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Short note

Excitation energy partition in deeply inelastic collisions between ^{40}Ar and Ag at 27 MeV per nucleon*

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Abstract : The dynamics of the two partners produced in dissipative collisions has been experimentally studied for the system ^{40}Ar + Ag at 27 MeV per nucleon. Primary masses of the fragments can then be calculated ; the excitation energy partition between the two fragments is derived from the number of particles evaporated by each fragment. We found that this division evolves from equipartition to a repartition close to thermal equilibrium in the excitation energy range 300-350 MeV or interaction times 5-10×10^{-22} s.

The conversion of relative kinetic energy into heat during the lifetime of the dinuclear complex formed in damped heavy-ion reactions has been largely studied at low energies during the last fifteen years$^{1-2)}$. Of particular interest is the question of how heat, or excitation energy, is partitioned between the partners. The answer was given recently$^{3,4)}$: for small damping (≃ 50 MeV) an equipartition of excitation energy is observed and, as the system progresses towards large damping (150-200 MeV), it approaches thermal equilibrium. Clearly the lifetime of the intermediate dinuclear complex formed is too short (a few 10^{-21} s) to attain a complete thermal equilibrium between both partners. This evolution is satisfactorily reproduced by stochastic nucleon exchange models$^{5-6)}$.

With the persistence of dissipative collisions at incident energies as high as about 30 MeV per nucleon$^{7-8)}$ it is very interesting to study the evolution of the excitation energy partition. Indeed shorter lifetimes of the intermediate complex are involved but also nucleon-nucleon collisions play a much more important role in the heating of the system.

This study was done on the ^{40}Ar + Ag system at 27 MeV per nucleon through an exclusive experiment between the two partners of dissipative collisions. The experimental technique and the set up as well as the data reduction to derive the relative velocity of the two partners and the recoil velocity of the intermediate complex have been described elsewhere$^{9-7)}$. As observed at low energies the emission angle of the light partner, relatively to the grazing angle, is directly connected with the degree of relaxation of the interacting system. However from the recoil velocity of the intermediate complex which is found to differ from the center of mass velocity, we infer the presence of preequilibrium particles emitted early during the collision. This fact as well as the presence of dissipative collisions is well sustained by semi-classical calculations based on the Landau-Vlasov equation which well reproduced our experimental observables (recoil and relative velocities)$^{8)}$. We recall that in this theoretical approach the interplay between mean field features and two-body collisions is taken into account.

Experimentally, we were not able to disentangle preequilibrium particles from particles evaporated by the light partner. Then we derived from semi-classical calculations the number of preequilibrium nucleons A_{PE} as well as the total energy removed by these nucleons E_{PE} as a function of impact parameter measured by the recoil velocity of the intermediate complex$^{10,11)}$. In this way and from the experimental knowledge of dynamics of the two partners, primary masses :

$$A'_L = \frac{A_{TOT} - A_{PE}}{\sin \theta_L} \left(\frac{<V_L>}{\sin <\theta_H>} + \frac{<V_H>}{\sin \theta_L} \right)^{-1}$$

of different final light partners (with atomic number Z_L : 5-12) and total excitation energy :

$$E^* = \text{Total Kinetic Energy Loss} - E_{PE} + Q$$

were deduced. The quantity A_{TOT} refers to the total mass of the system and only mean quantities are used in calculating A'_L. At each value of θ_L, the most probable angle of the correlated heavy partner, $<\theta_H>$, was determined as well as the associated mean velocities $<V_L>$ and $<V_H>$ which are supposed not modified by the deexcitation of light and heavy partners. Note that A'_L are only calculated for $\theta_L \geq 15°$ (to suppress bias due to strongly peaked angular distributions) and do not suffer the relevant remarks from ref.$^{12)}$. Concerning E^*, Q refers

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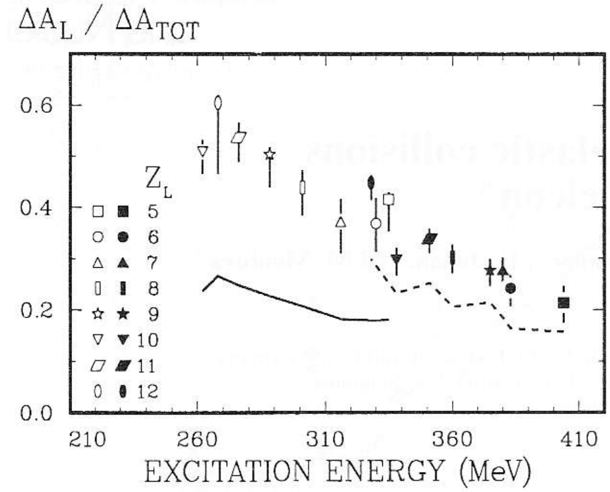
* Experiment performed at the GANIL National Facility in Caen, France



Ratio of the number of evaporated nucleons by the light partner to the total number of evaporated nucleons for different atomic numbers of the detected light partners. Open (full) symbols refer to $\theta_L=15°$ *(30°). Full (dashed) line indicates, for* $\theta_L=15°$ *(30°) the derived ratios* $A'_L/(A_{TOT}-A_{PE})$ *which are expected for a thermal equilibrium. Error bars come mainly from uncertainties in determining the velocity and the most probable angle of the heavy partner.*

to the mass balance and we have to mention that primary masses of heavy partners A'_H were derived from :

$$A'_H = A_{TOT} - A_{PE} - A'_L.$$

Then the number of nucleons evaporated by the light partner ΔA_L was normalized to the total number of evaporated nucleons :

$$\Delta A_{TOT} = A_{TOT} - A_{PE} - A_H - A_L.$$

The quantity A_H refers to the measured heavy mass and A_L is taken equal to $2\ Z_L + 0.5$. The figure shows the evolution of $\Delta A_L/\Delta A_{TOT}$ for different degrees of relaxation characterized by two detection angles θ_L = 15 and 30° and different Z_L : 5-12, as a function of the total excitation energy. The values observed, which reflect the energy partition provided that evaporated nucleons from light and heavy partners carry away in average the same energy (which was verified by simulations), are found to evolve from energy equipartition for total excitation energy close to 260-290 MeV to a repartition close to thermal equilibrium for total excitation energy larger than 350 MeV (lines in figure). Note that the above hypothesis on preequilibrium emission affects the values of the total excitation energy but not its repartition. From the direct correspondence between θ_L and the impact parameter (or recoil velocity) obtained from semi-classical calculations[8], we can deduce interaction times in the range $5\text{-}10\times10^{-22}$ s. As compared to low energies we observe a shortening in time to approach a thermal equilibrium in dissipative collisions. This shortening has to be connected with the enhancement of two body collisions which reduce the energy relaxation time[13].

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