Description of the multinucleon transfer reactions within dinuclear system model

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Letter

Systematic studies to produce heavy above-target nuclides in multinucleon transfer reactions

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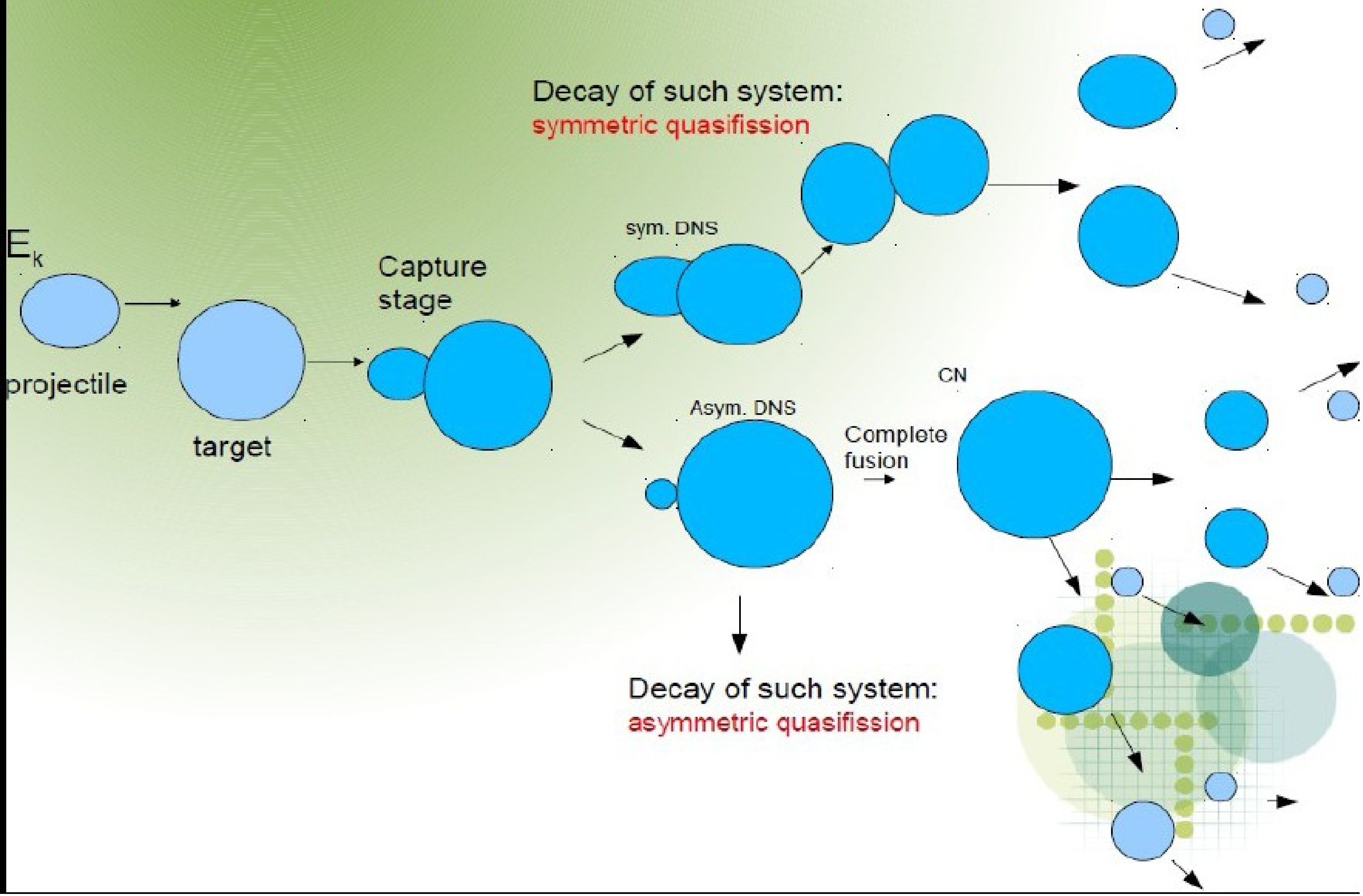
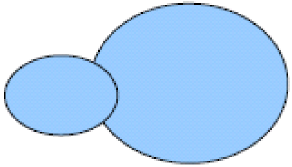
Dinuclear system conception



Capture=formation of di-nuclear system

Partial capture cross section for given **L** is:

$$\sigma_{cap} = \pi \lambda\!\!\!^{-2} (2L+1) P_{cap}(E_{c.m.}, L)$$



The distance between nuclei in DNS system is $R_{min}=R_1+R_2+0.5$ fm

where $$\lambda\!\!\!^{-2} = \hbar^2 / (2 \mu E_{c.m.})$$

$$E_{c.m.} = \frac{A_1 A_2}{A_1 + A_2} E_{lab}$$

and

$$P_{cap}(E_{c.m.}, L) = (1 + EXP(2\pi(V_b(L) - E_{c.m.})/h\omega_L)^{-1}$$

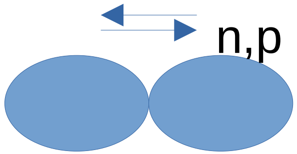
is a capture probability given by Hill-Wheeler.

$$L_{kin} \hbar = pb$$

b – impact parameter

p - momentum

Nucleon transfer and decay



Time evolution of the system by nucleon transfer between DNS nuclei and DNS decay is treated in the framework of transport approach with the system of coupled master equations:

$$\frac{dP_{Z_1,A_1,Z_2,A_2}}{dt} = \Delta^{(-,0)}_{Z_1+1,A_1+1,Z_2-1,A_2-1} P_{Z_1+1,A_1+1,Z_2-1,A_2-1}(t) + \Delta^{(+,0)}_{Z_1-1,A_1-1,Z_2+1,A_2+1} P_{Z_1-1,A_1-1,Z_2+1,A_2+1}(t)$$
$$+\Delta^{(0,-)}_{Z_1,A_1+1,Z_2,A_2-1} P_{Z_1,A_1+1,Z_2,A_2-1}(t) + \Delta^{(0,+)}_{Z_1,A_1-1,Z_2,A_2+1} P_{Z_1,A_1-1,Z_2,A_2+1}(t)$$
$$-(\Delta^{(-,0)}_{Z_1,A_1,Z_2,A_2} + \Delta^{(+,0)}_{Z_1,A_1,Z_2,A_2} + \Delta^{(0,-)}_{Z_1,A_1,Z_2,A_2} + \Delta^{(0,+)}_{Z_1,A_1,Z_2,A_2} + \Lambda^{d}_{Z_1,A_1,Z_2,A_2}) P_{Z_1,A_1,Z_2,A_2}(t)$$

Number of differential equations N is equal to the number of energetically possible DNS configurations.

$$Y_{Z_1,A_1,Z_2,A_2} = \Lambda^{d}_{Z_1,A_1,Z_2,A_2} \int_0^t P_{Z_1,A_1,Z_2,A_2}(t)\,dt$$

Nucleon transition and decay rates

$$\Delta_i = 2\pi k \frac{R_1 R_2}{R_1 + R_2} \sqrt{\frac{\rho'_{DNS}}{\rho_{DNS}}}$$

k=0.1 and has dimension 10^{21} 1/(fm s)

L.G. Moretto and J.S. Sventek, Physics Letters B 58, 26 (1975)

$$\rho_{DNS} = \int_0^{Ex_{DNS}-\epsilon} \int_0^{Ex_{DNS}} \rho_1(Ex_1)\,\rho_2(Ex_{DNS}-\epsilon-Ex_1)\,d\epsilon\,dEx_1$$

$$Ex_{DNS} = E_{c.m.} - Q_{DNS} - V_{DNS}, \textit{where}\; Q_{DNS} = B_P + B_T - (B_1 + B_2)$$

$$\Lambda^d_{Z_1,A_1,Z_2,A_2} = \frac{\int_0^{Ex_{DNS}-B_d-\epsilon'} \int_0^{Ex_{DNS}-B_d} \rho_1(Ex_1)\,\rho_2(Ex_{DNS}-B_d-\epsilon'-Ex_1)\,d\epsilon'\,dEx_1}{h\int_0^{Ex_{DNS}-\epsilon} \int_0^{Ex_{DNS}} \rho_1(Ex_1)\,\rho_2(Ex_{DNS}-\epsilon-Ex_1)\,d\epsilon\,dEx_1}$$

Calculation of binding energies

$$B_i = B_{mac}(Z, A, \beta_i) + \delta W_{g.s.}(Z, A) * f(\beta_i, Ex_i) + \delta P * g(\beta_i, Ex_i)$$

Droplet Model of Myers and Swiatecki, Annals of Physics, 84,186-210 (1974)

$$\delta P = (-6((-1)^N + (-1)^Z))/A^{(1/2)}$$

$$\delta W_{g.s.}(Z, A) = B_{\exp} - B_{mac}(Z, A, \beta_{g.s.}) - \delta P$$

$$f(\beta, Ex) = e^{\frac{-R_0^2(\beta - \beta_{g.s.})^2}{4\pi a^2}} e^{-Ex/Ed}$$

Myers and Swiatecki, Nucl. Phys. 81,(1966) p.1-60.

Ed=18.5 MeV, a=0.36 fm, r_0=1.16 fm

Interaction potential of DNS

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

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

where $F(\mathbf{r_1}-\mathbf{r_2}) = C_0[F_{\rm in}\frac{\rho_0(\mathbf{r_1})}{\rho_{00}} + F_{\rm ex}(1-\frac{\rho_0(\mathbf{r_1})}{\rho_{00}})]\delta(\mathbf{r_1}-\mathbf{r_2})$ is the Skyrme-type density-depending effective nucleon-nucleon interaction, which is known from the theory of finite Fermi systems [28], and $\rho_0(\mathbf{r}) = \rho_1(\mathbf{r}) + \rho_2(\mathbf{R}-\mathbf{r})$, $F_{\rm in,ex} = f_{\rm in,ex} + f'_{\rm in,ex}\frac{(N-Z)(N_2-Z_2)}{(N+Z)(N_2+Z_2)}$. 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.

Survival probability W^{sur} is calculated within transition state model

Particle emission width from excited nuclei:

$$\Gamma_i = \frac{m_i R^2}{\pi \hbar^2 \rho_{CN}(E^*_{CN})} \int_0^{E^*_{CN} - B_i} \rho_{res}(E^*_{CN} - B_i - \epsilon)\epsilon d\epsilon,$$

Decay width for fission:

$$\Gamma_Z = \frac{1}{2\pi \rho(E_{ex})} \int_0^{E_{ex} - B_Z} \rho'(E_{ex} - B_Z - \varepsilon) d\varepsilon$$

Final cross sections for multinucleon transfer products

$$\sigma_{Z',A'} = \sum_L \sigma_{cap}(L) * Y^{norm}_{Z,A}(L) * W^{sur}(L)$$

Results

Reactions	E_{lab}	$E_{c.m.}$	V_b	J_{max}
$^{48}Ca+^{208}Pb$	236	191.72	173	70
$^{50}Ti+^{208}Pb$	242.8	195.7	191	36
$^{40}Ar+^{209}Bi$	194.3	163.07	159.5	28

Table 1: Initial conditions of considered reactions. Energy units are given in MeV

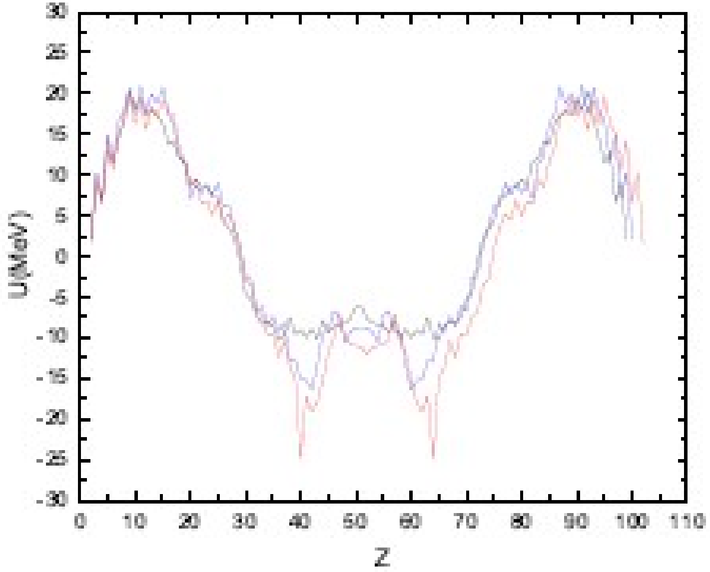
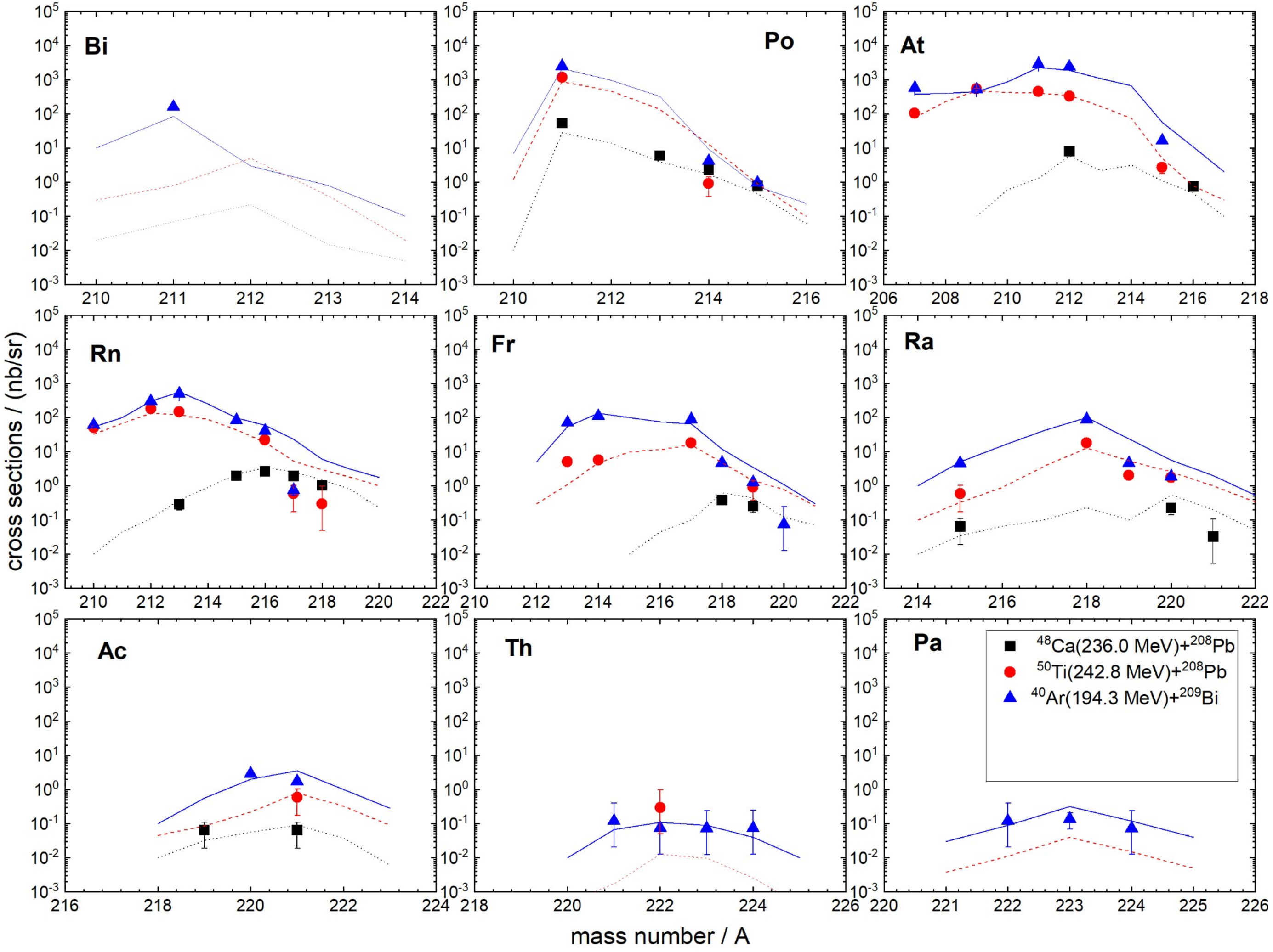


Figure 1: Driving potentials for the reactions $^{40}Ar+^{209}Bi$(black line) $^{48}Ca+^{208}Pb$(blue line) and $^{50}Ti+^{208}Pb$ (red line).

Comparison of calculated and experimental cross sections



Conclusions

Dynamical description of the multinucleon transfer reactions 48Ca+208Pb, 50Ti+208Pb and 40Ar+209Bi in the framework of DNS model is presented.

Calculated yields of above target nuclides up to 8 proton(plus neutrons) are in good agreement with experimental data measured at FLNR JINR.

Calculations reveal that nucleon transfer from lighter magic nuclei are more suppressed.

The direct relation of transition coefficients and driving potential of dinuclear system provides a simplicity and a high predictive power of the model.