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# Isospin dynamics and nuclear dipolar degree of freedom

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**Summary.** — The strong connection between the dipolar signal as obtained from the measured velocities and charge of all fragments produced in a heavy collision and the dynamics of the isospin equilibration processes is illustrated. Effects due to both statistical and dynamical mechanisms are shortly discussed. Experimental data related to semi-peripheral collisions induced on the $^{48}$Ca + $^{27}$Al at 40 MeV/nucleon system are also shown and compared with CoMD-III calculations.

## 1. – Introduction

It is well known that in the Fermi energy domain the Heavy Ions collisions are interpreted phenomenologically through a fast pre-equilibrium stage described using dynamical models and later-stage processes described by statistical decay models. The two stages involve rather different densities and excitation energies being the dynamical stage able to populate the most exotic regions of Nuclear Matter (even if for short time). This will produce a kind of mixing effect in the parameter values governing the density dependence of the effective interaction which is the basic quantity in every model aiming to describe the collision process. Taking as much advantage as possible of the today's high efficiency multi-detectors, the measure of observables in principle closely linked to only the dynamical stage can represent a step forward in the studies related to the effective interaction. In particular in this paper we discuss on the Isospin equilibration phenomenon closely linked to the density dependence of the Symmetry Energy and leading to the redistribution in momentum-space of the charge/mass excess $\beta = (N - Z)/A$ of the emitted particles and fragments.

 

## 2. – Statistical models and Isospin

To better understand the need to separate the effects produced by the two reaction stages we shortly recall some works studying the role played by Isospin in the statistical decay processes. In the Fermi Energy domain, for peripheral and semi-peripheral collisions the angular correlations can help disentangling statistical effects from the dynamical ones, while in multi-fragmentation or in more central processes the separation can be rather problematic (see for example [1] ). Statistical decay determines the final cooling mechanism of the hot sources already starting from an excitation energy of the primary sources of about 2-2.5 MeV/A and this clearly determines the charge/mass of the final products. In statistical models Isospin affects the level density and temperature producing remarkable effects on light charged particles multiplicity [2]. The multi-step cascade (first step or last step) heavily affects the isoscaling parameters which are widely used to describe the ratio between charge-mass distributions of fragments produced in collision between similar systems. As a consequence this dependence is transferred to the value of the Symmetry Energy which is computed from the above parameters [3]. All these dependences clearly produce in many cases an heavy blurring effect of the primary effects produced in the dynamical stage.

## 3. – The Dipolar Signal

Triggered by the need to clearly disentangle the dynamical from statistical stage we decided to investigate the derivative of the average total dipole in the final configuration $\langle \overrightarrow{D} \rangle$; by using the measured charge $Z_i$ and velocities $\overrightarrow{V}_i$ of the different fragments produced trough the collision we obtain:

$$\langle \overrightarrow{D} \rangle = \langle \sum_{i=1}^{m} Z_i (\overrightarrow{V}_i - \overrightarrow{V}_{c.m.}) \rangle_{\mathcal{K}}. \tag{1}$$

The brackets indicate the average value over an ensemble $\mathcal{K}$ of selected events. $\overrightarrow{V}_{C.M}$ is the center of mass (C.M.) velocity and $m$ is, event by event, the number of charged fragments.

The interest on this quantity is due two main reasons:

a) as shown in refs. [4], [5], [6], this quantity is closely linked with charge/mass equilibration process because it represents the average time derivative of the total dipolar signal in the asymptotic stage (expressed in unit of $e$). As shown from dynamical microscopic calculations in a collision process between two nuclei 1 and 2 having different charge/mass asymmetries, $\mid \langle \overrightarrow{D} \rangle \mid$ changes in time from the value $\langle \overrightarrow{D} \rangle \equiv \overrightarrow{D}_m = \frac{1}{2}\langle \mu \rangle (\langle \beta_2 \rangle - \langle \beta_1 \rangle)(\langle \overrightarrow{V}_1 - \overrightarrow{V}_2 \rangle)$ to smaller values in the pre-equilibrium stage reflecting the spontaneous approach to the equilibrium.

b) because of the symmetries of the statistical decay mode, $\langle \overrightarrow{D} \rangle$ is not affected by the statistical emission of all the produced sources in later stages. This essentially happens because, due to the vectorial character of this quantity, for well reconstructed events statistical effects by definition are self-averaged to zero [4], [7]. Therefore $\langle \overrightarrow{D} \rangle$ is a rather well suited global variable to selectively evidence dynamical effects related to the Isospin equilibration process.

To better illustrate this in Fig.1 we show as function of time the average dipolar signals and density in the C.M. of the $^{48}Ca + ^{27}Al$ colliding system. The calculations

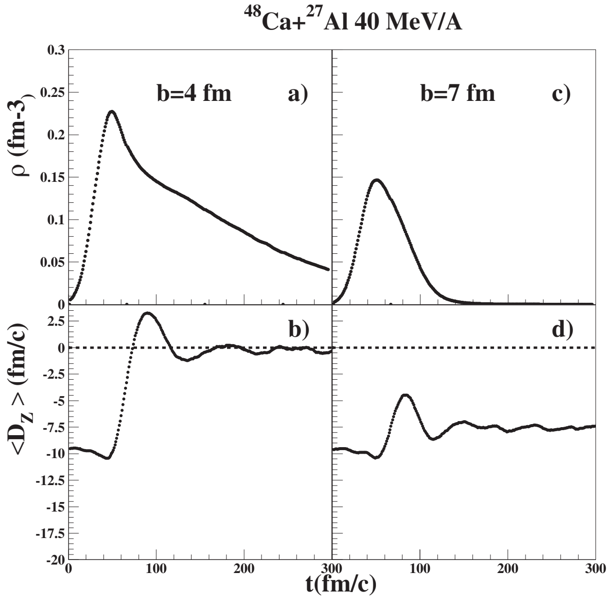


Fig. 1. – CoMD-III calculations for the $^{48}Ca + ^{27}Al$ system. The Dipolar signal and the C.M. average density are plotted as a function of time for two different impact parameters

are performed with the CoMD-III model [8], [9]. We can see that the average dipolar signal reaches a constant value in a relatively short time interval (about 100 fm/c) even though the cooling mechanism of the hot sources go on for longer time. From the plot of the density it is also seen that for more central collision the average density reached is about 60% higher than in the semi-peripheral one.

## 4. – Experimental results and comparison with model calculations

The experimental investigation on this subject [8] was performed for the first time on the $^{48}Ca + ^{27}Al$ system at 40 MeV/A with the multi-detector CHIMERA [10], [11] at the LNS laboratories. In this first stage of investigation we have measured the effective partial dipolar signal $\langle D^c_Z \rangle$ along the beam axis. This reduced value of the dipolar signal is obtained by substituting, event by event, the true center of mass velocity appearing in the definition of $\langle D_Z \rangle$ with the one associated to the subsystem formed by all the identified charged particles. In this way possible systematic errors are eliminated.

Final results are shown in Fig. 2 (panels a,b,c) where we plot as red points $\langle D^c_Z \rangle$ as a function of $Z_b$ (the charge of the biggest detected fragments) for a total kinetic energy loss less than 350 MeV. In the different panels we show as black points the calculated value according to CoMD-III+Gemini [9] calculations. $\langle D^c_Z \rangle$ shows a good sensitivity to the parameters of the effective interaction. The comparison allows to establish a good agreement with experimental data for an iso-vectorial stiffness parameter $\gamma \simeq 1$ and a Symmetry Energy at the saturation point equal to 32 MeV. To recover information on the global degree of Isospin equilibration we evaluated $\langle D_Z \rangle$ through calculations by using the same set of parameters which gives the best agreement for the reduced value $\langle D^c_Z \rangle$ the corresponding comparison is shown in Fig.2 (panel d). The difference between

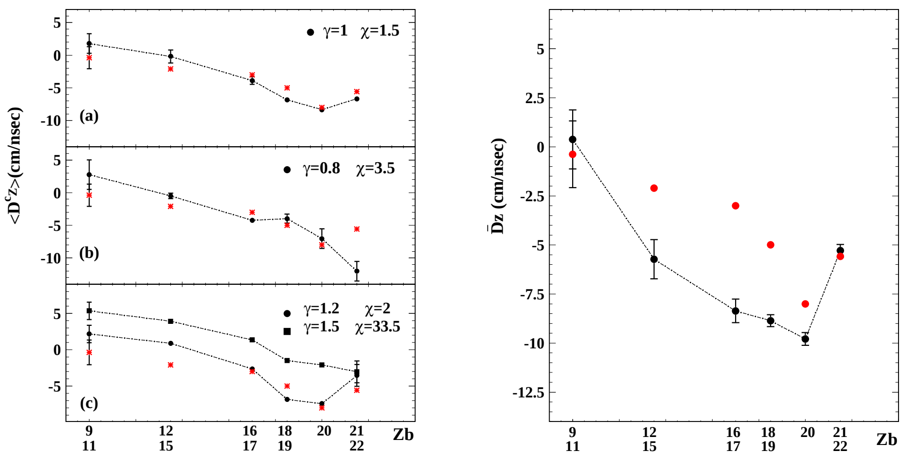


Fig. 2. – On the left part a comparison of the measured value of $\langle D_Z^c \rangle$(red point) with CoMD-III calculations made for different parameter values is performed. On the right $\langle D_Z^c \rangle$ is compared to the calculated $\langle D_Z \rangle$.

the two quantities (red and black points in Fig.4) moreover give us an estimation of the effect associated to the undetected free neutrons which clearly participate to determining the global degree of Isospin equilibration.

## 5. – Conclusive remarks

Recently a new campaign of measurements had been performed for the same system and for the symmetric one $^{40}Ca + ^{40}Ca$ at 40 MeV/nucleon at LNS with the CHIMERA multi-detector. The improved detector performances should permit to explore also the more central collisions(higher density). Moreover,the information coming from the symmetric reference system will allow $\langle D_Z \rangle$ to be corrected for possible systematic errors and to obtain therefore a direct measurement of the global effect produced by the neutron emission on the Isospin equilibration process.

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