Alpha-Particle Emission in the Interaction of ^{14}N with ^{59}Co at Incident Energies of 250 and 400 MeV

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Introduction

In the present work, the results of measured inclusive double-differential cross sections of α-particles emitted in the interaction of ^{14}N with ^{59}Co at incident energies of 250 and 400 MeV are presented. The experimental data were collected in a wide angular range, from 8 to 120 degrees in the laboratory system. The analysis of these data suggests that the measured α-particle spectra contain contributions originating from various reaction mechanisms, all of which are important at these relatively high energies. We compare our results with those of a similar experiment [1] using ^{12}C as projectile, with the same target nucleus and a similar energy range. A comparison is also made with theoretical model-code predictions based on the equilibrium and pre-equilibrium reaction mechanisms.

A new modification of the statistical code PACE was developed by O.V. Fotina *et al.* [2] based on Griffin's model of non-equilibrium processes to describe the spectra of nucleons and other light particles emitted in the non-equilibrium stage of compound nucleus formation. Those authors also took into account the contribution coming from the equilibrium stage of the process within the framework of the statistical model. For this purpose, the statistical code PACE was modified to accommodate pre-equilibrium processes for the estimation of double-differential cross sections. Furthermore, the probable effect of the clustering process of the projectile nucleus on the yield of secondary α-particles was added [3].

Experimental procedure

Beams of ^{14}N ions with energies of 250 and 400 MeV were delivered by the k200 cyclotron of iThemba LABS, South Africa. A description of this facility and its associated experimental equipment may be found elsewhere [4]. The targets were mounted in aluminium frames with 25 mm diameter apertures. Targets of ^{93}Nb with different thicknesses (1.72 mg/cm^2 and 2.65 mg/cm^2) were used in the measurements at, respectively, 250 and 400 MeV incident energy. The thickness of the ^{59}Co target was 1.00 mg/cm^2. The target thicknesses were confirmed by means of the energy loss of α-particles from a ^{228}Th source, to an accuracy of better than 5%. Standard fast coincidence electronics and an online computer were used to acquire and store the event data stream. Corrections for electronic dead time were based on pulses which were fed to the preamplifier test inputs. The overall systematic uncertainty of the absolute cross-section values is estimated to be less than 10%.

Results and Discussion

Fig. 1 shows α-particle spectra at various angles in the reaction of ^{14}N with ^{59}Co at 250 MeV. It is observed at very forward angles (8˚-15˚) that the cross section remains almost constant with a very broad maximum around 100 MeV, beyond which a gradual decrease is observed. These broad maxima and high energy tails are interpreted as the signature of non-equilibrium (direct) emission of α-particles. At larger angles, however, the broad maxima disappear and the cross section decreases rapidly with α-particle energy. It is observed that towards larger angles, the contribution from break-up followed by incomplete fusion (ICF) and other non-equilibrium phenomena become dominant, which are responsible for the high-energy tails. We have compared our experimental results with predictions by means of the modified PACE code (see Fotina et al. [2]) taking into account equilibrium and pre-equilibrium processes.

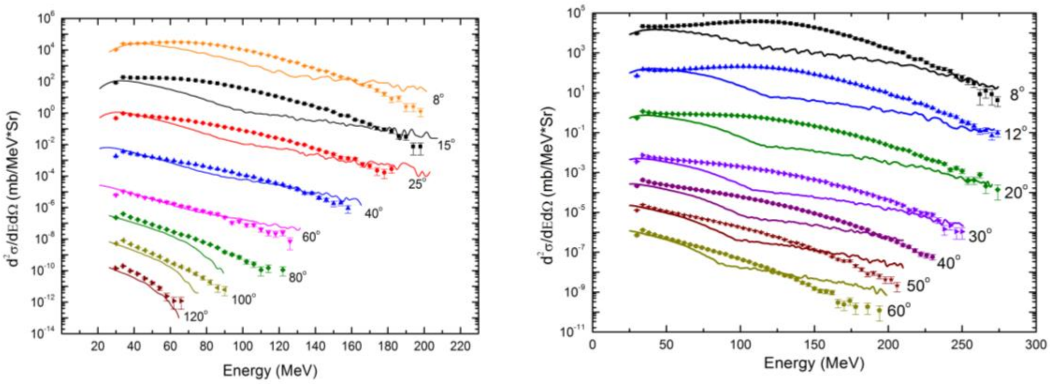

Fig. 1: *Comparison of experimental α-particle spectra (symbols) with predictions by means of the modified PACE code (solid lines) for the ^{14}N + ^{59}Co reaction at 250 MeV (left) and 400 MeV (right). The spectra have been scaled, for the purpose of clarity, by successive decades.*

At forward angles (15˚ and 25˚) there is a large underestimation by the code as in this region the contribution from multi-step pre-equilibrium processes of de-excitation is probably very much dominant, which is not taken into account in the present model code. Also, perhaps underestimating the yield of α-particles in the energy region around 100 MeV is associated with a significant fraction of the fission process (5 % for the ^{14}N + ^{59}Co reaction at 250 and 10 % at 400 MeV according to PACE estimates). There may be a possibility of α-particle emission from break-up reaction or other non-equilibrium mechanisms. In the present experimental results, such "alpha emissions" have not been excluded. At still larger angles (backward angles), the contribution from pre-equilibrium emission also becomes negligible as mostly only those α-particles emitted in the equilibrium state/complete fusion (CF) state persists.

Fig. 2 shows alpha-particle spectra for the same reaction at 400 MeV incident energy for angles ranging from 8˚- 60˚. Here also we see the similar trend in experimental results but the underestimation by modified PACE calculation is more pronounced. This was expected as at higher incident energy the contribution from multi-step pre-equilibrium processes further increases. The inability of modified PACE [2] to take into account this mechanism has only broadened the difference between experimental and calculated results.

Conclusions

From the experimental data, we can conclude that at such high energies the maximum contribution to the α-particle spectra comes from non-equilibrium mechanisms (ICF and pre-equilibrium) and also by CF at the most backward angles. The pre-equilibrium and equilibrium contributions are of the same order. The α-particle emission from direct processes is dominant at very forward angles (below 20˚).

We tried to reproduce these results using ALICE2014 as in our earlier work [5] but this was far from satisfactory. In contrast, PACE, modified to include pre-equilibrium and cluster formation probabilities, gave much better agreement. The predictions still exhibit large underestimation at small emission angles but the overall agreement is much improved. More refinement may lead to even better results.

References

[1] E. Gadioli *et al.*, Nucl. Phys. A 654 (1999), 523.
[2] O. V. Fotina *et al.*, Int. Jour. Mod. Phys. E 19, 1134 (2010).
[3] D. Fabris *et al.*, Acta Phys. Polonica B 46, 447 (2015).
[4] J.V. Pilcher *et al.*, Phys. Rev. C 40 (1989) 1937.
[5] J. Acharya *et al.*, Phys. Rev. C 97 (2018), 034607.