GRAZING: few-nucleon transfer and quasi-elastic scattering (brief survey)

1. Basic features

Code GRAZING [1] is based on the semi-classical model of Aage Winther [2] proposed for description of inelastic scattering and nucleon transfer in grazing collision of heavy ions. This model combines classical motion of colliding nuclei along trajectories in the entrance and exit channels with quantum calculation of the probabilities for excitation of collective states and nucleon transfer. Inelastic excitations of nuclei, neutron and proton transfers are assumed to be independent of each other and occur mainly at the distance of closest approach of colliding nuclei (named “turning point” in elastic scattering). The cross sections are calculated in a natural way by summation over impact parameters (angular moments of relative motion). The model describes quite well few nucleon transfer processes with low kinetic energy loss. The code itself is organized in such a way that user has not to input a lot of characteristics of colliding nuclei; most of them are incorporated into internal data base of the code.

2. Mass and charge distributions

Probabilities of neutron and proton transfers in the model depends strongly on the single-particle level densities of nuclei near the Fermi energies (the larger is the density the higher is the transfer probability)

$$g^{\nu} = \frac{3N}{2\varepsilon^{\nu}}\frac{15}{\delta^{\nu}}, \qquad g^{\pi} = \frac{3N}{2\varepsilon^{\pi}}\frac{15}{\delta^{\pi}}.$$

The model parameters δ^{ν} and δ^{π} (which can be changed by user) define the standard level density parameter $a = \pi^2(g^{\nu} + g^{\pi})/6$. Experimental values of this parameter [3] (obtained from average distances between neutron resonances) are shown in Fig. 1 along with those derived from formulas for g^{ν} and g^{π} at different values of $\delta = \delta^{\nu} = \delta^{\pi}$. As can be seen parameters δ^{ν} and δ^{π} can be changed in the interval of $5 \le \delta^{\nu}, \delta^{\pi} \le 10$. Default values of these parameters are $\delta^{\nu} = \delta^{\pi} = 8$.

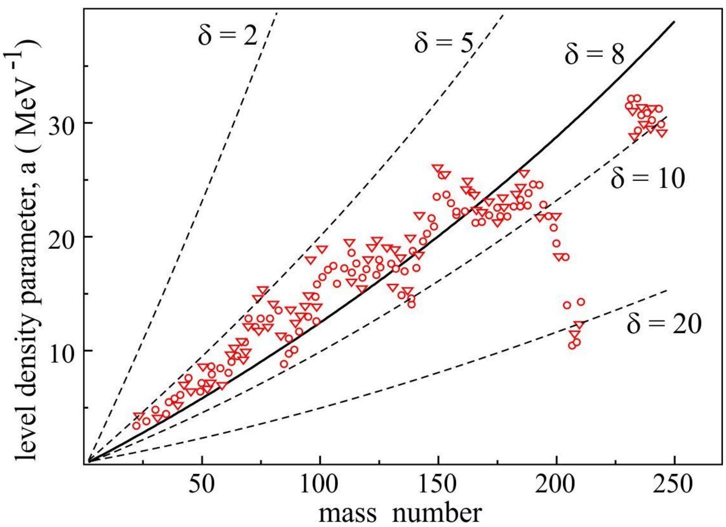

Fig. 1 Experimental [3] and calculated level density parameters.

In Fig. 2 typical mass distributions of projectile-like fragments are shown depending on proton and neutron transfers. Usually at the default values of parameters $\delta^{\nu} = \delta^{\pi} = 8$ the GRAZING code underestimates the transfer probability of two and more protons. The situation might be improved if the different values of these parameters are used for proton and neutron transfers, i.e., $\delta^{\pi} < \delta^{\nu}$.

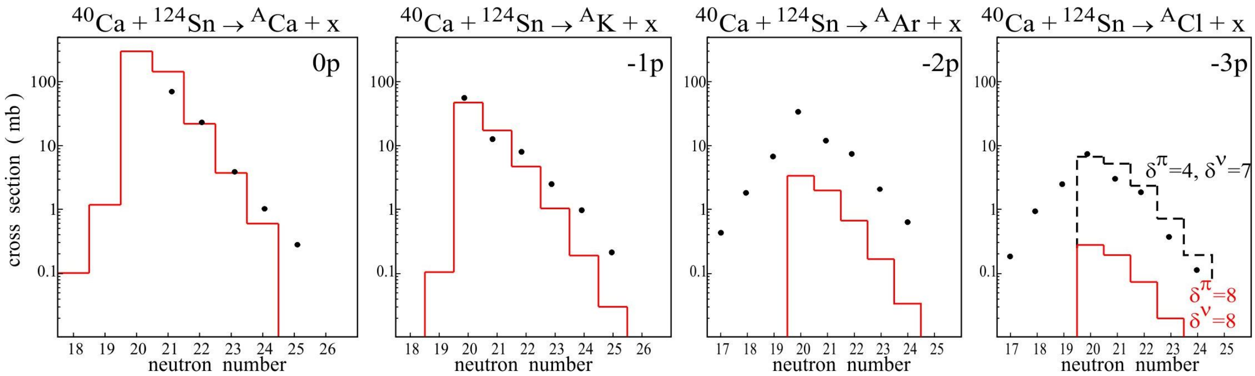

Fig. 2 Mass distributions of projectile-like fragments in the channels of pure neutron transfer, 1, 2 and 3 proton stripping in collisions of ^{40}Ca with ^{124}Sn target at 170 MeV beam energy [4]. The histograms are the GRAZING calculations with standard values of parameters $\delta = \delta^{\nu} = \delta^{\pi} = 8$ and with $\delta^{\pi} = 4, \delta^{\nu} = 7$ (dashed histogram at the right plot). The points show the experimental data.

In whole the GRAZING code describes rather well the cross sections for a few nucleon transfers. Multi-nucleon transfers as well as quasi-fission processes taking place in damped collisions of heavy ions with significant overlap of their surfaces cannot be describe within this code. As an example in Fig. 3 are shown (energy and angular integrated) experimental and calculated charge distributions of projectile-like fragments formed in collisions of $^{56}Fe+^{165}Ho$ at E_{lab}=462 MeV. The semi-classical model of grazing collisions is not aimed on description of the processes with large energy loss and nucleon fluxes taking place at smaller impact parameters and large overlapping on colliding nuclei (see below energy distributions).

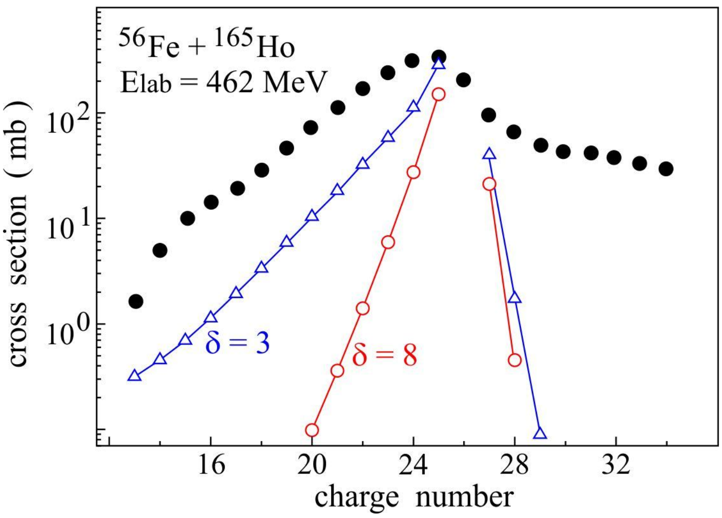

Fig. 3 Charge distributions of projectile-like fragments in collisions of ^{56}Fe with ^{165}Ho at 462 MeV beam energy [5]. Open symbols are the GRAZING calculations with the standard values of parameters $\delta^{\nu} = \delta^{\pi} = 8$ (circles) and with $\delta^{\nu} = \delta^{\pi} = 3$ (triangles).

3. Angular distributions

It is well known that angular distributions of reaction fragments formed in quasi-elastic processes are bell-shaped with maximum at the corresponding grazing angle dependent on colliding nuclei and energy. The GRAZING code gives such distribution for most of the reactions at not so high colliding energies.

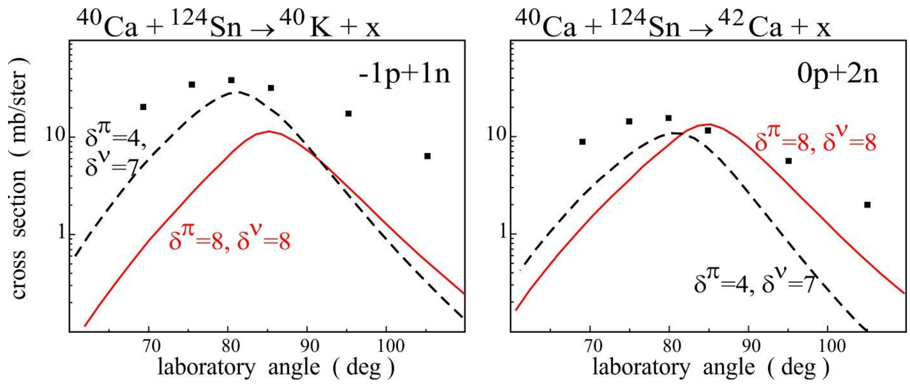

Fig. 4 Angular distributions of projectile-like fragments in collisions of ^{40}Ca with ^{124}Sn target at 170 MeV beam energy [4]. Calculations are performed with standard values of parameters $\delta^{\nu} = \delta^{\pi} = 8$ (solid curves) and with the values of $\delta^{\nu} = 7, \delta^{\pi} = 4$ (dashed curves).

4. Energy distributions

As a rule, energy distributions of reaction products in heavy ion collisions have two quite distinguishable components corresponding to quasi-elastic processes and to deep inelastic scattering with large energy loss (see, for example, Fig. 5). Deep inelastic component is not reproduced by the GRAZING code and this is the main reason for impossibility to describe the wide mass distributions of reaction fragments in damped collisions of heavy ions (see Fig. 3). The same can be seen in Fig. 6 showing the double energy-angle distribution of fragments (Wilczynski plot): the GRAZING code reproduces only upper part of the distribution corresponding to small energy losses.

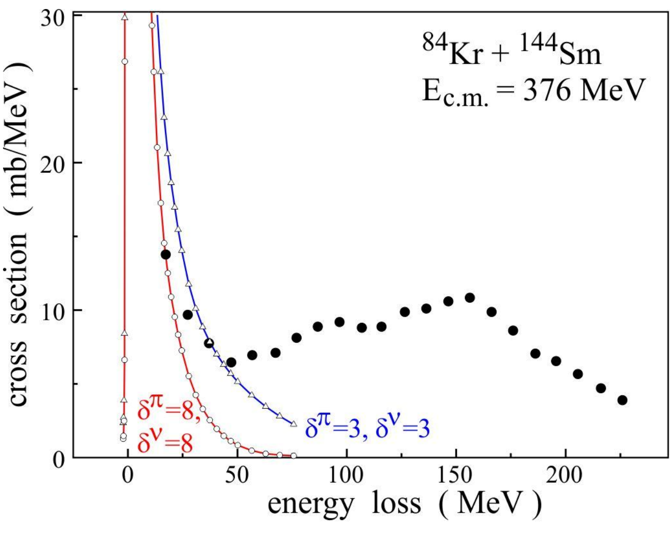

Fig. 5 Energy distribution of reaction fragments formed in collisions of ^{84}Kr with ^{144}Sm at $E_{lab.}$=595 MeV [6]. GRAZING calculations are performed with standard values of parameters $\delta^{\nu} = \delta^{\pi} = 8$ (circles) and with the values of $\delta^{\nu} = \delta^{\pi} = 3$ (triangles).

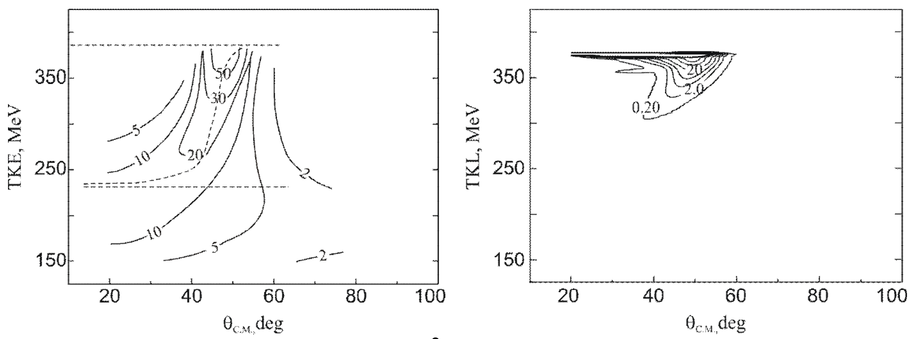

Fig. 6 Double differential cross section $d^2\sigma/dEd\Omega$, mb/MeV·sr (Wilczynski plot) for ^{84}Kr with ^{144}Sm at $E_{lab.}$=595 MeV. Experimental data (left panel) are from [6]. GRAZING calculations (right panel) are performed with standard values of parameters.

References

[1] http://personalpages.to.infn.it/~nanni/grazing/
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[3] A.V. Ignatyk, *Statistical Properties of Excited Atomic Nuclei*, Energoatomazidat, Moscow, 1983 [Report INDC(CCP)-233/L (1985) IAEA, Vienna].
[4] L. Corradi et al., Phys. Rev., C**54** (1996) 201.
[5] A.D. Hoover et al., Phys. Rev., **C25** (1982) 256.
[6] A.C. Mignerey et al., Phys. Rev., **C29** (1984) 158.