Production of doubly magic nucleus ^{100}Sn in fusion reactions via particle and cluster emission channels

Sh. A. Kalandarov

Bogolyubov Laboratory for Theoretical Physics,
Joint Institute for Nuclear Research, Dubna, Russia

Production of doubly magic nucleus ^{100}Sn in fusion reactions

GANIL experiment(Phys. Rev. Lett. V77, 2400(1996))

$^{50}Cr+^{58}Ni$ reaction at 5.1MeV/nucleon produce $^{108}Te(E_{ex}=92MeV$ at $J=0)$

$^{108}Te \rightarrow {}^{100}Sn+\alpha 4n$ with **40nb** cross section.

Alternative method was suggested in ORNL
by A. Korgul et.al.(Phys.Rev.C77,034301, 2008)

$^{58}Ni+^{54}Fe$ reaction at 240MeV produce $^{112}Xe((E_{ex}=58MeV$ at $J=0))$

$^{112}Xe \rightarrow {}^{108}Xe+4n$ with ~**1nb** cross section.

^{108}Xe-^{104}Te-^{100}Sn α decay chain

Adiabatic and diabatic pictures of nuclear fusion

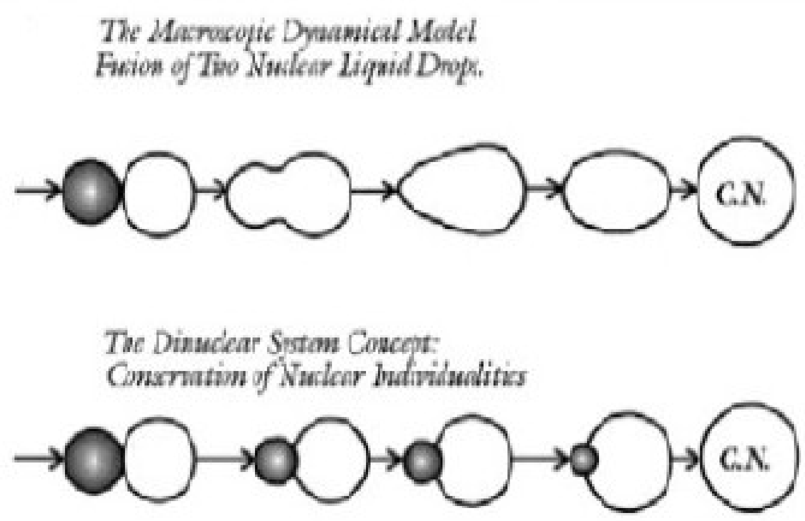
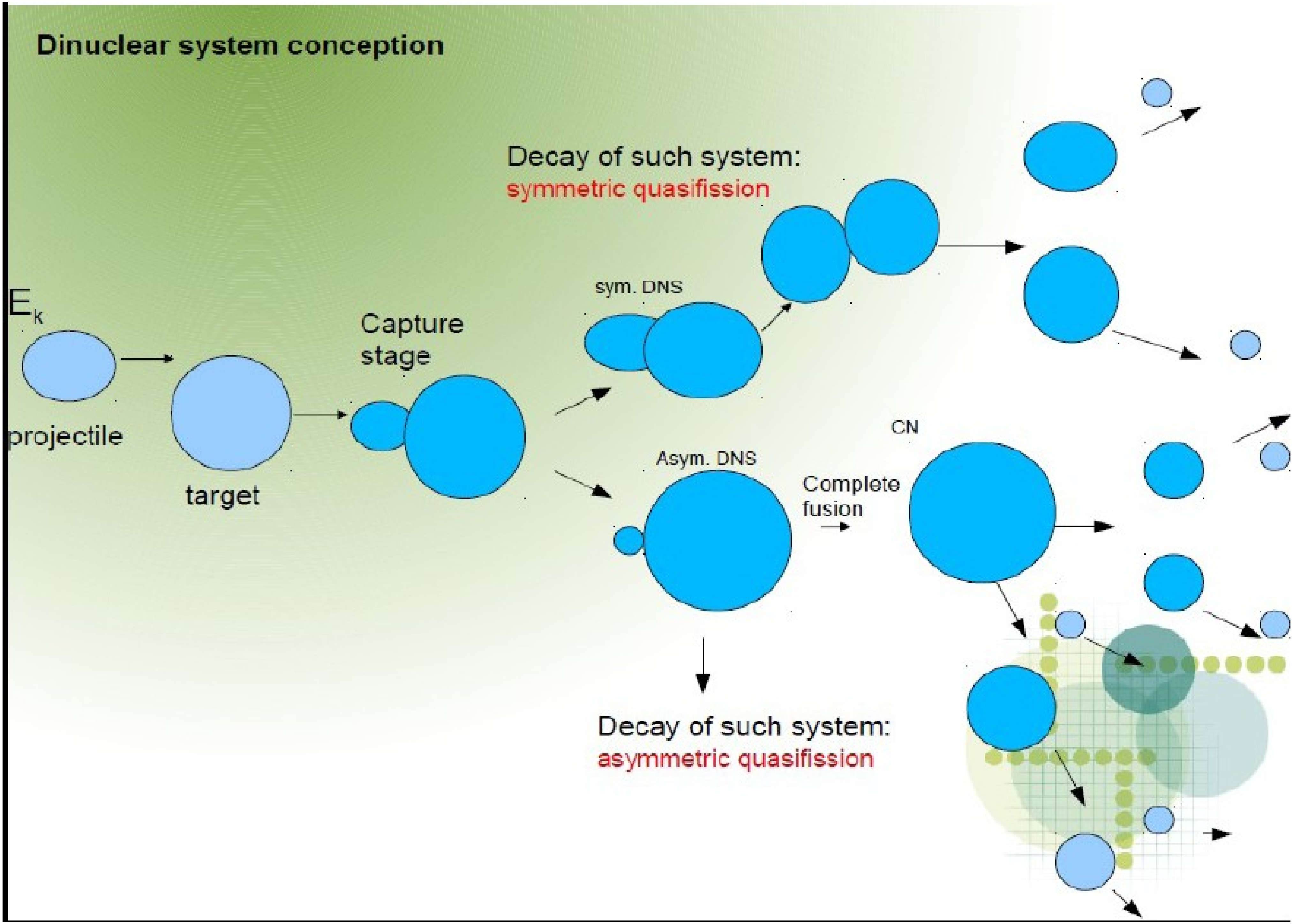
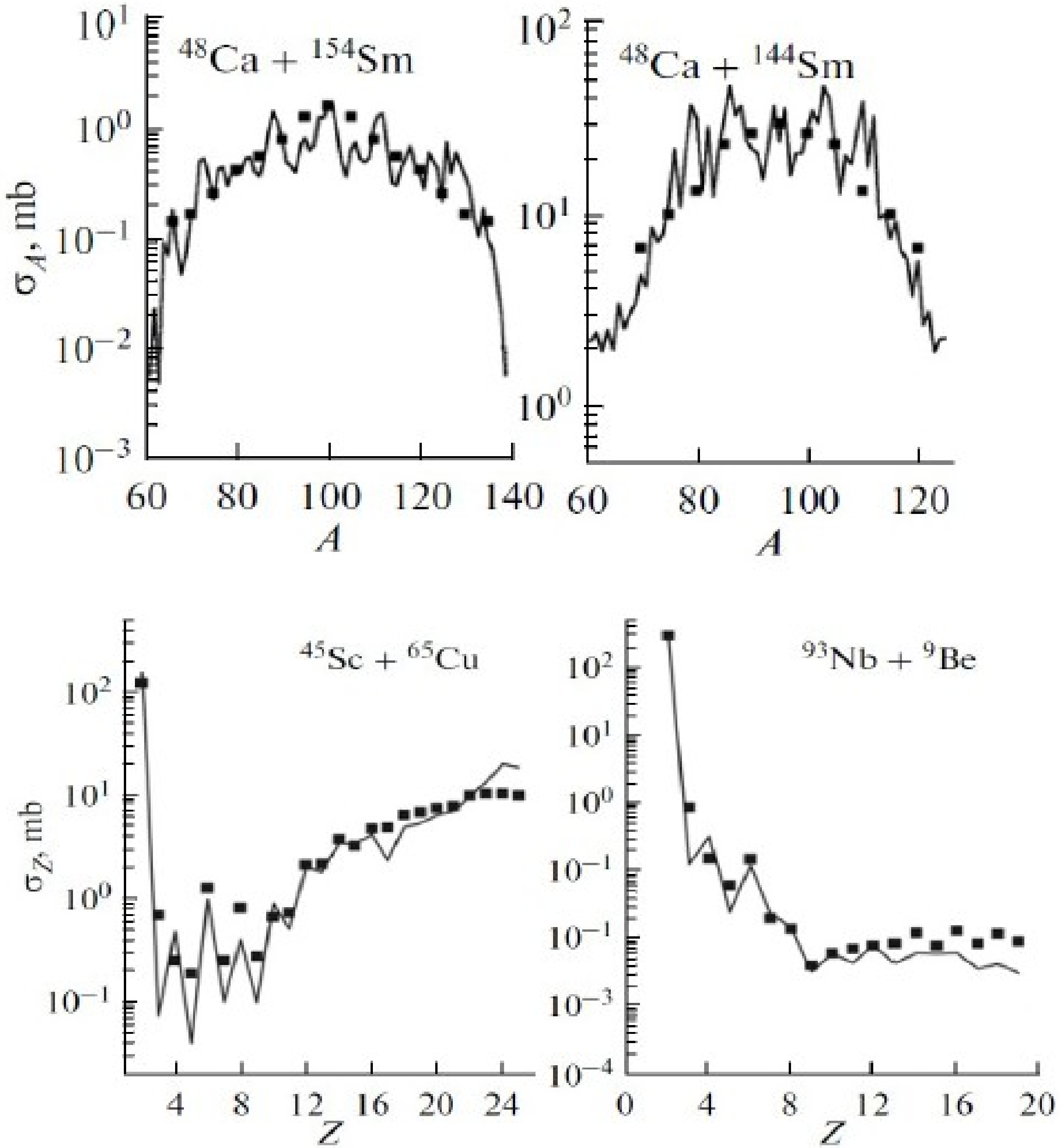


Fig. 1. Schematic illustration of the compound nucleus formation process within the framework of the MDM- and DNS-concept.


Dinuclear system conception
Decay of such system:
symmetric quasifission
sym. DNS
E$_k$
projectile
target
Capture
stage
Asym. DNS
Complete
fusion
CN
Decay of such system:
asymmetric quasifission

Examples of applications of the model



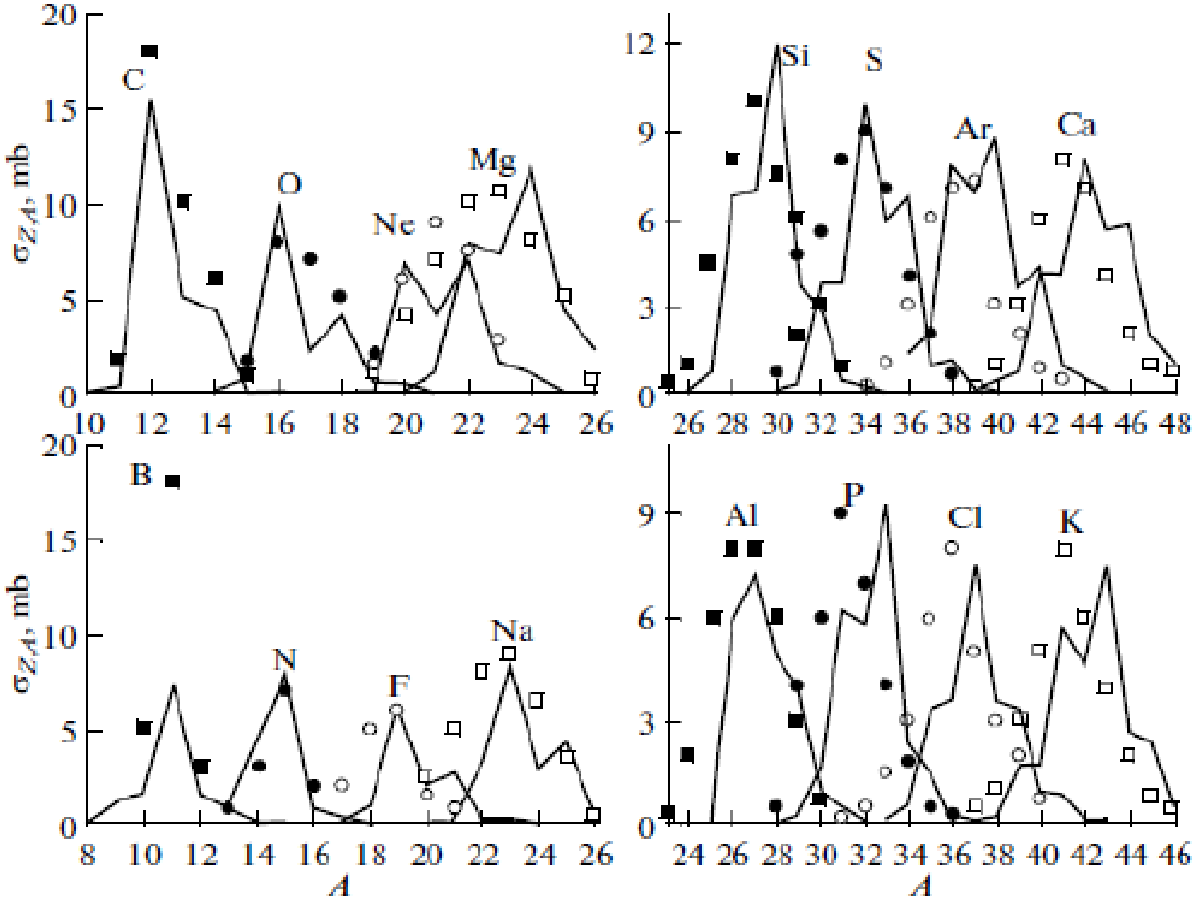


Fig. 28. Calculated (solid lines) and measured [41] (symbols) isotopic distributions of products originating from the ^{84}Kr + ^{27}Al reaction at E_{lab} = 10.6 MeV/nucleon that are indicated in the figure.

Sh. A. Kalandarov et al.,

PHYSICAL REVIEW C **82**, 044603 (2010)
PHYSICAL REVIEW C **83**, 054619 (2011)
PHYSICAL REVIEW C **84**, 054607 (2011)
PHYSICAL REVIEW C **84**, 064601 (2011)

Some results

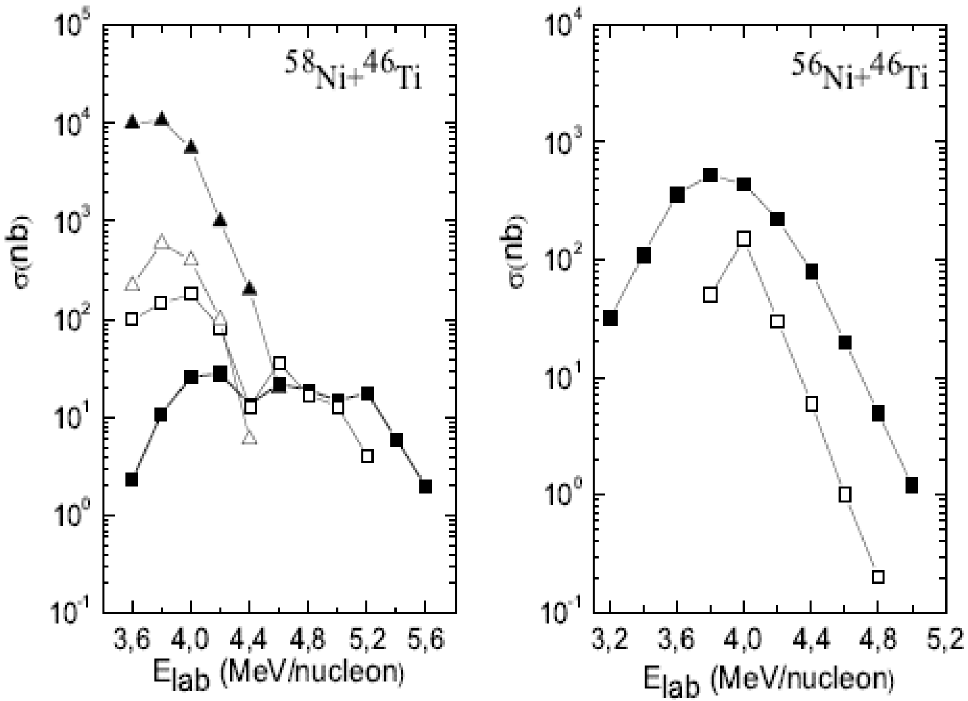


FIG. 2: Calculated excitation functions for production of ^{100}Sn(■), ^{101}Sn (□), ^{102}Sn (▲), ^{103}Sn (△) in indicated fusion reactions by xn decay channels.

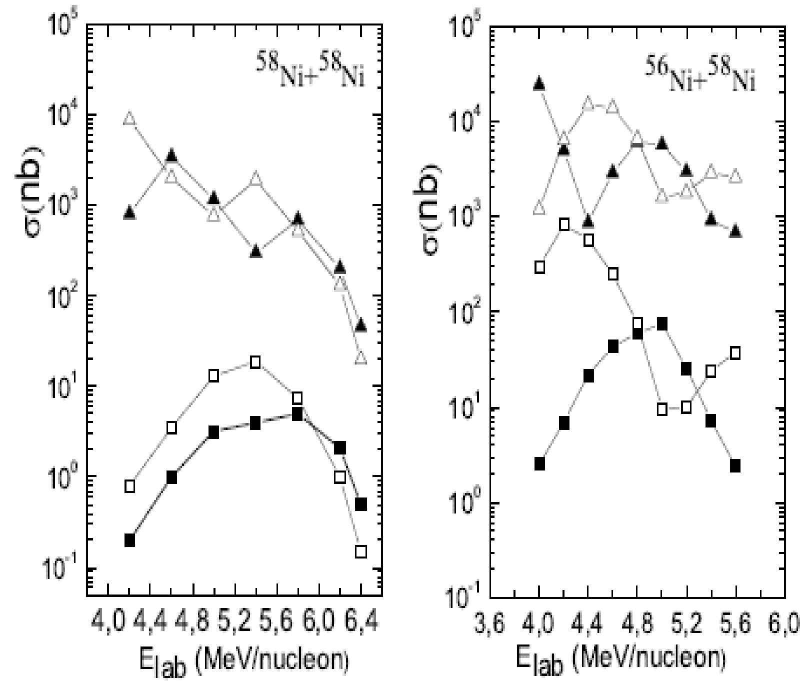


FIG. 5: Calculated excitation functions for production of ^{100}Sn(■), ^{101}Sn (□), ^{102}Sn (▲), ^{103}Sn (△) in indicated fusion reactions by cluster emission channels. See the text for the details.

Potential energy of DNS

$$U(R,Z,A,J) = B_1 + B_2 + V(R,Z,A,\beta_1,\beta_2,J) - [B_{12} + E_{12}^{rot}(J)],$$

$$V(R,Z,A,\beta_1,\beta_2,J) = V_C(R,Z,A,\beta_1,\beta_2) + V_N(R,Z,A,\beta_1,\beta_2) + \frac{\hbar^2 J(J+1)}{2\Im(R,A,\beta_1,\beta_2)}$$

$$V_N = \int \rho_1(\mathbf{r_1})\rho_2(\mathbf{R}-\mathbf{r_2})F(\mathbf{r_1}-\mathbf{r_2})d\mathbf{r_1}d\mathbf{r_2},$$

where $F(\mathbf{r_1}-\mathbf{r_2}) = C_0[F_{\text{in}}\frac{\rho_0(\mathbf{r}_1)}{\rho_{00}} + F_{\text{ex}}(1-\frac{\rho_0(\mathbf{r}_1)}{\rho_{00}})]\delta(\mathbf{r_1}-\mathbf{r_2})$ is the Skyrme-type density-depending effective nucleon-nucleon interaction, which is known from the theory of finite Fermi systems [28], and $\rho_0(\mathbf{r}) = \rho_1(\mathbf{r}) + \rho_2(\mathbf{R}-\mathbf{r})$, $F_{\text{in,ex}} = f_{\text{in,ex}} + f'_{\text{in,ex}}\frac{(N-Z)(N_2-Z_2)}{(N+Z)(N_2+Z_2)}$. Here, $\rho_1(\mathbf{r_1})$ and $\rho_2(\mathbf{r_2})$, and N_2 (Z_2) are the nucleon densities of, respectively, the light and the heavy nuclei of the DNS, and neutron (charge) number of the heavy nucleus of the DNS.

$$\rho_i(\mathbf{r}) = \frac{\rho_{00}}{1 + \exp((r - R_i(\theta'_i, \varphi'_i))/a_{0i})}$$

$$R_i = R_{0i}(1 + \beta_i Y_{20}(\theta'_i, \varphi'_i)),$$

$$\Im(R, A, \beta_1, \beta_2) = k_0(\Im_1 + \Im_2 + \mu R^2),$$

$$\Im_i = \frac{1}{5} m_0 A_i (a_i^2 + b_i^2),$$

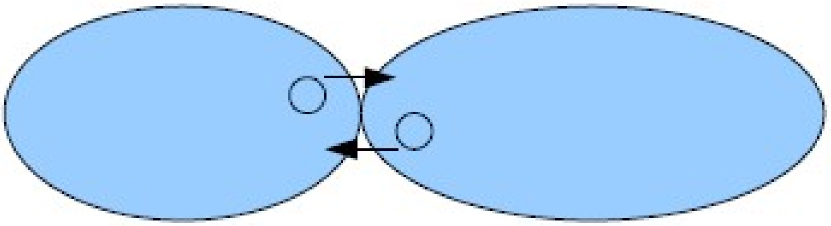
$$a_i = R_{0i}\left(1 - \frac{\beta_i^2}{4\pi}\right)\left(1 + \sqrt{\frac{5}{4\pi}}\beta_i\right),$$

$$b_i = R_{0i}\left(1 - \frac{\beta_i^2}{4\pi}\right)\left(1 - \sqrt{\frac{5}{16\pi}}\beta_i\right).$$

$$V_C(R, \alpha_1, \alpha_2) = \frac{Z_1 Z_2}{R} e^2 + \frac{Z_1 Z_2}{R^3} e^2 \left\{ \left(\frac{9}{20\pi}\right)^{1/2} \sum_{i=1}^{2} R_{0i}^2 \beta_2^{(i)} P_2(\cos\alpha'_i) + \frac{3}{7\pi} \sum_{i=1}^{2} R_{0i}^2 [\beta_2^{(i)} P_2(\cos\alpha'_i)]^2 \right\},$$

Here, $a_T = 0.56$ fm and $a_P = a_T - 0.015|\eta|$ are the diffusenesses of the DNS heavy and light nuclei, respectively (light nucleus has small diffuseness), and $R_{P(T)} = r_0 A_{P(T)}^{1/3}$ ($r_0 = 1.16$ fm) is the radius of nucleus "P" ("T"). Deformed nuclei are treated in the pole-to-pole orientation.

Nucleon exchange between DNS nuclei



$$\frac{d}{dt}P_{Z,N}(t) = \Delta^{(-,0)}_{Z+1,N}P_{Z+1,N}(t) + \Delta^{(+,0)}_{Z-1,N}P_{Z-1,N}(t)$$
$$+ \Delta^{(0,-)}_{Z,N+1}P_{Z,N+1}(t) + \Delta^{(0,+)}_{Z,N-1}P_{Z,N-1}(t)$$
$$-(\Delta^{(-,0)}_{Z,N} + \Delta^{(+,0)}_{Z,N} + \Delta^{(0,-)}_{Z,N} + \Delta^{(0,+)}_{Z,N}$$
$$+ \Lambda^{qf}_{Z,N} + \Lambda^{fis}_{Z,N})P_{Z,N}(t),$$

With the transport coefficients:

$$\Delta_{Z,N}^{(\pm,0)}(\Theta)=\frac{1}{\Delta t}\sum_{P,T}^{Z}|g_{PT}|^2 n_P^T(\Theta)[1-n_T^P(\Theta)]$$

$$\times\frac{\sin^2[\Delta t(\epsilon_P-\epsilon_T)/2\hbar]}{(\epsilon_P-\epsilon_T)^2/4},$$

$$\Delta_{Z,N}^{(0,\pm)}(\Theta)=\frac{1}{\Delta t}\sum_{P,T}^{N}|g_{PT}|^2 n_P^T(\Theta)[1-n_T^P(\Theta)]$$

$$\times\frac{\sin^2[\Delta t(\epsilon_P-\epsilon_T)/2\hbar]}{(\epsilon_P-\epsilon_T)^2/4},$$

$$\Lambda_{Z,N}^{qf}(\Theta)=\sum_n \Lambda_{Z,N}^{qf}(n)\Phi_{Z,N}(n,\Theta),$$

$$\Lambda_{Z,N}^{fis}(\Theta)=\sum_n \Lambda_{Z,N}^{fis}(n)\Phi_{Z,N}(n,\Theta).$$

Adamian G.G. et al,Physics of Atomic Nuclei, 55, 3(1992)

$$g_{PT}(R)=\frac{1}{2}\int d\mathbf{r}\psi_T^*(\mathbf{r})[U_T(\mathbf{r})+U_P(\mathbf{r}-\mathbf{R})]\psi_P(\mathbf{r}-\mathbf{R})$$

$$\Lambda_{Z,N}^{qf}(\Theta)=\frac{\omega}{2\pi\omega^{B_{qf}}}\left(\sqrt{\left(\frac{\Gamma}{2\hbar}\right)^2+(\omega^{B_{qf}})^2}-\frac{\Gamma}{2\hbar}\right)$$

$$\times\exp\left(-\frac{B_{qf}(Z,N)}{\Theta(Z,N)}\right),$$

Phenomenological approach:

$$\Delta_{Z,A}=\lambda_{zz'}\rho_z$$

$$\lambda_{zz'}=2\pi k\frac{R1R2}{R1+R2}\frac{1}{(\rho_z\rho_z')}$$