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Stopping power as a signature of dissipative processes in heavy-ion collisions

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Summary. — In heavy-ions collisions different observables have been studied in order to get an insight about dissipative processes taking place in the excited nuclear system. Among them, we can focus on the ratio between the transverse and longitudinal kinetic energy components, or stopping power R_E. A substancial reduction of this quantity has been recently evidenced by the INDRA collaboration at incident energies between 32 and 100 A MeV, for various symmetric systems. In this work, the impact of σ_{nn} on the stoping power R_E is studied in the framework of the microscopic DYWAN model. Calculations have been performed in Xe+Sn central collisions at incident energies between 45 and 100 A MeV, where the theoretical values are shown to be more sensitive to σ_{nn}. They are compared with experimental data and with the results of the semiclassical Landau-Vlasov model.

1. – Introduction

Nuclear matter properties can be probed through the analysis of pertinent observables in heavy-ions collisions. One of them is the stopping power R_E, defined as the ratio between transverse and longitudinal kinetic energies. This observable is a measure of the transfer of energy from the initial entrance channel to the intrinsic degrees of freedom [1,2] and can be related to the nucleon-nucleon cross-section σ_{nn}. Transport characteristics should give new insights on the competition between the mean-field and the individual two-body collisions, notably when studying the dissipation of the available energy.

In this work, the behavior of R_E in terms of σ_{nn} in heavy-ions collisions at intermediate energies is investigated in the framework of the DYWAN (DYnamical WAvelets in Nuclei) model. This approach is based on the microscopic Extended Time-Dependent Hartre-Fock description using wavelets analysis techniques [3].

2. – The stopping power

The isotropy ratio R_E is defined as

$$R_E = \frac{\Sigma E_{tran}}{\Sigma E_{long}}, \tag{1}$$

where E_{tran} and E_{long} are, respectively, the transverse and the longitudinal energy components of the reactions ejectiles. R_E can vary between two extremes values: it equals one in the case of isotropic emission and is lower than one, for small energy transfers at the entrance channel. We can estimate this limit by calculating the stopping power with the Fermi gas model. Let us consider two perfect Fermi spheres, separated one from the other by the initial relative momentum $p(E_{inc})$, which depends on the initial incident energy E_{inc}. Within the Fermi model, R_E is given by the following expression:

$$R_E(E_{inc}) = \frac{1}{1 + \alpha \frac{5}{4} \frac{E_{inc}}{E_F}}, \tag{2}$$

where E_F is the Fermi energy.

Increasing α from zero to one, the stopping power changes from the isotropic case to the limit of transfers. The experimental data of the system Xe + Sn at E_{inc} between 15 and 100 A MeV [1] show a reduction of R_E with the increase of the incident energy and reach a minimum around the Fermi energy. At higher energies, the stopping increases and seems to saturate.

3. – Theoretical results

In order to study the effects of the nucleon-nucleon cross-section on the stopping power, we simulate in-medium effects as suggested in ref. [1] by multiplying the cross-section by a global factor F taking values between 0 and 1. The implemented energy and isospin-dependent nucleon-nucleon cross-section was proposed by Chen in ref. [4]. To extract the R_E values, we select the emitted particles by excluding the quasi-projectile and the quasi-target in binary collisions or, in the case of fusion, the remaining residue. As shown in fig. 1, for each value of F, the stopping power decreases with the energy and seems to saturate for the values of E_{inc} above 90 A MeV. Furthermore, we observe a global decrease of the stopping with the energy above 50 A MeV with the diminution of the F factor. As shown in fig. 1, the "entrance channel" R_E value, that is the initial value of the stopping power and which is supposed to depend only on the incident energy, is lower than expected. This is related with the fact that the Fermi energy, extracted by fitting our numerical results with eq. (2), is 32 MeV. Due to this low E_F value the simulation resultats, represented by the solid orange line, is shifted downwards with respect the reference courbe, in dashed line.

In fig. 2 the factor F is displayed as a function of E_{inc}. Experimental data are in full dots and the semiclassical Landau-Vlasov model yields in open squares. In order to comply the theoretical values of the correction factor F with the experimental data we applied the procedure of ref. [2], which consists in browsing up and down the range of F values compatible with the experimental errors for each energy. This method gives the mean value (solid line) and the corresponding uncertainty (blue zone).

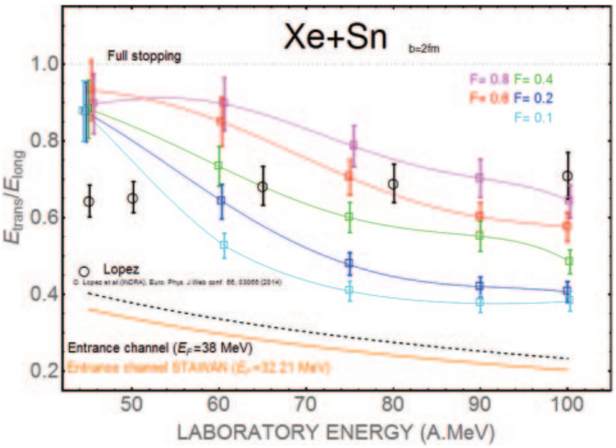

Fig. 1. – Influence of the nucleon-nucleon cross-section through the in-medium factor on the nuclear stopping. The R_E is calculated with the free distributions functions, after the geometric-exclusion of the biggest clusters.

We can observe that the DYWAN results show a fast increase of the F factor compared to the semiclassical Landau-Vlasov model [2] and to the experimental data [1]. Nevertheless, this two approaches support an increase of the "in-medium" factor F as a function of the system energy. Moreover we can conclude on a significant diminution of σ_{nn} around E_F.

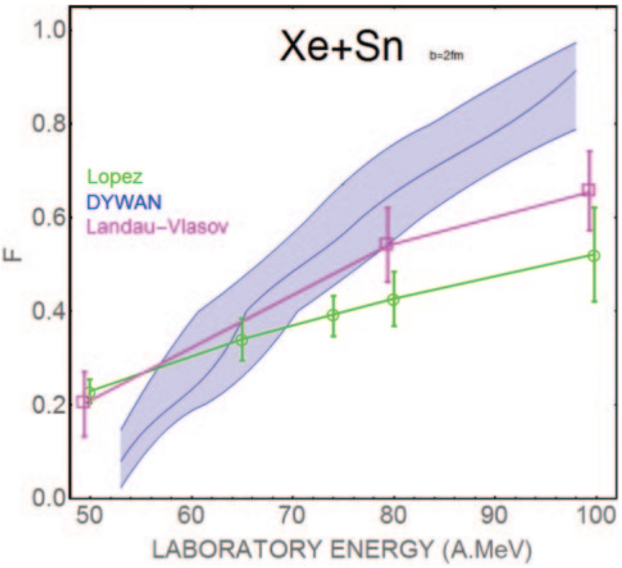

Fig. 2. – Evolution of the in-medium factor as a function of the energy. The blue zone show the DYWAN results, green circles are the in-medium parametrisation suggested by the INDRA Collaboration [1] and pink squares correspond to the semiclassical Landau-Vlasov model parametrisation using the same effective force [2].

4. – Conclusion

In this paper we analyzed the behavior of the stopping power as a function of σ_{nn} in the Xe + Sn collision for a variety of incident energies in the framework of the DYWAN model. As suggested in [1], we introduced a global multiplicative factor F affecting the nucleon-nucleon cross-section. A reduction of the stopping power R_E has been evidenced around E_F. Except at incident energy around 60 MeV/A, our results seem to indicate a lower reduction for the lowest energies and a higher reduction of the highest energies. Complementary developments are needed on the DYWAN model. In particular, the use of a simplified Skyrme force: the Zamick force, well adapted in semiclassical models, could present deficiencies in a more sophisticated description as DYWAN.

REFERENCES

[1] INDRA Collaboration (Lopez O. *et al.*), *Phys. Rev. C*, **90** (2014) 064602.
[2] Basrak Z., Eudes P. and de la Mota V., *Phys. Rev. C*, **93** (2016) 054609.
[3] Besse G., de la Mota V. and Eudes P., in preparation.
[4] Chen K. *et al.*, *Phys. Rev. C*, **166** (1968) 949.