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


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

$^{108}$Te $\rightarrow ^{100}$Sn+α4n 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 ($E_{ex} =58$MeV at J=0))

$^{112}$Xe $\rightarrow ^{108}$Xe+4n with $\sim$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

Capture stage

Decay of such system: asymmetric quasifission
Examples of applications of the model

- $^{48}\text{Ca} + ^{154}\text{Sm}$
- $^{48}\text{Ca} + ^{144}\text{Sm}$
- $^{45}\text{Sc} + ^{65}\text{Cu}$
- $^{93}\text{Nb} + ^{9}\text{Be}$

Graphs showing the cross-sections $\sigma_A, \text{mb}$ and $\sigma_Z, \text{mb}$ as a function of $A$ and $Z$. 
Fig. 28. Calculated (solid lines) and measured [41] (symbols) isotopic distributions of products originating from the $^{84}\text{Kr} + ^{27}\text{Al}$ 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)
FIG. 2: Calculated excitation functions for production of $^{100}\text{Sn}(\square)$, $^{101}\text{Sn}(\square)$, $^{102}\text{Sn}(\triangle)$, $^{103}\text{Sn}(\triangle)$ in indicated fusion reactions by xn decay channels.

FIG. 5: Calculated excitation functions for production of $^{100}\text{Sn}(\square)$, $^{101}\text{Sn}(\square)$, $^{102}\text{Sn}(\triangle)$, $^{103}\text{Sn}(\triangle)$ in indicated fusion reactions by cluster emission channels. See the text for the details.
Potential energy of DNS

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

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

\[ V_N = \int \rho_1(\mathbf{r}_1) \rho_2(\mathbf{R} - \mathbf{r}_2) F(\mathbf{r}_1 - \mathbf{r}_2) d\mathbf{r}_1 d\mathbf{r}_2, \]

where \( F(\mathbf{r}_1 - \mathbf{r}_2) = C_0 [F_{\text{in}} \frac{\rho_0(\mathbf{r}_1)}{\rho_0} + F_{\text{ex}} (1 - \frac{\rho_0(\mathbf{r}_1)}{\rho_0})] \delta(\mathbf{r}_1 - \mathbf{r}_2) \) is the Skyrme-type density-dependent 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.
\[ \rho_i(r) = \frac{\rho_{00}}{1 + \exp((r - R_i(\theta'_i, \varphi'_i))/a_{0i})} \]

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

\[ \mathcal{S}(R, A, \beta_1, \beta_2) = k_0(\mathcal{S}_1 + \mathcal{S}_2 + \mu R^2) \]

\[ \mathcal{S}_i = \frac{1}{5} m_0 A_i \left( a_i^2 + b_i^2 \right), \]

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

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

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

\[ + \frac{3}{7\pi} \sum_{i=1}^{2} R_{0i}^2 \left[ \beta_2^{(i)} P_2(\cos \alpha'_i) \right]^2 \}

Here, \( a_T = 0.56 \text{ fm} \) and \( a_P = a_T - 0.015 \rho \) are the diffusenesses of the DNS heavy and light nuclei, respectively (light nucleus has small diffuseness), and \( R_{P(T)} = r_0 A^{1/3}_{P(T)} \) (\( r_0 = 1.16 \text{ fm} \)) is the radius of nucleus ``P'' (``T''). Deformed nuclei are treated in the pole-to-pole orientation.
Nucleon exchange between DNS nuclei

\[
\frac{d}{dt} P_{Z,N}(t) = \Delta_{Z+1,N}^{(-,0)} P_{Z+1,N}(t) + \Delta_{Z-1,N}^{(+,0)} P_{Z-1,N}(t) \\
+ \Delta_{Z,N+1}^{(0,-)} P_{Z,N+1}(t) + \Delta_{Z,N-1}^{(0,+)} P_{Z,N-1}(t) \\
- (\Delta_{Z,N}^{(-,0)} + \Delta_{Z,N}^{(+,0)} + \Delta_{Z,N}^{(0,-)} + \Delta_{Z,N}^{(0,+)} \\
+ \Lambda_{Z,N}^{qf} + \Lambda_{Z,N}^{fis}) P_{Z,N}(t),
\]
With the transport coefficients:

\[
\Delta_{Z,N}^{(\pm,0)}(\Theta) = \frac{1}{\Delta t} \sum_{P,T}^Z |g_{PT}|^2 n_T^P(\Theta) \left[ 1 - n_T^P(\Theta) \right] \times \sin^2 \left[ \frac{\Delta t(\epsilon_P - \epsilon_T)/2\hbar}{(\epsilon_P - \epsilon_T)^2/4} \right],
\]

\[
\Delta_{Z,N}^{(0,\pm)}(\Theta) = \frac{1}{\Delta t} \sum_{P,T}^N |g_{PT}|^2 n_T^P(\Theta) \left[ 1 - n_T^P(\Theta) \right] \times \sin^2 \left[ \frac{\Delta t(\epsilon_P - \epsilon_T)/2\hbar}{(\epsilon_P - \epsilon_T)^2/4} \right],
\]

\[
\Lambda_{Z,N}^{g_f}(\Theta) = \frac{\omega}{2\pi \omega B_{qf}} \left( \sqrt{\left( \frac{\Gamma}{2\hbar} \right)^2 + (\omega B_{qf})^2} - \frac{\Gamma}{2\hbar} \right) \times \exp \left( - \frac{B_{qf}(Z,N)}{\Theta(Z,N)} \right).
\]

Phenomenological approach:

\[
\Delta_{Z,A} = \lambda_{zz} \rho_z
\]

\[
\lambda_{zz} = 2\pi k \frac{R1R2}{R1 + R2} \frac{1}{\rho_z \rho_z'}
\]