FR9700881

Decay patterns of Target-like and Projectile-like Nuclei in $^{84}Kr+^{197}Au$, ^{nat}U Reactions at E/A=150 MeV*

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Abstract:

The reactions $^{84}Kr+^{197}Au$ and $^{84}Kr+^{nat}U$ were studied at E/A=150 MeV employing the large-volume neutron multiplicity filter ORION at SATURNE. The observed correlations between the atomic number of projectile-like nuclei and neutron multiplicity indicate large excitation energies in the primary projectile- and target-like fragments. Angular correlations between the fission fragments of the U-like nucleus and the projectile-like fragments show a memory of the reaction plane, however no indications of spin effects are found.

The aim and context of this experiment

This experiment is part of an extensive programme which aims at investigating simultaneously the dissipation of translational energy into heat and the transfer of orbital angular momentum into intrinsic spin of the interacting nuclei in an extended energy domain. Data have been obtained for such a system at barrier energies[1)] and more recently at GANIL at E/A=35 MeV[2)]. It was thus interesting to complement the data at much higher energies where the dissipation mechanism is expected to be quite different. For this purpose the experiment was carried out at the National facility SATURNE where Kr could be accelerated at energies exceeding those available at GANIL. The Kr projectile is massive enough for the interaction with the target nucleus to be followed over a broad range of impact parameters through some leftover from the projectile. Two massive target nuclei were chosen: a highly fissionable one to study fission, very sensitive to spin effects, and a complementary target -Au- to get rid of the backing/impurities of any U target.

The experimental set-up (Fig.1)

The large efficiency, $4m^3$ scintillator detector ORION, was utilized in order to measure on an event-by-event basis the number of emitted neutrons and thus get a relevant information about the violence of the collision or associated dissipated energy. Due to the sectorization of the detector, spatial information could also be provided. The projectile-like nuclei, all with velocities close to that of the beam, were identified in Z and localized in Θ and Φ by means of a pair of annular strip Si-detector (annular and radial strips) mounted as a telescope with the beam passing through its central hole. As for the fission fragments, they were detected in coincidence by their energy loss and relative time of flight and located using two standard PPAC detectors set vis à vis and parallel to the beam direction. The fission events are thus characterized by a large set of observables: the total and differential neutron multiplicity, the atomic number and the polar and azimuthal angles Θ and Φ of the projectile-like nucleus, the Θ and Φ of the two fission fragments issued from the target nucleus making possible kinematical reconstruction of the fissioning nucleus.

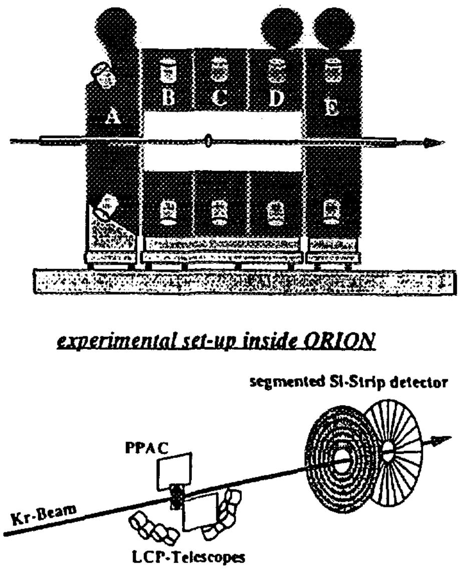

Fig.1. Schematic view of the experimental set-up

In addition to the previous detectors a set of nine silicon telescopes was aimed at the detection of light charged particles from 15 to 150 degrees.

Energy dissipation

The most sensitive data in order to infer the energy deposition are shown in Fig.2 where the measured average neutron multiplicity (filled squares) are given for the five sectors of ORION and the whole detector as a function of the Z of the outgoing projectile-like nucleus. These data have been checked against a two-step model including an Intra Nuclear Cascade step (described by the ISABEL computer code)[3] followed by the GEMINI[4] evaporation code for three contributing sources (the Pre-Equilibrium Particles, the Target-Like Nucleus and Projectile-Like Nucleus). Care is taken to include in these results the production of secondary neutrons generated by the primary reaction products in all materials of the reaction chamber, scintillator tank, shieldings and walls of the cave by employing the CERN-developed code GEANT/FLUKA[5]. Finally the neutron detection efficiency of ORION is taken into account to fold the calculated data and make them directly comparable with the measured ones.

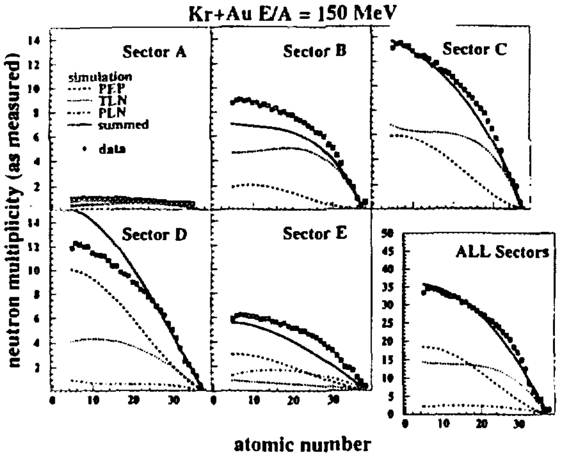

Fig.2. Comparison between the simulations and the experimental data (see text).

Such calculations lead to a general large over-estimate of the neutron multiplicity values and a factor of 0.4 has to be applied on the excitation energies generated by ISABEL in order to mach the measured neutron multiplicities. The overall agreement can then be considered as satisfactory. The detailed contribution of Projectile-like (PLN), Target-like Nuclei (TLN) and the Pre-Equilibrium Particles (PEP) to the total neutron multiplicity is shown in Fig.2. It has also been checked that the multiplicity of evaporated like charged particles from the TLN (inferred from the backward data) is in reasonable agreement with those deduced with the reduced excitation energies.

Mean E*/A of 1.1, 2.1, 3.2 and 5 MeV are thus deduced for TLN in coincidence with final PLN of Z=30, 25, 20 and 15 respectively, showing the efficient heating of nuclei following rather peripheral collisions of 150 MeV/A Kr with U. This confirms, at least qualitatively, the findings of previous high-energy experiments[6]. Clearly the interacting nuclei do not act as mere spectators at high bombarding energy.

Fission for probing the spin effects

With the U target, fission was observed for 47% of the total reaction cross section which makes this decay process a significant probe for the primary nucleus-nucleus interaction. The fission probability has been studied as a function of average Z of the outgoing PLN and associated neutron multiplicity. It shows a maximum close to 1 for PLN with Z=34 to 23 (associated measured neutron multiplicities from 10 to 30, respectively). For higher Z values of the PLN, fission becomes more and more unlikely but still represents a 20% probability for PLN with Z=15.

The coincidence events between the PLN and the two fission fragments of the TLN show that, despite the small scattering angle values at which most of the PLN are detected (close to the grazing angle of 0.9 degrees), a kinematical effect is preserved on the average between the PLN and the reconstructed TLN. As a consequence the plane containing the beam axis and the PLN velocity vector can be considered as the reaction plane and the fission process can be used to search for spin effects.

Whatever the violence of the collision -selected by the neutron multiplicity- no alignment or a weak alignment of the spin with the plane perpendicular to the fission plane has been observed as already noticed elsewhere[7]. This can be taken as an indication that the mechanism of generating spin and excitation energy in residual nuclei at such bombarding energies must be quite different from, e.g. binary dissipative collisions prevailing at lower bombarding energies.

Summary

For the first time, neutron multiplicity measurements were used for studying collisions between heavy nuclei at relativistic bombarding energies. Average secondary Z's of PLN and alpha-particle multiplicities were described qualitatively as a function of neutron multiplicity assuming an Intra Nuclear Cascade followed by evaporation, provided the predicted excitation energies are reduced by a factor 0.4. Large thermal energies (up to E*/A=5 MeV) are deposited in the TLN. Fission is observed up to high excitation energies in the Kr+U interaction. No indication of spin effects on the angular distribution of fission fragments was found in contrast with what is observed at smaller bombarding energy.

References

* A detailed account of the present data can be found in Nucl. Phys. (in press)
1) D.v.Harrach et al., Phys.Rev.42 (1979) 1728
2) M.Josset et al., this volume
3) Y.Yariv and Z.Fraenkel, Phys. Rev. C20 (1979) 2227, C24 (1981)488
4) R.J.Charity et al., Nucl. Phys. A483 (1988)371
5) CERN application software Group GEANT, CERN long Writeup W5013, 1993
6) C.Stéphan et al. , Phys. Lett. B262 (1991)6
7) W.Trautmann and the ALADIN collaboration, GSI-Nachrichten 07-93