquisition systems (DAQ) were used

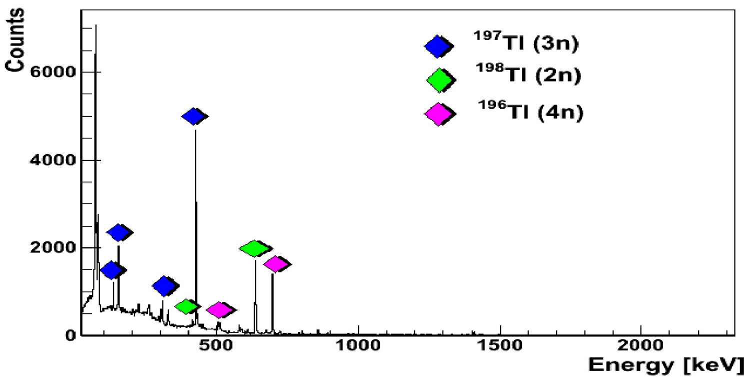

Figure 2. Gamma spectrum conditioned by the X-ray detection obtained for the activation measurement at 28 MeV.

in parallel, an analogical (spectroscopy amplifier, multichannel analyzer) and a digital one. The digital DAQ was a triggerless system based on TNT cards which recorded both the amplitude and the arrival time of the signals from the preamplifiers of the two HPGe detectors. The system used a trapezoidal algorithm for energy reconstruction and allowed to measure both singles and coincident events from the two HPGe detectors. Figure 2 shows such a coincident spectrum with the characteristic X-rays of Hg for the activation measurement at 28 MeV beam energy. The peaks for the low energy lines in ^{197}Tl lay on a much lower background which substantially reduces the error bars. A special case is represented by the incomplete fusion channel (α, n) which means fusion with deuterium followed by one neutron evaporation. The heavy residue is in this case 195Au with a half life of 186.1 days. Such a long lifetime makes the main decay line (98.8 keV in ^{195}Pt) very difficult to observe. After a long cooling time (723 days), the targets were remeasured with an ultra low background gamma spectrometer placed in a salt mine at a depth of 208 m.

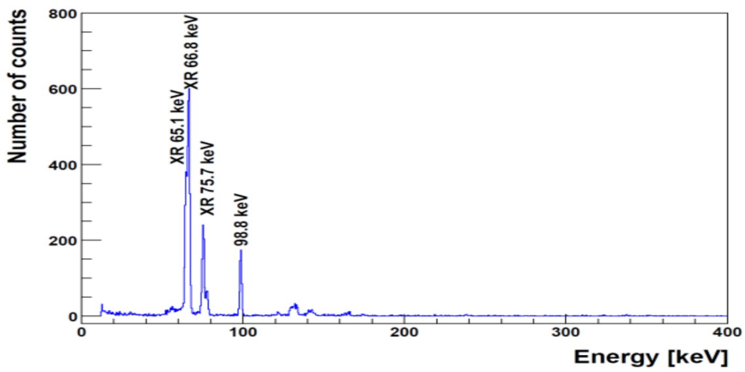

Figure 3. Salt mine gamma ray spectrum recorded after 723 days from the activation experiment.

The results were spectacular: figure 3 shows the spectrum measured for only 3250 seconds and a neat peak is observed over a small background at 98.8 keV.

The mean value of (5.44 ± 0.16) fm is in a reasonable agreement with the ^{13}C ground-state radius of (5.22 ± 0.09) fm. The latter method for estimating the radius is certainly promising, but still involves large uncertainties.

Results and discussion

The main results of the presented experiment are the cross sections for the most important fusion-evaporation channels (2n, 3n, 4n) that served to obtain the total fusion cross section for ^{6}Li energies in the range 24.5 till 34 MeV (figure 4). Also, the cross sections for the incomplete fusion channels with deuterium (from the ^{6}Li breakup) followed by one and two neutron evaporation (the main channels for d capture) were measured. Their sum provides the breakup cross section (d capture) which is also illustrated in figure 4. The d-capture cross section dominates over the total fusion cross section. It is interesting to make a comparison between the results obtained in the present work and those obtained for a similar study made on the heavier isotope ^{198}Pt [6].

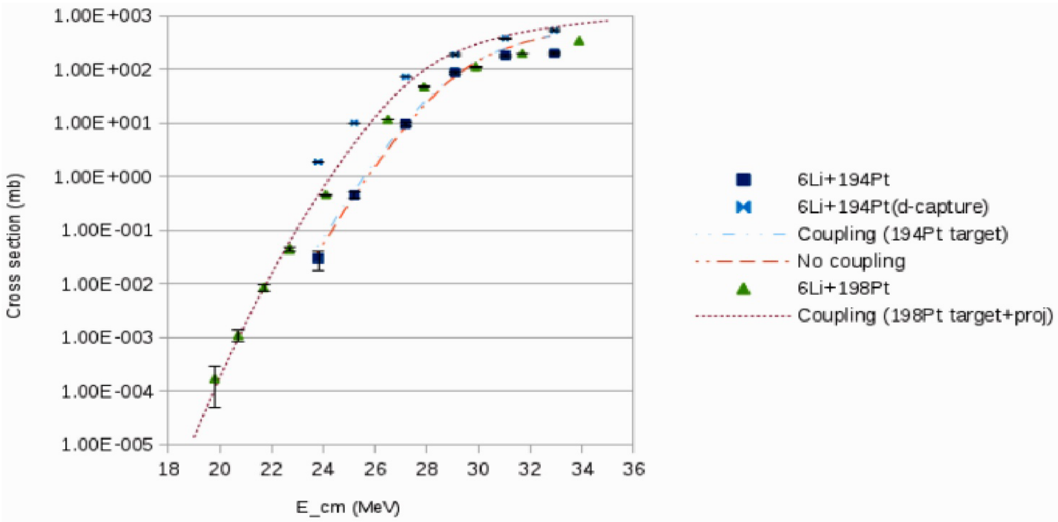

Figure 4. Experimental d-capture and total fusion cross sections compared with the (^{6} Li+ ^{198} Pt) [6] data and CCFULL results.

A marked enhancement of the below barrier cross section is observed for the reaction on ^{198}Pt as compared with ^{194}Pt. This is true for both d capture and total fusion cross section. Such an isotopic effect was already observed in the interaction of ^{6}Li projectiles with Sm isotopes [10]. In the frame of a quantum diffusion treatment, the effect was put on the account of a deformation change of the target (from oblate to prolate) that takes place in the approach phase [5]. To make the comparison easier to follow, figure 4 shows the experimental results for ^{6}Li fusion with ^{194,198}Pt, together with calculations with and without coupling. One can see that in the case of ^{194}Pt the data are well reproduced with coupling of only target states and that this coupling brings only a small correction compared to the uncoupled calculations (single barrier). Differently, the calculations for ^{198}Pt need to include also projectile couplings (the unbound $\{3^+\}$ state) in order to reproduce the measured data. The subtle nature of couplings that take place when the two nuclei come close to each other in the fusion process is yet far from being completely understood and for this reason, making predictions before measurement is hazardous. Nevertheless, few considerations about the energetic of the process (Q values) may give a hint about the fate of the process. It was already remarked [11] that neutron transfer channels with positive Q value may enhance the fusion probability. Let us follow this idea for the case of a sequential fusion of the two clusters that form ^{6}Li. The Q values for the d capture are 9.5 MeV for ^{194}Pt and 10.5 MeV for ^{198}Pt, both large positive values, slightly higher for 198 Pt, which explains the high measured d capture cross sections (the dominant channel at below barrier energies). The subsequent process in which the fused products (^{196}Au, ^{200}Au) capture the remaining alpha particle has negative Q values of -1.67 MeV and - 0.5 MeV respectively. If we imagine a sequential fusion scenario in which the approaching ^{6}Li first breaks into (d+ α), d fuses leading to a highly excited nucleus (therefore with a *higher diffuseness*) that captures the alpha particle in the last stage, then obviously the higher observed sub-barrier fusion cross sections for ^{198}Pt will be favored. In conclusion, the complete and incomplete fusion of ^{6}Li with ^{194}Pt was measured, using the activation technique. The results, when compared with the reaction (^{6}Li+ ^{198}Pt) [6] indicate a strong isotopic effect, known already for the Sm isotopes. Coupled channel calculations including only target excitations are sufficient to reproduce the data at energies below/around the Coulomb barrier. In a sequential breakup fusion mechanism, the implied Q values seems to favor the sub barrier enhancement of the fusion cross section of the heavier isotope.

Acknownledgments

This work was partially supported by the Romanian Ministry of Education through contract number PN-II-ID-PCE-2011-3-0370 (UEFISCDI).

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