The fusion process of $^{48}\text{Ca}$ induced reactions is studied with the two-step model. In this model, the fusion process is divided into two stages: first, the sticking stage where projectile and target come to the touching point over the Coulomb barrier from infinite distance, and second, the formation stage where the di-nucleus formed with projectile and target evolve to form the spherical compound nucleus from the touching point. By the use of the statistical evaporation model, the residue cross sections for different neutron evaporation channels are analyzed. From the results, optimum reactions are given to synthesize $Z = 117$ element with $^{48}\text{Ca}$ induced reactions.

1. Introduction

Since the time when the nuclear shell model was constructed, the question – where the next double magic nucleus beyond $^{208}\text{Pb}$ is – has always attracted physicists’ attention. It is expected to have a long life time due to the additional stability by
the closed shell. Based on the shell model with a single particle potential, the next double magic nucleus is predicted to be of 114 protons and 184 neutrons. Other theories predict that the next magic proton number may also be 120, 126. Thus, the location of the next double magic nucleus in the nuclear chart is model- or even parameter-dependent. In order to prove an existence of such elements, we have to synthesize them, since there is no sure evidence of such elements in the nature until now. How to reach them is still very difficult experimentally.

With the development of experimental facilities, the minimum cross section that could be detected is about picobarn or even lower and accordingly many superheavy elements (SHE) with proton number \( Z \geq 100 \) were discovered. Among the discovered SHE, the decay chains are not always connected with known nuclei. Therefore, where the magic nucleus is located and how to reach it is still an open question. SHE events have been detected for \( Z = 114 - 116, 118 \), except for \( Z = 117 \). For those SHE where \( Z \geq 114 \), the so-called hot fusion reaction with \(^{48}\text{Ca}\) as a projectile is adopted.

The neighbors of \( Z = 117 \) are synthesized with projectile \(^{48}\text{Ca}\), then it is natural to think that \( Z = 117 \) can also be synthesized with the same projectile. If it is true, the optimum target and incident energy should be suggested. However, because of the complexity of heavy ion fusion processes, no commonly accepted reaction theory is available. Nevertheless, several theoretical attempts have been made to explain or predict the experiments, for example, the two-step model which will be used in this paper\(^2\), DNS model\(^3\), QMD-based model\(^4\), and the other two models in Refs.\(^5\)\(^6\). A common problem faced by these theories is the hindrance of fusion, which is simply characterized by so-called extra-push energy in addition to the Coulomb barrier energy, i.e., the additional energies needed in order to form a compound nucleus in the heavy ion collisions. For theoretical prediction of fusion and thus residue cross sections, an understanding of the mechanism of the hindrance is indispensable.

Recently, the present authors et al. have proposed a mechanism where the main origin of the hindrance is due to a relative position between the di-nucleus configuration formed by the sticking of incident ions and the conditional saddle point or more generally the ridge line in the liquid drop energy (LDM) energy surface of the composite system\(^7\). The model explains the extra-push energy and furthermore gives an energy dependent fusion probability\(^8\). The two-step model is based on the mechanism, including effects due to collision processes over the Coulomb barrier, which will be briefly recapitulated below.

The purpose of the present paper is to provide a reliable prediction for synthesis of the new superheavy element with \( Z = 117 \), that is, to suggest most promising target isotopes of berkelium and to predict excitation functions for \( xn \) residue cross sections which give an optimum \( E_{\text{c.m.}} \) and a peak value of residue cross sections. For that, we employ the two-step model for fusion process and a part of HIVAP code\(^9\) for the decay process, where a calibration of only one free parameter is made by the use of the neighboring reactions with the target \(^{244}\text{Pu}\) and \(^{248}\text{Cm}\). The paper is arranged as follows: Sec. 2 describes the two-step model used in the description of
fusion process; Sec. 3 shows the results of calculations and discussions; Sec. 4 gives a summary.

2. Two-step model

Based on the theory of compound nucleus reactions, the residue cross sections are given as follows:

$$\sigma_{\text{res}} = \pi \lambda^2 \sum J (2J + 1) P^J_{\text{fusion}}(E_{\text{c.m.}}) \cdot P^J_{\text{surv}}(E^*)$$

where \( \lambda = \lambda/(2\pi) = h/\sqrt{2\mu E_{\text{c.m.}}} \), \( J \) is the total angular momentum quantum number and \( \mu \) the reduced mass. \( P_{\text{fusion}} \) and \( P_{\text{surv}} \) denote the fusion and the survival probabilities, respectively. The latter one is given by the statistical theory, although there are ambiguities in the parameters in the properties of heavy and superheavy nuclei, which give rise to uncertainties in calculating the residue cross sections. In addition, the first one, \( P_{\text{fusion}} \), the fusion probability of massive systems, is essentially unknown. The reason is the so-called fusion hindrance in heavy ion collisions, which is experimentally well known, but is not understood in its mechanism. In lighter systems, the fusion probability is well determined by the Coulomb repulsion and nuclear attraction between projectile and target, while in massive systems fusion does not occur in the same way. One must give an additional incident energy (extra-push energy) to explain the data. There are two interpretations trying to explain the phenomenon: one is due to the dissipation of the initial kinetic energy during two-body collisions passing over the barrier\(^{10}\), and the other one is due to the dissipation of the energy of collective motions which would lead an amalgamated system to the spherical compound nucleus\(^{11}\). Because the two mechanisms are considered in different stages of the fusion process, the two mechanisms can be combined into a single model, the two step model\(^{2,12}\), in which energy dissipation takes place in both stage: the overcoming of Coulomb potential before touching point, called approaching phase, and the evolution of the amalgamated system after touching point\(^{11}\), called formation phase. Because they are the successive processes, they should be connected. The method of statistical connection\(^{13}\) has been proposed in the two step model, which will be explained later in the application.

In the description of approaching phase, we have two options: one is that the phase may be described as collision process under frictional forces, as done in Ref\(^{2}\), the other choice is to adopt an empirical formula to reproduce the experimental capture cross sections and then extend it to unknown region\(^{14}\). In the formation phase, we describe dynamical evolution of the amalgamated mononuclear system toward the spherical shape under frictional forces acting on collective motions of excited nuclei. For each angular momentum \( J \), the sticking probability \( P^J_{\text{stick}} \), i.e. the probability from infinite distance to the contact point, and formation probability \( P^J_{\text{form}} \), i.e., the probability from the contact point to the spherical compound nucleus, can be worked out and then fusion probability and fusion cross section get the form,

$$P^J_{\text{fusion}}(E_{\text{c.m.}}) = P^J_{\text{stick}}(E_{\text{c.m.}}) \cdot P^J_{\text{form}}(E_{\text{c.m.}}),$$

(2)
and

\[ \sigma_{\text{fusion}}(E_{\text{c.m.}}) = \pi \lambda^2 \sum_J (2J + 1) P_J^{\text{fusion}}(E_{\text{c.m.}}), \]  

respectively.

### 2.1. Approaching phase

In this phase, following Eq.(4) in Ref.\[5\] and under the assumption of \( B_0/(\sqrt{2}H) \gg 1 \), the capture probability for each partial wave is given as

\[ P_J^{\text{stick}}(E_{\text{c.m.}}) = \frac{1}{2} \left\{ 1 + \text{erf} \left[ \frac{1}{\sqrt{2}H} \left( E_{\text{cm}} - B_0 - \frac{h^2 J(J+1)}{2\mu R_B^2} \right) \right] \right\}, \]  

where \( B_0 \) is the barrier height of the Coulomb potential, \( H \) the width of the Gaussian distribution of the barrier height, \( R_B \) the distance between two centers of projectile and target at the Coulomb barrier. In the Ref.\[5\] 45 reactions are used to obtain the values of the parameters \( H \) and \( B_0 \). However they might not be adequate for very heavy systems, such as the systems studied in this paper. A reasonable method is that we use the same form of formulas but with different \( C \) (a factor in the empirical formula to calculate \( H \), see Ref.\[5\]) and \( B_0 \) to fit the capture cross sections of systems which are very close to \(^{48}\text{Ca} + \text{Bk} \) reactions. The three \(^{48}\text{Ca}\)-induced systems to be fitted are \(^{48}\text{Ca} + ^{238}\text{U} \), \(^{48}\text{Ca} + ^{244}\text{Pu} \) and \(^{48}\text{Ca} + ^{248}\text{Cm} \). Here barrier height \( B_0 \) in Eq.(4) is referred to \( B \) of Ref.\[5\] and now \( B_0 \) is,

\[ B_0 = B + \Delta B. \]  

The fitted results are shown in Fig. 1. With a constant value of \( C \) and a linear increase of the barrier shift \( \Delta B \) with proton number \( Z \), the capture cross sections are very well reproduced. Because berkelium has only one more proton in addition to curium, the \( \Delta B \) is extrapolated to be 4.5 MeV, as is seen in Fig. 2. With Eq.(4), Eq.(5) and the re-fitted data \( C \) and \( \Delta B \), sticking probability \( P_J^{\text{stick}} \) of \(^{48}\text{Ca} + \text{Bk} \) is calculated with confidence.

According to the surface friction model, the relative kinetic energy is completely damped at the contact point, and reaches the thermal equilibrium with the heat bath. The radial momentum is, thus, Gaussian distributed. This is the initial condition for successive process, i.e., in the next formation phase. Thus, the method is called statistical connection.

### 2.2. Formation phase

In this process the amalgamated mononuclear system evolves from the contact point into compound ground state. In order to describe shapes of the amalgamated system, three parameters are necessary at least. In the Two-Center parametrization, they are the distance between two centers \( z \), the mass asymmetry \( \alpha \), and the neck correction factor \( \varepsilon \). The first one is defined as a dimensionless parameter as follows,

\[ z = R/R_0, \]
Fig. 1. Fit of the experimental capture cross section to get appropriate \( C \) and \( \Delta B \).

Fig. 2. Extrapolation of the shift of Coulomb barrier for Ca + Bk. The solid circles correspond to experimental data, while the open one is an extrapolation for Ca+Bk.

where \( R \) denotes the distance between the two centers of the harmonic potentials, and \( R_0 \) the radius of the spherical compound nucleus. The second one is defined as usual,

\[
\alpha = \frac{A_1 - A_2}{A_1 + A_2},
\]
where $A_1$ and $A_2$ are mass numbers of the constituent nuclei. The neck correction factor is defined by the ratio of the smoothed height at the connection point of the two harmonic potentials and that of spike potential. In the description, nuclear shapes are defined by equi-potential surface with a constant volume. For example, $\varepsilon = 1.0$ means no correction, i.e., di-nucleus shape, while $\varepsilon = 0.0$ means no spike, i.e., flatly connected potential, which describes highly deformed mono-nucleus. Thus, the $\varepsilon$ describes shape evolution of the compound system from di-nucleus to mono-nucleus. Since we know that the inertia mass for the $\varepsilon$ degree of freedom is small, its momentum is expected to be quickly equilibrated, compared with the other two degrees of freedom. And furthermore, LDM potential is rather steep with respect to the $\varepsilon$, and then $\varepsilon$ very quickly reaches the end, at $\varepsilon = 0.0$, starting with $\varepsilon = 1.0$. This is natural, considering the strong surface tension of nuclear matter and a sensitive change of the surface area due to variation of the $\varepsilon$. Actually, due to actions of the random force associated to the friction, the $\varepsilon$ reaches to the equilibrium quickly, far quicker than the time scale of radial fusion motion. Thus, we take the $\varepsilon = 0.1$ (an average value in the equilibrium) during the fusion process. The initial parameters for $z$ and $\alpha$ are

$$z_0 = (A_p^{1/3} + A_t^{1/3})/(A_p + A_t)^{1/3},$$

and

$$\alpha_0 = (A_t - A_p)/(A_t + A_p),$$

respectively.

The evolution of the pear-shaped mono-nucleus after contact point are described by the multi-dimensional Langevin equations

$$\frac{dq_i}{dt} = (m^{-1})_{ij}p_j,$$

$$\frac{dp_i}{dt} = -\frac{\partial U^J}{\partial q_i} - \frac{1}{2}\frac{\partial}{\partial q_i}(m^{-1})_{jk}p_jp_k - \gamma_{ij}(m^{-1})_{jk}p_k + g_{ij}R_j(t),$$

where summation is implicitly assumed over repeated suffixes. In the above equations, $i, j$ takes 1 or 2, $q_1, q_2$ stands for $z$ and $\alpha$, respectively, while $p_1, p_2$ for the associate momenta with $z, \alpha$, respectively. $U^J$ is the liquid drop potential calculated by two-center model in addition with the rotational energy of the system calculated with rigid body moment of inertia. $R_i$ is the random force with Gaussian distribution,

$$\langle R_i(t) \rangle = 0,$$

$$\langle R_i(t)R_j(t') \rangle = 2\delta_{ij}\delta(t - t').$$

g_{ij}$ is the strength of the random force which depends on the friction tensor $\gamma_{ij}$ and temperature $T$ through the third line in Eq.(6), where $T^J =$
\( \sqrt{(E_{\text{c.m.}} + Q - E_{\text{shell}} - E_{J\text{rot}})/a} \) is defined in the case of compound ground state for each total angular momentum. The shell correction energy \( E_{\text{shell}} \) and the nuclear mass are taken from P. Möller’s calculations. The level density parameter \( a \) is taken approximately to be \( (A_p + A_t)/10 \) for massive nucleus.

Examples of trajectories obtained are displayed in Fig. 3 with four trajectories starting from the same contact point with the same momentum and evolving in the same liquid drop energy surface. It shows that the random force plays very crucial role in the formation of compound nucleus. In Fig. 3 two samples form compound nucleus and the others undergo a re-separation (quasi-fission). At the contact point only initial momentum in \( z \) degree of freedom is included because we assume that \( \alpha \) does not change in the approaching phase, and then no initial momentum should be considered in the \( \alpha \) degree of freedom. (In reality, nucleon exchanges would occur, which gives rise to a distribution, and maybe to initial momentum.) Calculating \( N \) trajectories for the same initial radial momentum \( p_0 \) and counting the number of trajectories, which form compound nucleus, as \( N' \), then a probability is given as

\[ F^J(p_0, T^J) = \frac{N'}{N}. \]

Because the radial momentum in the contact point is Gaussian distributed, centered at \( \tilde{p}_0^J \) due to a heating-up process by the dissipation-fluctuation dynamics,

\[ g^J(p_0, \tilde{p}_0^J, T^J) = \frac{1}{\sqrt{2\pi\mu T}}e^{-\frac{(p_0 - \tilde{p}_0^J)^2}{2\mu T}}, \]
then finally the formation probability takes the form,

\[
P_{\text{form}}(E_{\text{c.m.}}) = \int F^J(p_0, T) g^J(p_0, \bar{p}_0^J, T^J) dp_0,
\]

which gives an example of the statistical connection between approaching phase and formation phase. Here \( \bar{p}_0^J \), i.e., the average of \( p_0 \), is set to zero, according to the results by the surface friction model. However it should be noticed that \( \bar{p}_0^J = 0 \) does not always hold, for example, in lighter systems, such as \( ^{100}\text{Mo} + ^{100}\text{Mo} \). Inserting the results of Eq.(4) and Eq.(7) into Eq.(2), the fusion probability for each partial wave and consequently fusion cross section can be calculated.

2.3. Fusion cross section

With the method described in Sec. 2, \( P_{\text{stick}} \) and \( P_{\text{form}} \) are calculated for different partial waves in reactions \( ^{48}\text{Ca} + ^{243-251}\text{Bk} \). As an example, the results of \( P_{\text{stick}} \), \( P_{\text{form}} \) and \( P_{\text{fusion}} \) for \( ^{48}\text{Ca} + ^{247}\text{Bk} \) are shown in Fig. 4. It is obvious that the three probabilities increase with increasing incident energy, while in the angular momentum direction, a larger angular momentum gives smaller probabilities because the rotational energies increase both the Coulomb barrier in approaching phase and liquid drop saddle point in the formation phase.

After systematic calculation of \( P_{\text{stick}}(E_{\text{c.m.}}) \) and \( P_{\text{form}}^J(E^*) \) for each reaction and taking Eq.(3) into account, the fusion cross sections for \( ^{48}\text{Ca} + ^{243-251}\text{Bk} \) are calculated and shown in Fig. 5. Since the fusion cross section mainly depends on the bulk properties, such as Coulomb potential, liquid drop potential, the variation of \( \sigma_{\text{fusion}} \) for different targets is not very large. For example, at \( E^* = 20 \) MeV, the ratio of \( \sigma_{\text{fusion}} \) between targets \( ^{243}\text{Bk} \) and \( ^{251}\text{Bk} \) is only 5.85.

3. Calculation of residue cross sections and discussions

In order to calculate the residue cross sections, the HIVAP code, based on standard evaporation decay theory, is adopted. Before systematic calculations for \( \text{Ca} + \text{Bk} \), we try to obtain some parameters by fitting the measured 3\( n \) and 4\( n \) evaporation residue cross sections for \( ^{48}\text{Ca} + ^{248}\text{Cm} \). Actually the shell correction energies are the most crucial quantities in residue calculations, because they effectively give the fission barrier for SHE. They are not yet firmly predicted, thus we may use the shell correction energy from Ref.20 but with a free reduction parameter \( f \), namely, \( E_{\text{shell}} = f \cdot E_{\text{shell}0} \). The factor \( f \) is a reduction of the shell correction energy, and thus, that of the fission barrier in SHEs. Therefore, it gives rise to reductions of the absolute values of residue cross sections, but does not change general feature of the excitation functions, i.e., peak positions etc., though decreasing slopes in higher energies are a little affected. The introduction of the factor \( f \), thus, is appropriate for predictions of residue cross sections. Using fusion probability for \( ^{48}\text{Ca} + ^{248}\text{Cm} \) and the HIVAP code, \( f \) is determined to be 0.45. Results are shown in Fig. 6. It is seen that the residue cross section of the 3\( n \) and 4\( n \) channels are well reproduced.
with the value of \( f = 0.45 \). Using the same value of \( f \), the calculated residue cross sections for \( {}^{48}\text{Ca} + {}^{244}\text{Pu} \) are also coincide with the experimental data. Since the targets of the reactions we study have only one more proton, the value of \( f \) should work also in \( \text{Ca+}\text{Bk} \) case.

With all the ingredients that do not leave any ambiguity, systematic residue cross sections for \( {}^{48}\text{Ca} + {}^{243-251}\text{Bk} \) are calculated. The corresponding results are shown in Fig. 4. It is easy to see that because the shell correction energy gives rise to crucial effect on the fission barrier, the variation of the maximum residue cross section among different reactions is larger than that for the fusion cross section.

Fig. 4. The probabilities in the approaching phase, formation phase and their product for \( {}^{48}\text{Ca} + {}^{247}\text{Cm} \). (a) sticking probability, (b) formation probability, (c) fusion probability (product of sticking and formation probability).
Fig. 5. Calculated fusion cross sections for $^{48}$Ca + $^{243,251}$Bk reactions.

Fig. 6. Evaporation residue cross sections. The shell reduction parameter $f$ is set to 0.45 to reproduce the data in Ref.[1]

For $^{243}$Bk the maximum residue cross section is $\sigma_{res} = 0.19$ pb in $3n$ evaporation channel, while for $^{251}$Bk the corresponding value is 2.8 pb, one order larger. In order to show the importance of the shell effects to the residue cross section, the relation between maximum $\sigma_{res}$ and shell correction energy is given in Fig. 8.

In the present study, the fission barrier in decay process is $B_f = B_{LD} - E_{shell}$. Since the LD fission barrier $B_{LD}$ is very small in the reactions considered, the
Fig. 7. Systematic calculation of residue cross sections for $^{48}\text{Ca} + ^{243-251}\text{Bk}$. The dotted line, solid line, dash-dotted line and dashed line stands for $2n$, $3n$, $4n$, $5n$ evaporation channels, respectively.

Fission barrier mainly depends on the shell correction energy. Therefore in Fig. 8, when the shell correction is decreasing with increasing mass number, the maximum residue cross section for SHE is increasing. It shows that the shell correction is very important in the prediction of SHE, and consequently these predictions are very sensitive to the reliability of this parameter.

In Table 1, the relatively larger residue cross sections of $^{48}\text{Ca}$-induced reactions to synthesize SHE are listed. The maximum residue cross section is for the reaction $^{48}\text{Ca} + ^{251}\text{Bk}$ where $\sigma_{\text{res}} = 2.77$ pb. However according to the lifetime of the berkelium isotopes listed in Table 1, the lifetime of $^{251}\text{Bk}$ is too short to be a target since the experimental performance usually takes several weeks to explore the SHE events. According to this factor, the optimum reactions to synthesize $Z = 117$ are $^{48}\text{Ca} + ^{249}\text{Bk}$ with $\sigma_{\text{res}}(3n) = 1.04$ pb at $E_{\text{c.m.}} = 203.3$ MeV and $^{48}\text{Ca} + ^{247}\text{Bk}$ with $\sigma_{\text{res}}(3n) = 0.75$ pb at $E_{\text{c.m.}} = 204.4$ MeV. It should be mentioned that the absolute residue cross sections depend on the reduction factor $f$ of $E_{\text{shell}}$ of the compound.
Fig. 8. The relation between the maximum residue cross sections and corresponding shell correction energies taken from Ref.[20].

Table 1. The residue cross sections of 3n and 4n evaporation channels for the $^{48}$Ca induced reactions to synthesize $Z = 117$.

| Target | Lifetime  | $E_{c.m.}$ (MeV) | $\sigma_{res}$(pb) | $E_{c.m.}$ (MeV) | $\sigma_{res}$(pb) |
|--------|-----------|------------------|-------------------|------------------|-------------------|
| $^{243}$Bk | 4.50h     | 207.5            | 0.19              | 215.9            | 0.015             |
| $^{244}$Bk | 4.35h     | 206.1            | 0.09              | 215.1            | 0.045             |
| $^{245}$Bk | 4.94d     | 206.0            | 0.38              | 214.4            | 0.047             |
| $^{246}$Bk | 1.80d     | 204.5            | 0.22              | 213.4            | 0.14              |
| $^{247}$Bk | 1380y     | 204.4            | 0.75              | 212.6            | 0.15              |
| $^{248}$Bk | 23.7h     | 203.3            | 0.31              | 211.7            | 0.34              |
| $^{249}$Bk | 320d      | 203.3            | 1.04              | 211.0            | 0.35              |
| $^{250}$Bk | 3.2h      | 201.4            | 0.63              | 209.4            | 0.86              |
| $^{251}$Bk | 0.9h      | 200.9            | 2.77              | 208.4            | 1.25              |

system and the reliability of $E_{\text{shell}}$ itself. It has been confirmed that if the factor $f$ is changed, only the absolute values of $\sigma_{res}$ are changed, while the relativity of the $\sigma_{res}$ between different reactions and the incident energies correspond to the maximum $\sigma_{res}$ change with only negligible values. The result indicates that the reaction $^{48}$Ca + $^{249}$Bk is optimum, no matter which value $f$ takes.

4. Summary

As a summary, the fusion reactions where $^{48}$Ca bombards berkelium isotopes are studied with the two-step model, in which the fusion process is considered to include two consecutive phases – approaching phase and formation phase. In the approaching phase, empirical formula by W. J. Swiatecki et al. is adopted with the two parameters re-fitted to the superheavy systems. In the formation phase, two di-
mensional Langevin equations are used to study the evolution of the amalgamated system to the compound nucleus. Then, the HIVAP code is used to calculate the residue cross section. The results shows that an optimum reaction system is $^{48}$Ca + $^{249}$Bk and that an optimum $E_{\text{c.m.}} = 203.3$ MeV for 3n residue cross section 1.04 pb. Since the maximum value of the cross section is not extremely small and is within a capability of experiment nowadays, we expect experiment for the system be performed to result in synthesis of the new element with $Z = 117$. Of course, in principle, there are still other ways to synthesize $Z = 117$, for instance, Br + Pb, Se + Bi, Mn + U. However according to the two-step model, the residue cross section would be smaller because of the larger fusion hindrance. To calculate residue cross sections, another code KEWPIE 2 is now available, which is newly developed, carefully taking into account special features in heavy and superheavy region. In future, by using the new code KEWPIE and the two-step model, we will make a systematic prediction for heavier elements, not only with the hot fusion path, but also cold fusion path.

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References

1. Yu. Ts. Oganessian, V. K. Utyonkov, Yu. V. Lobanov et al., Phys. Rev. C 74, 044602 (2006); Phys. Rev. C 70, 064609 (2004); Phys. Rev. C 69, 021601 (2004).
2. C. W. Shen, G. Kosenko, Y. Abe, Phys. Rev. C 66, 061602R (2002); B. Bouriquet et al., Eur. Phys. J. A 22, 9 (2004); Y. Abe et al., Phys. Atom. Nucl. 69, 1101 (2006).
3. W. Li, N. Wang, J. F. Li, et al., Euro. Phys. Lett. 64, 750(2003).
4. N. Wang, X. Z. Wu, Z. X. Li, et al., Phys. Rev. C 74, 044604(2006).
5. W. J. Swiatecki, K. Siwek-Wilczynska, and J. Wilczynski, Phys. Rev. C 71, 014602 (2005).
6. Z. H. Liu, J. D. Bao, Phys. Rev. C 74, 057602(2006).
7. Y. Abe, Eur. Phys. J. A 13, 143 (2002).
8. Y. Abe, D. Boilley, B. G. Giraud et al., Phys. Rev. E 61, 1125 (2000).
9. W. Reisdorf (private communication).
10. P. Frobrich et al., Nucl. Phys. A 406, 557 (1983).
11. W. J. Swiatecki, Phys. Scr. 24, 113 (1981).
12. Y. Abe et al., Prog. Theor. Phys. Suppl. 146, 104(2002); Y. Abe et al., Acta Phys. Pol. B 34, 2091 (2003).
13. D. Boilley et al., Eur. Phys. J. A 18, 627 (2003).
14. K. Siwek-Wilczynska, E. Siemaszko and J. Wilczynski, Acta Phys. Pol. B 33, 451 (2002); K. Siwek-Wilczynska, J. Wilczynski, Phys. Rev. C 69, 024611 (2004).
15. M. G. Itkis et al., Nuovo Cimento A 111, 783 (1998).
16. D. Boilley et al., in preparation.
17. Y Abe et al., Proc. Cluster08, to appear in Intern. J. Modern Phys. E (2008).
18. T. Wada et al., Phys. Rev. Lett. 70, 3538 (1993); Y. Abe et al., Phys. Rep. 275, 49 (1996).
19. K. Sato et al., Z. Phys. A 290, 145 (1979).
20. P. Möller et al., Atom. Data Nucl. Data Tables 59, 185 (1995).
21. M. Dahlinger and D. Vermeulen, Nucl. Phys. A 376, 94 (1982).
22. A. Marchix, Ph. D. thesis in Oct. 2007, Caen University, France.