原子核集团结构和衰变

任 中 洲

同 济 大 学 物 理 科 学 与 工 程 学 院

中科院紫金山天文台　2021. 03

报告提纲

一 轻原子核的集团态（结团态）研究：

^{20}Ne ,^{12}Be…

二 重原子核的集团效应：

重核 alpha衰变和集团放射性等

三 小 结

原子核结构理论简述

- 原子核内核子运动已有研究集中在：单粒子运动和集体运动。
- 单粒子运动：壳模型或平均场模型描述。集体运动：Bohr-Mottelson模型，互作用玻色子模型（IBM）描述等。　徐躬耦先生，王顺金老师，……
- 对核内核子间结团结构和结团态（集团态）研究稀少（相对上述两种模式）
- 近来研究表明，一些稳定核和不稳定核有集团态。这些态无法用壳模型或集体模型给出，如^{12}C的Hoyle态。

原子核结构理论简述

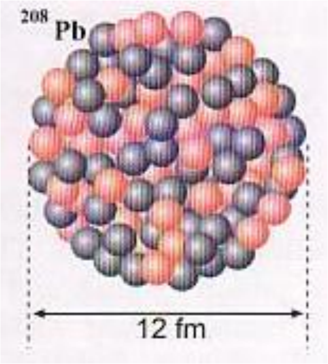
- 稳定线核基态性质和单粒子谱 → 壳模型 （Mayer-Jensen）
- 原子核低激发振动和转动谱 → 集体模型 （Bohr-Mottelson）
- 原子核结团态（集团态）性质研究 → ？？？

集团结构研究的新进展

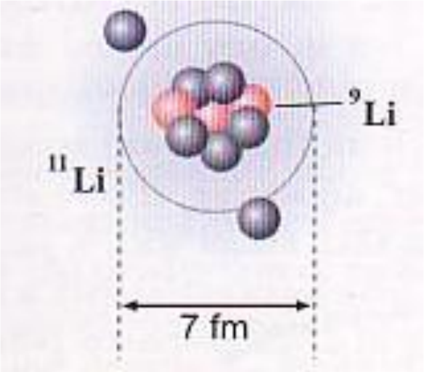
- 在轻核中，一些状态集团运动模式起主导作用。
- 在重核中存在alpha衰变和集团放射性，所以集团态的研究也很重要。
- 到目前为止，人们对于不稳定核的集团结构和集团态还不是非常清楚，预期新现象，新规律。
- 因此，原子核集团结构的研究最近是核物理和核天体物理的一个热点课题。

教科书：稳定核密度近似常数（^{208}Pb）
不稳定核：核密度变化，集团态出现

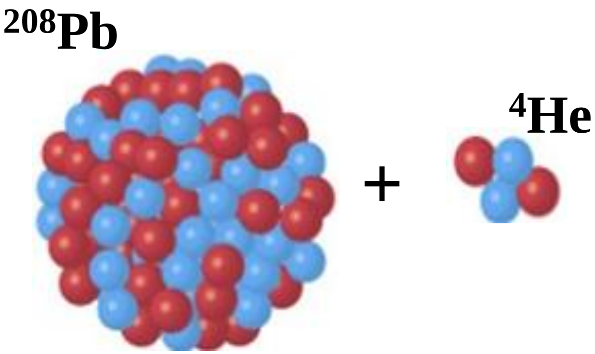
稳定核
^{208}Pb



奇特核
^{11}Li



不稳定核
^{212}Po 集团态



LETTER

How atomic nuclei cluster

J.-P. Ebran[1], E. Khan[2], T. Nikšić[3] & D. Vretenar[3]

Nucleonic matter displays a quantum-liquid structure, but in some cases finite nuclei behave like molecules composed of clusters of protons and neutrons. Clustering is a recurrent feature in light nuclei, from beryllium to nickel[1–3]. Cluster structures are typically observed as excited states close to the corresponding decay threshold; the origin of this phenomenon lies in the effective nuclear interaction, but the detailed mechanism of clustering in nuclei has not yet been fully understood. Here we use the theoretical framework of energy-density functionals[4,5], encompassing both cluster and quantum liquid-drop aspects of nuclei, to show that conditions for cluster formation can in part be traced back to the depth of the confining nuclear potential. For the illustrative example of neon-20, we show that the depth of the potential determines the energy spacings between single-nucleon orbitals in deformed nuclei, the localization of the corresponding wavefunctions and, therefore, the degree of nucleonic density clustering. Relativistic functionals, in particular, are characterized by deep single-nucleon potentials. When compared to non-relativistic functionals that yield similar ground-state properties (binding energy, deformation, radii), they predict the occurrence of much more pronounced cluster structures. More generally, clustering is considered as a transitional phenomenon between crystalline and quantum-liquid phases of fermionic systems.

举例一：欧洲科学家，能量密度泛函研究原子核集团态

Energy density functional theory

***Nature* 487, 341–344 (2012)**

RESEARCH LETTER

Ebran, Khan, Nikšić & Vretenar， Nature：
核子大小和核子间距相当时，集团主导

Use the theoretical framework of energy density functionals, encompassing both cluster and quantum liquid-drop aspects of nuclei

LETTER RESEARCH

a=b/r_0

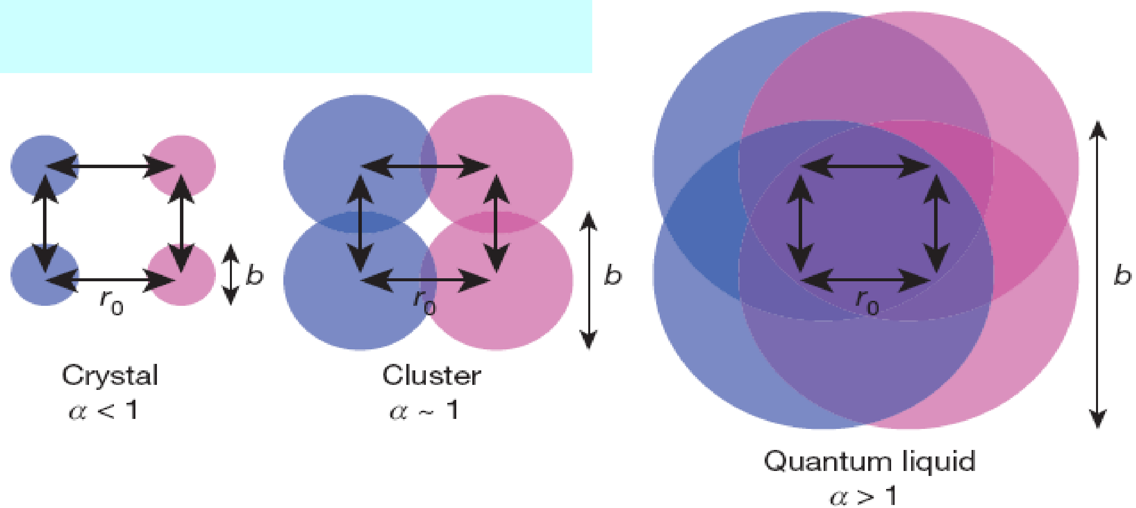


Figure 4 | Schematic illustration of the transition from a crystalline to a quantum liquid phase, including the cluster phase. The dimensionless parameter $\alpha = b/r_0$, where b is the dispersion of the fermion wavefunction and r_0 the typical inter-fermion distance, quantifies nuclear clustering. For a harmonic oscillator $\alpha = (\hbar R)^{1/2}(2mV_0)^{-1/4} r_0^{-1}$, where V_0 is the depth of the potential, R the radius of the system, m the mass of the nucleon and $\hbar$ Planck's constant/2π.

举例二：格点有效场理论研究A=3,4,6,12核
Lattice effective field theory

PRL **104,** 142501 (2010) PHYSICAL REVIEW LETTERS week ending 9 APRIL 2010

Lattice Effective Field Theory Calculations for $A = 3, 4, 6, 12$ Nuclei

Evgeny Epelbaum,[1,2] Hermann Krebs,[2,1] Dean Lee,[3,2] and Ulf-G. Meißner[2,1,4]

[1]*Institut für Kernphysik (IKP-3) and Jülich Center for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[2]*Helmholtz-Institut für Strahlen- und Kernphysik (Theorie) and Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn, Germany*
[3]*Department of Physics, North Carolina State University, Raleigh, North Carolina 27695, USA*
[4]*Institute for Advanced Simulation (IAS-4), Forschungszentrum Jülich, D-52425 Jülich, Germany*

(Received 29 December 2009; published 8 April 2010)

We present lattice results for the ground state energies of tritium, helium-3, helium-4, lithium-6, and carbon-12 nuclei. Our analysis includes isospin breaking, Coulomb effects, and interactions up to next-to-next-to-leading order in chiral effective field theory.

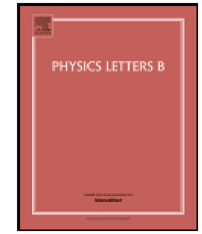
Lattice effective field theory (^{4}He-^{28}Si)

ELSEVIER

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb



Lattice effective field theory for medium-mass nuclei

CrossMark

Timo A. Lähde [a,*], Evgeny Epelbaum [b], Hermann Krebs [b], Dean Lee [c], Ulf-G. Meißner [a,d,e], Gautam Rupak [f]

[a] *Institute for Advanced Simulation, Institut für Kernphysik, and Jülich Center for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[b] *Institut für Theoretische Physik II, Ruhr-Universität Bochum, D-44870 Bochum, Germany*
[c] *Department of Physics, North Carolina State University, Raleigh, NC 27695, USA*
[d] *Helmholtz-Institut für Strahlen- und Kernphysik and Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn, Germany*
[e] *JARA – High Performance Computing, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[f] *Department of Physics and Astronomy, Mississippi State University, Mississippi State, MS 39762, USA*

A R T I C L E I N F O

Article history:
Received 15 January 2014
Received in revised form 28 February 2014
Accepted 12 March 2014
Available online 20 March 2014
Editor: W. Haxton

Keywords:
Nuclear structure
Chiral effective field theory
Lattice Monte Carlo

A B S T R A C T

We extend Nuclear Lattice Effective Field Theory (NLEFT) to medium-mass nuclei, and present results for the ground states of alpha nuclei from ^{4}He to ^{28}Si, calculated up to next-to-next-to-leading order (NNLO) in the EFT expansion. This computational advance is made possible by extrapolations of lattice data using multiple initial and final states. For our soft two-nucleon interaction, we find that the overall contribution from multi-nucleon forces must change sign from attractive to repulsive with increasing nucleon number. This effect is not produced by three-nucleon forces at NNLO, but it can be approximated by an effective four-nucleon interaction. We discuss the convergence of the EFT expansion and the broad significance of our findings for future *ab initio* calculations.

我们2012研究^{20}Ne Phys. Rev. C 86 (2012) 014301

PHYSICAL REVIEW C **86**, 014301 (2012)

New concept for the ground-state band in ^{20}Ne within a microscopic cluster model

Bo Zhou,[1,2,*] Zhongzhou Ren,[1,3,†] Chang Xu,[1,‡] Y. Funaki,[4] T. Yamada,[5] A. Tohsaki,[2] H. Horiuchi,[2,6] P. Schuck,[7,8] and G. Röpke[9]

[1]*Department of Physics, Nanjing University, Nanjing 210093, China*
[2]*Research Center for Nuclear Physics, Osaka University, Osaka 567-0047, Japan*
[3]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[4]*Nishina Center for Accelerator-Based Science, The Institute of Physical and Chemical Research (RIKEN), Wako 351-0198, Japan*
[5]*Laboratory of Physics, Kanto Gakuin University, Yokohama 236-8501, Japan*
[6]*International Institute for Advanced Studies, Kizugawa 619-0225, Japan*
[7]*Institut de Physique Nucléaire, CNRS, UMR 8608, F-91406 Orsay, France*
[8]*LPMMC, UMR 5493, F-38042 Grenoble 9, France*
[9]*Institut für Physik, Universität Rostock, D-18051 Rostock, Germany*

(Received 30 March 2012; revised manuscript received 24 May 2012; published 3 July 2012)

We propose a generalized wave function based on the flexible original THSR (Tohsaki, Horiuchi, Schuck, Röpke) wave function [A. Tohsaki *et al.*, Phys. Rev. Lett. **87**, 192501 (2001)], which is applicable to studies of general cluster structures in nuclei. The ground-state band in ^{20}Ne is investigated by using this generalized wave function and the energies obtained agree well with the experimental values. Moreover, it is found that the single generalized THSR wave functions almost completely coincide with the exact solutions of the $\alpha+^{16}$O resonating group method for the ground-state band in ^{20}Ne. For the ground state, for instance, the squared overlap between them is 99.3%. This indicates that the THSR model can also be extended to study more compact cluster states in nuclei such as, e.g., the ground-state band in ^{20}Ne.

2013年4月，任中洲等在北京Kavli理论物理研究所举办原子核结团物理会议，推动这方面研究

中国科学院卡弗里理论物理研究所(Kavli)

Program: Clustering Aspects in Nuclei

- **Date : from 2013-04-01 to 2013-04-26**
- **Local coordinators : Zhongzhou Ren (Chair, Nanjing University), Chang Xu (Nanjing University), Furong Xu (Peking University), Zaiguo Gan (Institute of Modern Physics), Shan-Gui Zhou (KITPC/ITP-CAS)**
- **International coordinators : Zhongzhou Ren (Chair, Nanjing University), Yanlin Ye (Peking University), W. Mittig (Michigan State University), P. Van Isacker (GANIL), G. Audi (Université de Paris Sud)**

国内 2013.6--2014.7：集团研究三篇PRL (南大，北大--兰州所，上海所)， rare

1. Bo Zhou(周波), Y. Funaki, H. Horiuchi, Zhongzhou Ren (任中洲), G. Röpke, P. Schuck, A. Tohsaki, Chang Xu(许昌), and T. Yamada，
   PRL 110, 262501 (2013)

2. Z. H. Yang (杨再宏), Y. L. Ye (叶沿林), Z. H. Li (李智焕), J. L. Lou (楼建玲), J. S. Wang (王建松)…
   PRL 112, 162501 (2014)

3. W. B. He (何万兵), Y. G. Ma (马余刚), X. G. Cao (曹喜光),X. Z. Cai (蔡翔舟),and G. Q. Zhang (张国强)
   PRL 113, 032506 (2014)

南京大学任中洲课题组

PRL 110, 262501 (2013): 非局域集团观点

PRL **110,** 262501 (2013) PHYSICAL REVIEW LETTERS week ending 28 JUNE 2013

Nonlocalized Clustering: A New Concept in Nuclear Cluster Structure Physics

Bo Zhou,[1,2,3,*] Y. Funaki,[3,†] H. Horiuchi,[2,4] Zhongzhou Ren,[1,5,‡] G. Röpke,[6] P. Schuck,[7,8] A. Tohsaki,[2]
Chang Xu,[1] and T. Yamada[9]

[1]*Department of Physics, Nanjing University, Nanjing 210093, China*
[2]*Research Center for Nuclear Physics (RCNP), Osaka University, Osaka 567-0047, Japan*
[3]*Nishina Center for Accelerator-Based Science, The Institute of Physical and Chemical Research (RIKEN), Wako 351-0198, Japan*
[4]*International Institute for Advanced Studies, Kizugawa 619-0225, Japan*
[5]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[6]*Institut für Physik, Universität Rostock, D-18051 Rostock, Germany*
[7]*Institut de Physique Nucléaire, Université Paris-Sud, IN2P3-CNRS, UMR 8608, F-91406, Orsay, France*
[8]*Laboratoire de Physique et Modélisation des Milieux Condensés, CNRS-UMR 5493, F-38042 Grenoble Cedex 9, France*
[9]*Laboratory of Physics, Kanto Gakuin University, Yokohama 236-8501, Japan*

(Received 5 April 2013; revised manuscript received 17 May 2013; published 24 June 2013)

We investigate the $\alpha + {}^{16}\mathrm{O}$ cluster structure in the inversion-doublet band ($K^\pi = 0_1^\pm$) states of $^{20}\mathrm{Ne}$ with an angular-momentum-projected version of the Tohsaki-Horiuchi-Schuck-Röpke (THSR) wave function, which was successful "in its original form" for the description of, e.g., the famous Hoyle state. In contrast with the traditional view on clusters as localized objects, especially in inversion doublets, we find that these *single* THSR wave functions, which are based on the concept of nonlocalized clustering, can well describe the $K^\pi = 0_1^-$ band and the $K^\pi = 0_1^+$ band. For instance, they have 99.98% and 99.87% squared overlaps for 1^- and 3^- states (99.29%, 98.79%, and 97.75% for 0^+, 2^+, and 4^+ states), respectively, with the corresponding exact solution of the $\alpha + {}^{16}\mathrm{O}$ resonating group method. These astounding results shed a completely new light on the physics of low energy nuclear cluster states in nuclei: The clusters are nonlocalized and move around in the whole nuclear volume, only avoiding mutual overlap due to the Pauli blocking effect.

在新构造的集团波函数中引入可以描述集团关联的新自由度。

在两种极端条件下可以变为传统的局域集团波函数和非局域的凝聚波函数。

将这个新的集团波函数应用到^{20}Ne的结团结构计算中，发现新波函数可以很好地描述^{20}Ne的正宇称转动带和负宇称转动带。

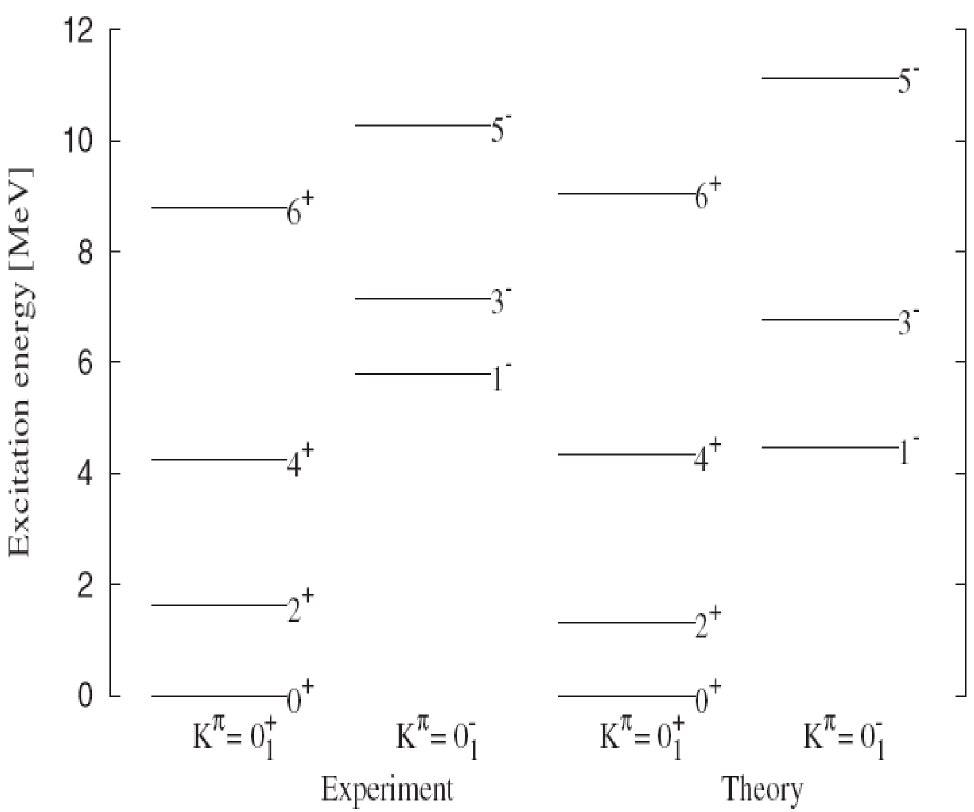


FIG. 4. The energy levels of the inversion doublet bands in ^{20}Ne reproduced by the hybrid wave function compared with the experimental levels.

PRL 110, 262501 (2013)

- **Zhou, …, Ren,…　PRL(2013) 论文结论：**
- 研究发现^{20}**Ne**的微观波函数是具有非局域特点的集团凝聚波函数。
- 在此之前，人们一直认为轻核中的集团结构具有类刚体的特点，这些集团在原子核中做局域的集团运动。
- 我们的研究清楚地表明，^{20}**Ne**中的^{4}**He**集团和^{16}**O**集团实际在做非局域集团运动，而非通常认为的局域运动。

国内研究组成果举例：PRL 2014， 北大叶沿林+兰州王建松课题组：^{12}Be中集团态实验研究

PRL **112,** 162501 (2014) PHYSICAL REVIEW LETTERS week ending 25 APRIL 2014

Observation of Enhanced Monopole Strength and Clustering in ^{12}Be

Z. H. Yang (杨再宏),[1] Y. L. Ye (叶沿林),[1,*] Z. H. Li (李智焕),[1] J. L. Lou (楼建玲),[1] J. S. Wang (王建松),[2] D. X. Jiang (江栋兴),[1] Y. C. Ge (葛愉成),[1] Q. T. Li (李奇特),[1] H. Hua (华辉),[1] X. Q. Li (李湘庆),[1] F. R. Xu (许甫荣),[1] J. C. Pei (裴俊琛),[1] R. Qiao (乔锐),[1] H. B. You (游海波),[1] H. Wang (王赫),[1,3] Z. Y. Tian (田正阳),[1] K. A. Li (李阔昂),[1] Y. L. Sun (孙叶磊),[1] H. N. Liu (刘红娜),[1,3] J. Chen (陈洁),[1] J. Wu (吴锦),[1,3] J. Li (李晶),[1] W. Jiang (蒋伟),[1] C. Wen (文超),[1,3] B. Yang (杨彪),[1] Y. Y. Yang (杨彦云),[2] P. Ma (马朋),[2] J. B. Ma (马军兵),[2] S. L. Jin (金仕纶),[2] J. L. Han (韩建龙),[2] and J. Lee (李晓菁)[3]

[1]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*

[2]*Institute of Modern Physics, Chinese Academy of Science, Lanzhou 730000, China*

[3]*RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*

北大叶沿林PRL:虽然集团态理论研究有大进展[4,6-8]，但实验仅证实少数集团态，主要是关于稳定核。

Recently it has been recognized that, compared to usual α-conjugate nuclei [5], a much larger number of cluster (molecular) configurations can be formed in an unstable nucleus, owing to numerous combinations of valence nucleons with the cluster cores [4]. Studies on such a new aspect of nuclear clustering have acquired strong interest in recent years [4,6]. However, although remarkable progress has been made from the theoretical side [4,6–8], only a few cluster states have been experimentally justified, focusing mainly on the stable nuclei [9].

[8] B. Zhou, Y. Funaki, H. Horiuchi, Z. Ren, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, and T. Yamada, Phys. Rev. Lett. **110**, 262501 (2013).

上海所马余刚组结团研究　ＰＲＬ论文

PRL 113, 032506 (2014)　PHYSICAL REVIEW LETTERS　week ending 18 JULY 2014

Giant Dipole Resonance as a Fingerprint of α Clustering Configurations in ^{12}C and ^{16}O

W. B. He (何万兵),[1,2] Y. G. Ma (马余刚),[1,3,*] X. G. Cao (曹喜光),[1,†] X. Z. Cai (蔡翔舟),[1] and G. Q. Zhang (张国强)[1]
[1]Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China
[2]University of the Chinese Academy of Sciences, Beijing 100080, China
[3]Shanghai Tech University, Shanghai 200031, China

ground state [36]. There are also many different configurational descriptions implying the α cluster structure in ^{20}Ne and ^{24}Mg, such as three-dimensional shuttle shape [5,13] or chain states [37,38] as well as nonlocalized cluster states [39]. Therefore, it is highly necessary and important [40] to look for new probes to diagnose different configurations for α-conjugate nuclei around the cluster decay threshold.

[39] B. Zhou, Y. Funaki, H. Horiuchi, Z. Ren, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, and T. Yamada, Phys. Rev. Lett. 110, 262501 (2013).

在20Ne和24Mg中，有很多显示alpha结团结构的工作，例如三维形状的描述[5,13]或链式态[37,38]，以及非局域化结团态[39]。

IOP Publishing

Reports on Progress in Physics

Rep. Prog. Phys. 77 (2014) 096301 (46pp)

doi:10.1088/0034-4885/77/9/096301

本文十余处引用上述两篇PRL文章。

Review Article

Unified studies of chemical bonding structures and resonant scattering in light neutron-excess systems, ^{10,12}Be

Makoto Ito[1,2,3] and Kiyomi Ikeda[2,3]

[1] Department of Pure and Applied Physics, Kansai Universit

[2] Research Center for Nuclear Physics (RCNP), Osaka Univ

Japan

[3] RIKEN Nishina Center for Accelerator-based Science, RIK

In a recent experiment [62], the IS monopole matrix element for the 0_3^+ state, corresponding to the band head of $\alpha + {}^8\mathrm{He}_{\mathrm{g.s.}}$, has been measured [62]. The observed $|\tilde{M}(\mathrm{IS})|$ strength is about 2.08, which is consistent with the GTCM calculation, $|\tilde{M}(\mathrm{IS})| = 3.53$, shown in table 5. The discrepancy between the experiment and the theory is expected to be the decay effect of the 0_3^+ state. The observed monopole strength contains the branching ratio of ^{12}Be, which finally decays into the α and ${}^8\mathrm{He}_{\mathrm{g.s.}}$ fragments, but theoretical calculation does not consider this decay effect. Therefore, the theoretical monopole strength calculated here should be reduced by the branching ratio, and the overestimation of the theoretical calculation is considered to be reasonable. The decay effect should be included in the GTCM calculation to compare with the observed strength directly.

[62] Yang Z H *et al* 2014 *Phys. Rev. Lett.* **112** 162501

IOP Publishing Reports on Progress in Physics

Rep. Prog. Phys. **77** (2014) 096301 (46pp) doi:10.1088/0034-4885/77/9/096301

Review Article

Ikeda等的综述文章引用

Unified studies of chemical bonding structures and resonant scattering in light neutron-excess systems, ^{10,12}Be

Makoto Ito[1,2,3] **and Kiyomi Ikeda**[2,3]

[1] Department of Pure and Applied Physics, Kansai University, Yamatecho, 3-3-35, Suita, Japan
[2] Research Center for Nuclear Physics (RCNP), Osaka University, Mihogaoka 10-1, Suita 567-0047, Japan
[3] RIKEN Nishina Center for Accelerator-based Science, RIKEN, Wako,351-0198, Saitama, Japan

[22] Bo Zhou, Funaki Y, Horiuchi H, Zhongzhou Ren, Röpke G, Schuck P, Tohsaki A, Chang Xu and Yamada T 2013 *Phys. Rev. Lett.* **110** 262501

我们论文被美国耶鲁大学Iachello教授等引用

PRL **114,** 192504 (2015) PHYSICAL REVIEW LETTERS week ending 15 MAY 2015

Origin of Low-Lying Enhanced *E*1 Strength in Rare-Earth Nuclei

M. Spieker,[1,*] S. Pascu,[1,2] A. Zilges,[1] and F. Iachello[3]
[1]*Institut für Kernphysik, Universität zu Köln, Zülpicher Straße 77, D-50937 Köln, Germany*
[2]*National Institute for Physics and Nuclear Engineering, R-77125 Bucharest-Magurele, Romania*
[3]*Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, Connecticut 06520-8120, USA*
(Received 16 October 2014; revised manuscript received 5 March 2015; published 12 May 2015)

Recently, an exploratory calculation for ^{212}Po was presented [31], indicating the existence of ^{208}Pb + α configurations when four-particle correlations are added to the shell-model calculations. This calculation provided a first hint at how to extend the well-established Tohsaki-Horiuchi-Schuck-Röpke wave function concept used for α-like condensates in light nuclei [21,32–34] to heavier nuclei. However, the general existence of α clustering in

[31] G. Röpke, P. Schuck, Y. Funaki, H. Horiuchi, Z. Ren, A. Tohsaki, C. Xu, T. Yamada, and B. Zhou, Phys. Rev. C **90**, 034304 (2014).

[34] B. Zhou, Y. Funaki, H. Horiuchi, Z. Ren, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, and T. Yamada, Phys. Rev. Lett. **110**, 262501 (2013).

这个计算提供了第一个线索，关于如何扩展轻核集团模型（THSR波函数）

[31]Roepke…Ren…, PRC90, 034304(2014)
[34]Zhou…Ren…, PRL110, 262501(2013)

We develop cluster model (THSR) from N=Z=Even nuclei (previous researches) to N=Z+1 nuclei (^{9}Be…, Lyu, Ren,..Horiuchi,…PRC 2015). Schematic Fig.:

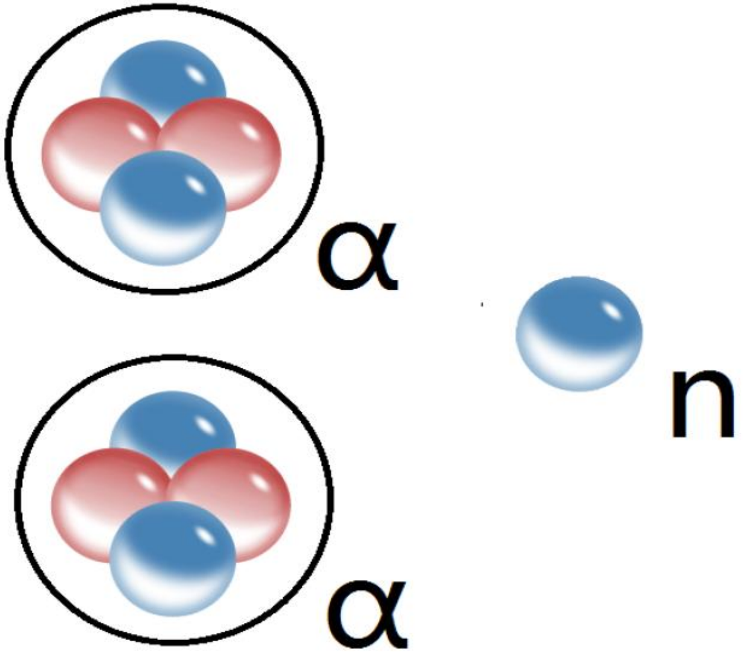


Figure: Cluster structure of ^{9}Be.

Lyu, Ren,… PRC2015: ^{9}Be(α+α+n) coupling of single-particle and cluster motions

PHYSICAL REVIEW C **91**, 014313 (2015)

Investigation of ^{9}Be from a nonlocalized clustering concept

Mengjiao Lyu,[1,2,*] Zhongzhou Ren,[1,3,†] Bo Zhou,[1,4,‡] Yasuro Funaki,[5] Hisashi Horiuchi,[2,6] Gerd Röpke,[7] Peter Schuck,[8,9] Akihiro Tohsaki,[2] Chang Xu,[1] and Taiichi Yamada[10]
[1] *School of Physics and Key Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, China*
[2] *Research Center for Nuclear Physics (RCNP), Osaka University, Osaka 567-0047, Japan*

The nonlocalized aspect of clustering, which is a new concept for self-conjugate nuclei, is extended for the investigation of the $N \neq Z$ nucleus ^{9}Be. A modified version of the Tohsaki-Horiuchi-Schuck-Röpke (THSR) wave function is introduced with a new phase factor. It is found that the constructed negative-parity THSR wave function is very suitable for describing the cluster states of ^{9}Be. Namely, the nonlocalized clustering is shown to prevail in ^{9}Be. The calculated binding energy and radius of ^{9}Be are consistent with calculations in other models and with experimental values. The squared overlaps between the single THSR wave function and the Brink + generator coordinate method wave function for the $3/2^{-}$ rotational band of ^{9}Be are found to be near 96%. Furthermore, by showing the density distribution of the ground state of ^{9}Be, the π-orbit structure is naturally reproduced by using this THSR wave function.

The effective nucleon-nucleon interaction of ^{9}Be : the Volkov potential + spin-orbit potential

- The Hamiltonian of ^{9}Be

$$H = \sum_{i=1}^{9} T_i - T_{c.m.} + \sum_{i<j}^{9} V_{ij}^N + \sum_{i<j}^{9} V_{ij}^C + \sum_{i<j}^{9} V_{ij}^{ls}$$

- Volkov No. 2 used as the central force of nucleon-nucleon potential.

$$V_{ij}^N = \{V_1 e^{-\alpha_1 r_{ij}^2} - V_2 e^{-\alpha_2 r_{ij}^2}\}\{W - M\hat{P}_\sigma \hat{P}_\tau + B\hat{P}_\sigma - H\hat{P}_\tau\}$$

- Two-body type G3RS term taken as the spin-orbit interaction.

$$V_{ij}^{ls} = V_0^{ls}\{e^{-\alpha_1 r_{ij}^2} - e^{-\alpha_2 r_{ij}^2}\}\mathbf{L}\cdot\mathbf{S}\hat{P}_{31}$$

Low energy states of ^{9}Be in cluster model (THSR), PRC 2015 , Lyu, Ren, …, Horiuchi,…

Excitation energy

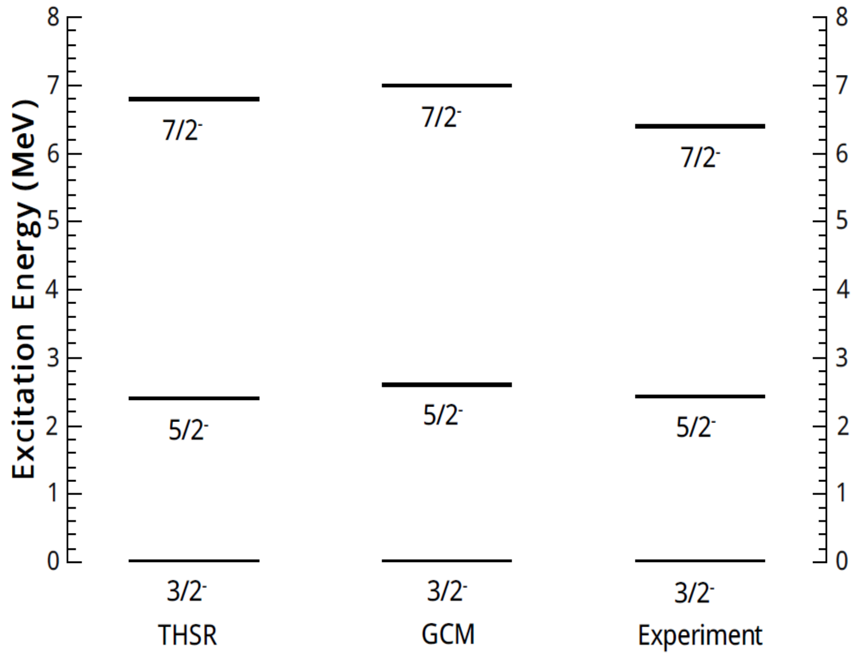
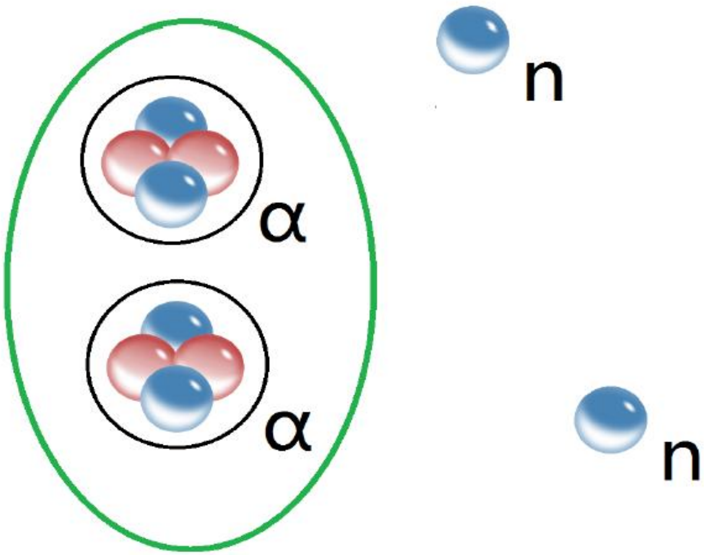


Figure: Excitation energy calculated with both the THSR wave function and the GCM method for the $3/2^{-}$ rotational band head.

We develop cluster model (THSR) from N=Z=Even nuclei (previous researches) to N=Z+2 nuclei (^{10}Be…, Lyu, Ren,..Horiuchi,…,PRC, 2016).



Schematic Fig.: Cluster structure of ^{10}Be

PHYSICAL REVIEW C **93**, 054308 (2016)

Investigation of ^{10}Be and its cluster dynamics with the nonlocalized clustering approach

Mengjiao Lyu,[1,2,*] Zhongzhou Ren,[1,3,†] Bo Zhou,[4,‡] Yasuro Funaki,[5] Hisashi Horiuchi,[2,6] Gerd Röpke,[7] Peter Schuck,[8,9] Akihiro Tohsaki,[2] Chang Xu,[1] and Taiichi Yamada[10]

[1]*School of Physics and Key Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, China*

[2]*Research Center for Nuclear Physics (RCNP), Osaka University, Osaka 567-0047, Japan*

[3]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

[4]*Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan*

[5]*Nishina Center for Accelerator-Based Science, Institute of Physical and Chemical Research (RIKEN), Wako 351-0198, Japan*

[6]*International Institute for Advanced Studies, Kizugawa 619-0225, Japan*

[7]*Institut für Physik, Universität Rostock, D-18051 Rostock, Germany*

[8]*Institut de Physique Nucléaire, Université Paris-Sud, IN2P3-CNRS, UMR 8608, F-91406, Orsay, France*

[9]*Laboratoire de Physique et Modélisation des Milieux Condensés, CNRS-UMR 5493, F-38042 Grenoble Cedex 9, France*

[10]*Laboratory of Physics, Kanto Gakuin University, Yokohama 236-8501, Japan*

(Received 24 December 2015; revised manuscript received 4 April 2016; published 5 May 2016)

We extend the concept of nonlocalized clustering to the nucleus ^{10}Be with proton number $Z = 4$ and neutron number $N = 6$ ($N = Z + 2$). The Tohsaki-Horiuchi-Schuck-Röpke (THSR) wave function is formulated for the description of different structures of ^{10}Be. Physical properties such as energy spectrum and root-mean-square

^{10}Be集团模型结果与实验和其他比较

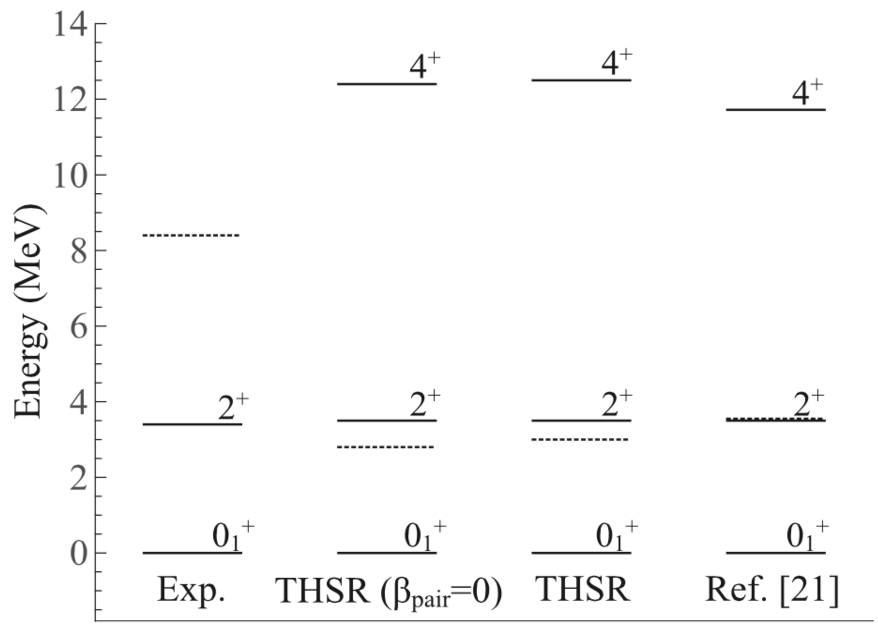


FIG. 3. The 0^+ ground state of ^{10}Be and its rotational band. "THSR" denotes calculated results with the THSR wave function. "THSR ($\beta_{\text{pair}} = 0$)" denotes calculated results with the THSR wave function and the $\beta_{\text{pair}} = 0$ limit. "Ref. [21]" denotes the results of the AMD method [21]. "Exp." denotes the experimental result. The dashed lines indicate the corresponding $\alpha + \alpha + n + n$ threshold -55.2 MeV.

Microscopic clustering in light nuclei

Freer等人的RMP论文专节介绍我们工作，指出我们发展集团模型算^{10}Be等

Martin Freer*

School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

3. Neutron-rich Be isotopes

Extended THSR wave functions have also been applied to neutron-rich nuclei. Since the container describing valence neutrons will have size parameters different from the container for the core part of the system, the use of the extended THSR wave function for neutron-rich nuclei is quite natural. Here we report the work of Lyu *et al.* (2015, 2016) which treats ^{9}Be and ^{10}Be, respectively.

In the case of ^{9}Be, the valence-neutron wave function $F(\vec{r})$ in the extended THSR wave function should have negative parity, and it is given by

$$F_n(\vec{r}) = \int d\vec{R} \exp\left(-\sum_{k=x}^{z} \frac{R_k^2}{\beta_k^2}\right) \exp(i\phi_R) \exp\left[-\frac{(\vec{r}-\vec{R})^2}{2b^2}\right]. \qquad (5.31)$$

The phase factor $\exp(i\phi_R)$ makes the parity of $F_n(\vec{r})$ negative. Lyu *et al.* (2015) treated the ground rotational-band levels $3/2^-$, $5/2^-$, and $7/2^-$ and found that the extended THSR wave functions of these levels have about 95% squared overlaps with the wave functions obtained by the GCM calculation by using $2\alpha + n$ three-body Brink wave functions.

In the case of ^{10}Be, the energy spectra of two rotational bands upon the ground state and the 0_2^+ state were calculated using single extended THSR wave functions and were compared with those obtained by AMD calculations (Suhara and Kanada-En'yo, 2010; Kobayashi and Kanada-En'yo, 2012). For the ground band, the extended THSR wave functions where two valence neutrons occupy the orbit $F_n(\vec{r})$ were used. The modifications of these extended THSR wave functions were also made by introducing the distance parameter $\vec{R}_{\rm pair}$ between the c.m. of the 2α system and the c.m. of the $2n$ system. It was reported that both kinds of extended THSR wave functions give very similar energy spectra compared to that of the AMD calculation (Kobayashi and Kanada-En'yo, 2012). For the excited band, the extended THSR wave functions were constructed by accommodating two valence neutrons into the σ-orbit-type single-neutron orbit. The obtained energy spectrum is very similar to but a little higher than the AMD energy spectra (Suhara and Kanada-En'yo, 2010; Kobayashi and Kanada-En'yo, 2012). The extended THSR wave function of the 0_2^+ state is not orthogonalized to that of the ground state, but the squared overlap between them is as small as 1.4%. We see thus that the wave functions as simple as the single extended THSR wave functions give very good results quite similar to AMD calculations.

Lyu, M., Z. Ren, B. Zhou, Y. Funaki, H. Horiuchi, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, and T. Yamada, 2015, "Investigation of 9Be from a nonlocalized clustering concept," Phys. Rev. C **91**, 014313.

Lyu, M., Z. Ren, B. Zhou, Y. Funaki, H. Horiuchi, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, and T. Yamada, 2016, "Investigation of 10Be and its cluster dynamics with the nonlocalized clustering approach," Phys. Rev. C **93**, 054308.

我们^{9}Be和^{10}Be工作被引用

^{9}B，发展结团模型，新程序，丰Z，库仑势，计入质子自由度和集团自由度耦合

PHYSICAL REVIEW C **97**, 054323 (2018)

Investigation of the ^{9}B nucleus and its cluster-nucleon correlations

Qing Zhao,[1,*] Zhongzhou Ren,[2,†] Mengjiao Lyu,[3,‡] Hisashi Horiuchi,[3,4] Yasuro Funaki,[5] Gerd Röpke,[6] Peter Schuck,[7,8] Akihiro Tohsaki,[3] Chang Xu,[1] Taiichi Yamada,[5] and Bo Zhou[9,10]

[1]*School of Physics and Key Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, China*
[2]*School of Physics Science and Engineering, Tongji University, Shanghai 200092, China*
[3]*Research Center for Nuclear Physics (RCNP), Osaka University, Osaka 567-0047, Japan*
[4]*International Institute for Advanced Studies, Kizugawa 619-0225, Japan*
[5]*Laboratory of Physics, Kanto Gakuin University, Yokohama 236-8501, Japan*
[6]*Institut für Physik, Universität Rostock, D-18051 Rostock, Germany*
[7]*Institut de Physique Nucléaire, Université Paris-Sud, IN2P3-CNRS, UMR 8608, F-91406, Orsay, France*
[8]*Laboratoire de Physique et Modélisation des Milieux Condensés, CNRS-UMR 5493, F-38042 Grenoble Cedex 9, France*
[9]*Institute for International Collaboration, Hokkaido University, Sapporo 060-0815, Japan*
[10]*Department of Physics, Hokkaido University, 060-0810 Sapporo, Japan*

^{9}B集团能谱与实验比较，高激发能也符合好

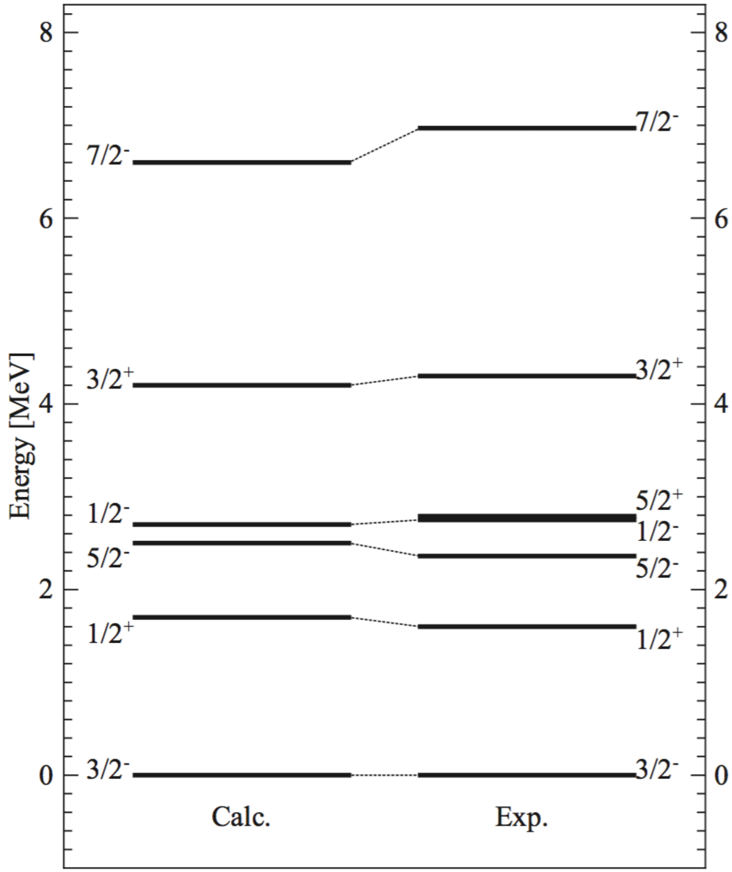


FIG. 8. Theoretical and experimental energy spectra of ^{9}B. The states with higher energy, which are found in experiment, are not considered in our calculation because of the limitation of computation power.

2016年 KITPC活动 任中洲 等组织

KITPC
中国科学院卡弗里理论物理研究所
Kavli Institute for Theoretical Physics China at the Chinese Academy of Sciences
开放交融
求真创新

HOME | ACTIVITIES | OUTREACH | TALKS | PREPRINT | DIRECTORY | VISITOR-INFO | NEWS | CONTACT | ITP

RELATED LINKS
Apply/Register
Introduction
Pictures
Schedule&Talks
Participants
Wiki-space

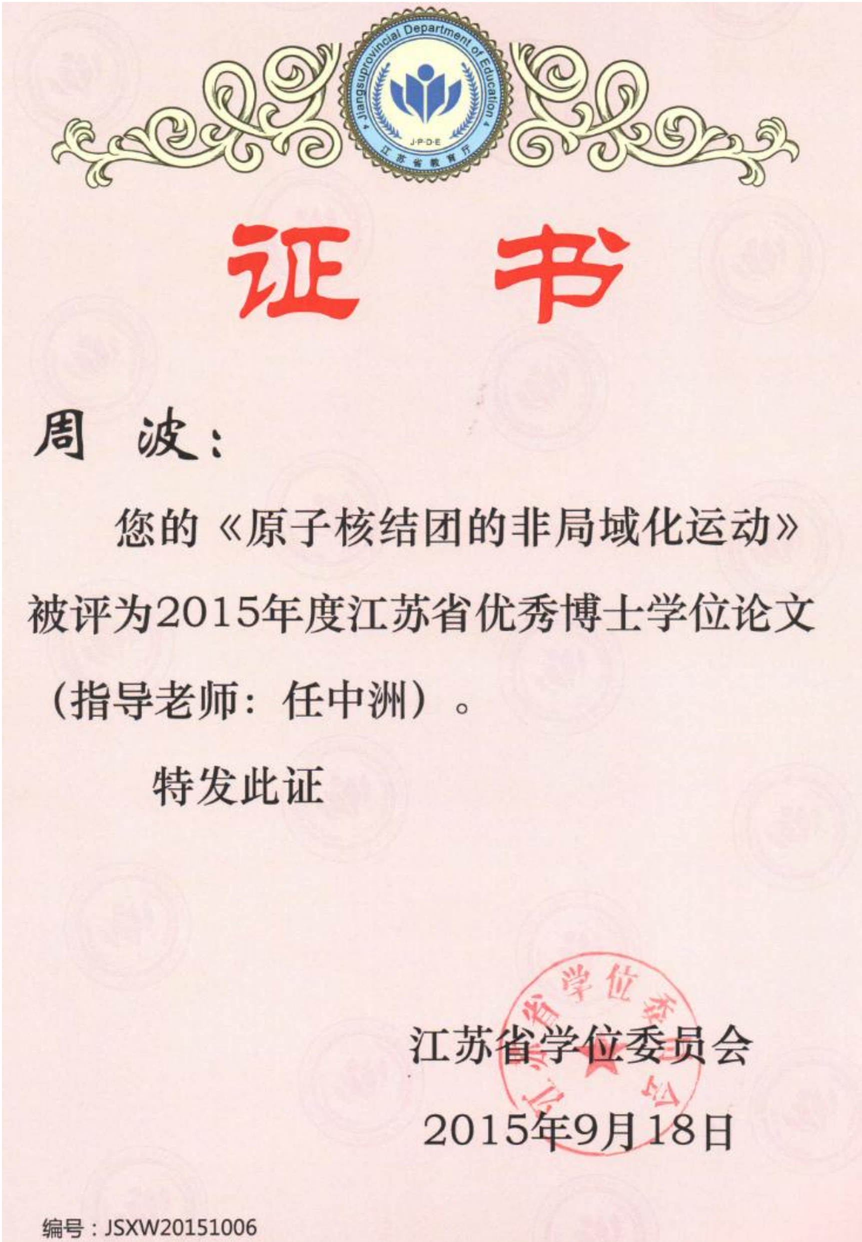
Clustering effects of nucleons in nuclei and quarks in multi-quark states

Date : From 2016-03-28 To 2016-04-22

Advisory committee :

Local coordinators : Qiang Zhao (Institute of High Energy Physics, CAS), Shan-Gui Zhou (Institute of Theoretical Physics, CAS), Chang Xu (Nanjing University),Feng-Kun Guo(Institute of Theoretical Physics, CAS)

International coordinators : Zhongzhou Ren (Chair, Nanjing University), Ulf-G. Meiβner (University of Bonn, Germany), Bing-Song Zou (Institute of Theoretical Physics, CAS), Hisashi Horiuchi (Osaka Univeristy, Japan), Peter Schuck (IN2P3-CNRS,



证 书

周 波：

您的《原子核结团的非局域化运动》被评为2015年度江苏省优秀博士学位论文（指导老师：任中洲）。

特发此证

江苏省学位委员会

2015年9月18日

编号：JSXW20151006

人才培养：

指导的博士生周波获
2015
江苏省优博论文

我们轻核结团研究：
2020，周波青年长江

下面：重核结团研究

我们组对重
核结团研究背景（徐先生—我---学生...）

- 源于我在兰州大学硕士二年级（1984.9—1985.7），寒假。
- 在南京大学读博期间，逐渐有了成果。1987， PRC；1988，PRC。1989，JPG. 1990, PLB, 两篇。
- 再后来研究超重核alpha衰变：1999-2003， → PRC, NPA
- 2003-- →建立模型，计算alpha衰变寿命：DDCM, MCCM等。

任中洲，徐躬耦，PRC 36 (1987) 456：重核 alpha clustering

PHYSICAL REVIEW C VOLUME 36, NUMBER 1 JULY 1987

Reduced alpha transfer rates in a schematic model

Ren Zhong-zhou and Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
(Received 27 January 1987)

The reduced alpha transfer rates are studied microscopically with a schematic model. Results for ground state to ground state alpha transfer reactions are given.

The model Hamiltonian is as follows:

$$H = H_0(+) + H_0(-) + H_1(+,-)\ , \tag{1}$$

where

$$H_0(\pm) = \pm\epsilon A(\pm) - 2\lambda_0 \left[\sum_\alpha B_\alpha^\dagger(\sigma,\pm) B_\alpha(\sigma,\pm) + \sum_\mu B_\mu^\dagger(\tau,\pm) B_\mu(\tau,\pm) \right]\ , \tag{2a}$$

任中洲，徐躬耦，PRC 36 (1987) 456

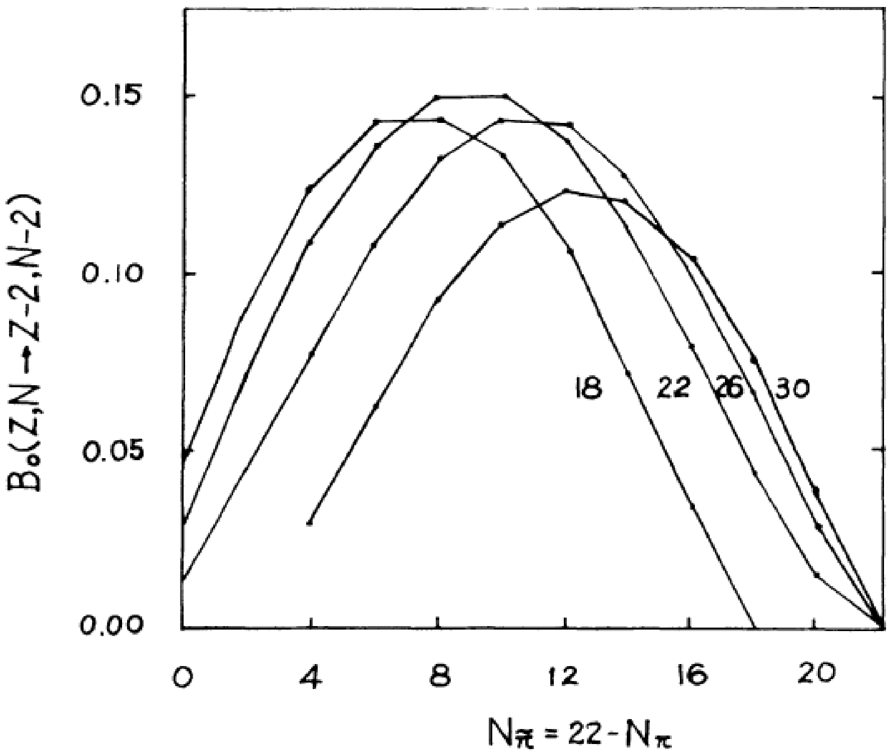


FIG. 2. Reduced α-transfer rates $B(Z,N \rightarrow Z-2, N-2)$ between ground states of nuclei with same value of $N_\nu - N_\pi$ as indicated in the figure, $N_\pi < 4l(-)+2$, $N_\nu > 4l(-)+2$. $\epsilon = 3.5$ MeV, $\lambda_0 = 1.0$ MeV, $\lambda_1 = 0.5$ MeV, $l(-) = 5$, $l(+) = 6$.

- 约化Alpha转移率

任中洲，徐躬耦， PRC 38 (1988) 1078

PHYSICAL REVIEW C VOLUME 38, NUMBER 2 AUGUST 1988

Evidence of α correlation from binding energies in medium and heavy nuclei

Ren Zhong-zhou
Department of Physics, Nanjing University, Nanjing, China

Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
and Department of Modern Physics, Lanzhou University, Lanzhou, China

(Received 23 March 1988)

If the effect of α clustering due to the interaction of the excited correlated proton pair with correlated neutron pairs in medium and heavy nuclei were taken into consideration, quasiparticle energies would not be simply additive. The empirical values of the extra term $\delta(\alpha)$ indicate that α correlations exist to a certain extent in these nuclei.

$$\delta B = \begin{cases} \Delta & \text{even-even nuclei} \\ 0 & \text{even-odd or odd-even nuclei} \\ -\Delta & \text{odd-odd nuclei} \end{cases} \qquad (3)$$

$$\delta B = \begin{cases} \Delta + \delta(\alpha) & \text{even-even nuclei} \\ 0 & \text{even-odd or odd-even nuclei} \\ -\Delta & \text{odd-odd nuclei} \end{cases} \qquad (4)$$

任中洲，徐躬耦，PRC 38 (1988) 1078

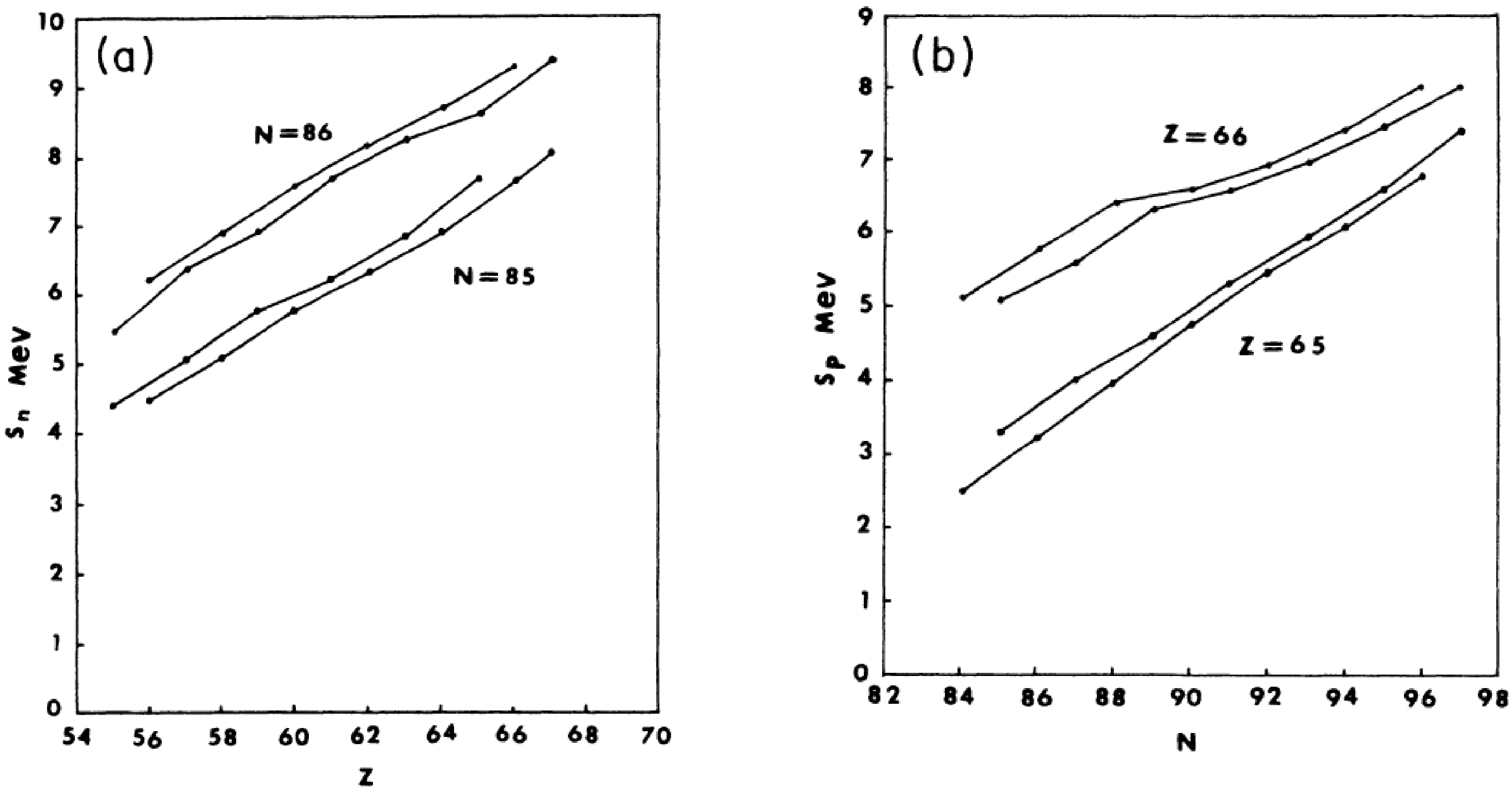


FIG. 1. (a) Neutron separation energies for nuclei with fixed N; (b) proton separation energies for nuclei with fixed Z.

任中洲，徐躬耦， JPG 15 (1989) 465

J. Phys. G: Nucl. Part. Phys. **15** (1989) 465–472. Printed in the UK

Shell and blocking effects in α-transfer reactions†

Ren Zhong-zhou‡ and Xu Gong-ou§

‡ Department of Physics, Nanjing University, Nanjing, China
§ Department of Physics, Nanjing University, Nanjing, China and Department of Modern Physics, Lanzhou University, Lanzhou, China

Received 18 July 1988

Abstract. Using a two-level pairing force model and assuming that α-clustering in ground states of medium and heavy nuclei is mainly the result of configuration mixing of cross-shell excitation of correlated pairs, shell and blocking effects in α-transfer reactions can be reasonably explained.

任中洲，徐躬耦， JPG 15 (1989) 465

2. The two-level pairing force model and the reduced pair transfer rates

The two levels of the model are introduced for representing the energy levels around proton and neutron Fermi energies in neighbouring shells. Nucleons in these two levels are interacting with each other with pairing forces. The model Hamiltonian is

$$H = H_0(+) + H_0(-) + H_1(+,-) \tag{1}$$

where

$$H_0(\pm) = \pm \varepsilon N_F(\pm) - \lambda_0 \sum_{\nu=0,\pm1} B_\nu^\dagger(\pm) B_\nu(\pm) \tag{2}$$

$$H_1(+,-) = -\lambda_1 \sum_{\nu=0,\pm1} B_\nu^\dagger(+) B_\nu(-) + \mathrm{HC} \tag{3}$$

$\pm\varepsilon$ represent the single-particle energies of upper and lower levels; λ_0, λ_1 represent the intensities of pairing forces related to the same level and to different levels; and

$$N_F(\pm) = \sum_{m,m_t} a_{m,m_t}^\dagger(\pm) a_{m,m_t}(\pm) \tag{4}$$

$$B_\nu^\dagger(\pm) = \frac{1}{\sqrt{2}} [a^\dagger(\pm) a^\dagger(\pm)]^{J=0}_{M=0}{}^{T=1}_{M_T=\nu} \qquad B_\nu(\pm) = (B_\nu^\dagger(\pm))^\dagger \tag{5}$$

Variation of reduced alpha transfer rates with valence protons and neutrons

$$B_0(Z,N\rightarrow Z-2,N-2)=B_0(Z-2,N-2\rightarrow Z,N)$$

$$=(N_{\tilde{\pi}}+2)\left[1-\frac{N_{\tilde{\pi}}}{2[2l(-)+1]}\right]N_{\nu}\left[1-\frac{N_{\nu}-2}{2[2l(+)+1]}\right]$$

$$\times\frac{1}{3}\lambda_1^2\left[\frac{1}{\Delta E_{\alpha}(N_{\tilde{\pi}},N_{\nu})}\left[1+\frac{2}{2l(+)+1}\right]+\frac{1}{\Delta E_{\tilde{\alpha}}(N_{\tilde{\pi}}+2,N_{\nu}-2)}\left[1+\frac{2}{2l(-)+1}\right]\right]$$

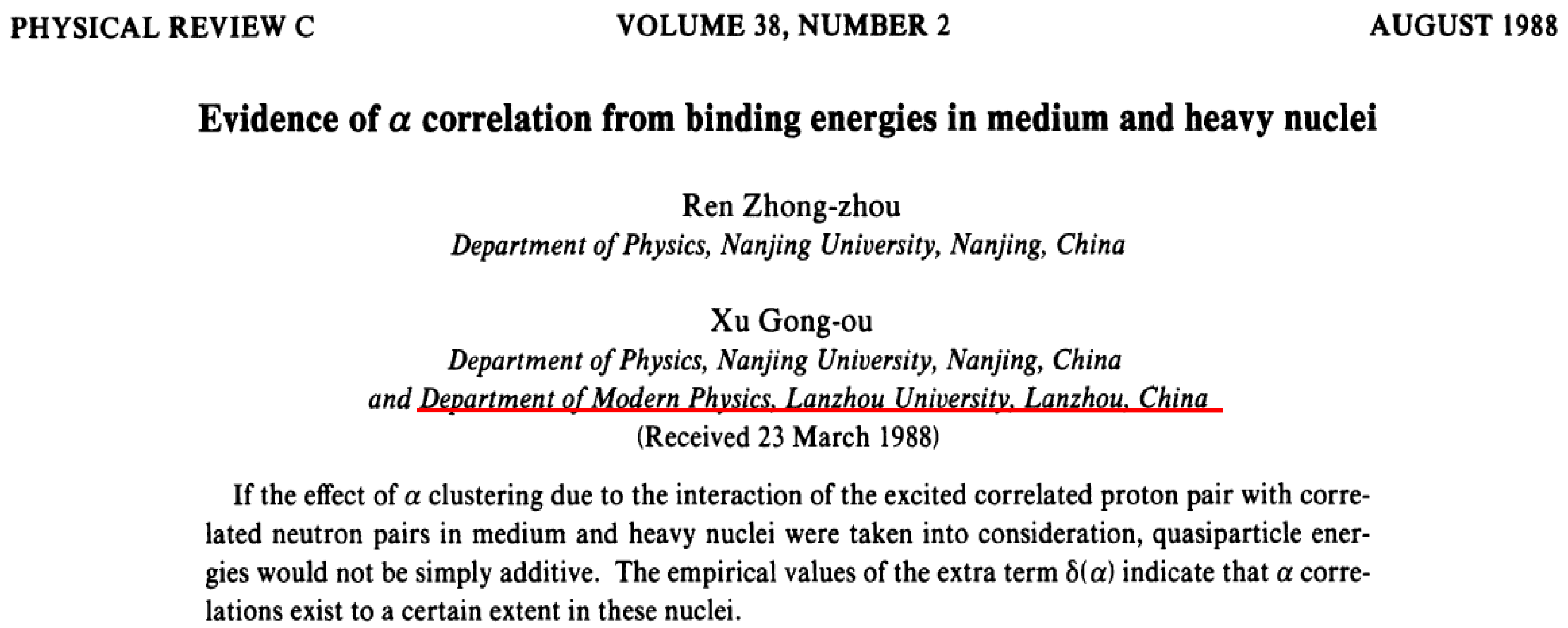
where

$$\Delta E_{\alpha}(N_{\tilde{\pi}},N_{\nu})=4(\epsilon-\lambda_0)-\frac{8\lambda_0}{2l(+)+1}+\frac{12\lambda_0}{2l(-)+1}+\frac{2\lambda_0 N_{\tilde{\pi}}}{2l(-)+1}$$

$$\Delta E_{\tilde{\alpha}}(N_{\tilde{\pi}},N_{\nu})=4(\epsilon-\lambda_0)+\frac{4\lambda_0}{2l(-)+1}+\frac{2\lambda_0 N_{\nu}}{2l(+)+1}\ .$$

Ren and Xu, PRC 1988: alpha correlation

任中洲　南京大学物理系
徐躬耦　南京大学物理系
　　　　兰州大学现代物理系



PHYSICAL REVIEW C　　VOLUME 38, NUMBER 2　　AUGUST 1988

Evidence of α correlation from binding energies in medium and heavy nuclei

Ren Zhong-zhou
Department of Physics, Nanjing University, Nanjing, China

Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
and Department of Modern Physics, Lanzhou University, Lanzhou, China

(Received 23 March 1988)

If the effect of α clustering due to the interaction of the excited correlated proton pair with correlated neutron pairs in medium and heavy nuclei were taken into consideration, quasiparticle energies would not be simply additive. The empirical values of the extra term $\delta(\alpha)$ indicate that α correlations exist to a certain extent in these nuclei.

系统研究奇Z超重核的基态性质，
预言未知超重核衰变能和寿命.

PHYSICAL REVIEW C **67**, 064302 (2003)

Ground state properties of odd-*Z* superheavy nuclei

Zhongzhou Ren,[1,2,*] Ding-Han Chen,[1] Fei Tai,[1] H. Y. Zhang,[3] and W. Q. Shen[3]
[1]*Department of Physics, Nanjing University, Nanjing 210008, People's Republic of China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator at Lanzhou, Lanzhou 730000, People's Republic of China*
[3]*Shanghai Institute of Nuclear Research, Shanghai 201800, People's Republic of China*
(Received 21 January 2003; published 5 June 2003)

The ground state properties of odd-*Z* superheavy nuclei in the mass range of $Z=97-115$ and $N=140-190$ are systematically investigated in deformed relativistic mean-field (RMF) theory. Special emphasis is placed on nuclear shell effect around $N=184$. Calculations clearly show that the RMF model can reliably reproduce the data of binding energy and α decay energy of known nuclei and can also be used to predict the binding energy of unknown nuclei. It is found that deformation plays an important role for many superheavy nuclei. For $N=184$ isotones, the lighter ones are approximately spherical but the heavier ones are deformed. The α-decay energies of $N=184$ isotones are lower than those of neighboring nuclei in some cases and higher in other cases. This demonstrates that there is a complicated structural behavior for $N=184$ isotones.

Oganessian et al, PRC72 2005

PHYSICAL REVIEW C 72, 034611 (2005)

Synthesis of elements 115 and 113 in the reaction $^{243}Am + ^{48}Ca$

Yu. Ts. Oganessian, V. K. Utyonkov, S. N. Dmitriev, Yu. V. Lobanov, M. G. Itkis, A. N. Polyakov, Yu. S. Tsyganov, A. N. Mezentsev, A. V. Yeremin, A. A. Voinov, E. A. Sokol, G. G. Gulbekian, S. L. Bogomolov, S. Iliev, V. G. Subbotin, A. M. Sukhov, G. V. Buklanov, S. V. Shishkin, V. I. Chepygin, G. K. Vostokin, N. V. Aksenov, M. Hussonnois, K. Subotic, and V. I. Zagrebaev
Joint Institute for Nuclear Research, RU-141980 Dubna, Russian Federation

K. J. Moody, J. B. Patin, J. F. Wild, M. A. Stoyer, N. J. Stoyer, D. A. Shaughnessy, J. M. Kenneally, P. A. Wilk, and R. W. Lougheed
University of California, Lawrence Livermore National Laboratory, Livermore, California 94551, USA

H. W. Gäggeler, D. Schumann, H. Bruchertseifer, and R. Eichler
Paul Scherrer Institute, Villigen CH-5232, Switzerland

(Received 21 March 2005; published 29 September 2005)

The results of two experiments designed to synthesize element 115 isotopes in the $^{243}Am + ^{48}Ca$ reaction are presented. Two new elements with atomic numbers 113 and 115 were observed for the first time. With 248-MeV ^{48}Ca projectiles, we observed three similar deca

Predictions of SHF and RMF compare well with MM results [12,13]

[13] Z. Ren *et al.*, Phys. Rev. C 67, 064302 (2003).

In our experiments, α-decay properties proposed by the MM nuclear model [6,7] were used for setting the initial experimental parameters. One should note that the predictions of other models within the Skyrme-Hartree-Fock-Bogoliubov (SHFB) and the relativistic mean-field (RMF) approaches compare well with the MM results (see, e.g., [12,13]). Unfortunately, calculations of the probability of spontaneous fission and electron capture for odd nuclei are rather scarce.

南京大学

Oganessian et al, PRC72 2005

V. DISCUSSION

The experimental α-decay energies $Q_\alpha^{\exp}$ of the synthesized isotopes and previously known odd-Z nuclei with $Z \geqslant 103$ are plotted in Fig. 9(a). The $Q_\alpha^{\exp}$ of even-Z nuclei, including those produced in our experiments [1,2,20], are plotted in Fig. 9(b) for comparison. The α-decay energies attributed to the isotopes of Mt and Bh coincide well with theoretical values [7], also plotted in the figures. The same can be seen for the last nuclei in the decay chain ^{275}Hs $\rightarrow$ ^{271}Sg $\rightarrow$ ^{267}Rf.

The trend of the $Q_\alpha(N)$ systematics predicted by the MM model [6,7] and confirmed by experimental data for odd-Z isotopes of Mt and Bh along with even-Z isotopes of Ds can

SHF [12, 49-51] and RMF [13, 52-57] compare well with the experimental results

considerable increase in T_α for the new heavier isotopes Db

[54] Z. Ren, Phys. Rev. C **65**, 051304(R) (2002).

[55] S. Das and G. Gangopadhyay, J. Phys. G **30**, 957 (2004).

[56] Z. Ren *et al.*, Phys. Rev. C **67**, 064302 (2003).

For the isotopes ^{279,280}Rg and ^{283,284}113 the difference between theoretical and experimental Q_α values is 0.6–0.9 MeV. Some part of this energy can be accounted for by γ-ray emission from excited levels populated during α decay. For the even-Z nuclei as well, the agreement between theory and experiment becomes somewhat worse as one moves from the deformed nuclei in the vicinity of neutron shells $N = 152$ and $N = 162$ to the more neutron-rich nuclides with $N \geqslant 169$. In this region, experimentally measured values of Q_α are less than the values calculated from the model by $\leqslant$0.5 MeV. Although the predicted Q_α values for the heaviest nuclei observed in our experiments are systematically larger than the experimental data as a whole, the trends of the predictions are in good agreement for the 23 nuclides with $Z = 106$–118 and $N = 165$–177, especially considering that the theoretical predictions of the MM model match the experimental data over a broad previously unexplored region of nuclides.

One should note that the predictions of other models for even-Z and odd-Z nuclei within the Skyrme-Hartree-Fock-Bogoliubov [12,49–51] and the relativistic mean-field [13,52–57] methods also compare well with the experimental results. These models predict the same spherical neutron shell at $N = 184$, but different proton shells, $Z = 114$ (MM) and $Z = 120$, 124, or 126 (SHFB, RMF), yet all describe the experimental data equally well. Such insensitivity with respect

重核alpha衰变：^{209}Bi。

典型的壳模型核(Z=83)，但有alpha衰变（集团）

Letters to nature

Nature 422, 876 (2003)

- **Experimental detection of α-particles from the radioactive decay of natural bismuth**

- **PIERRE DE MARCILLAC, NOËL CORON, GÉRARD DAMBIER, JACQUES LEBLANC & JEAN-PIERRE MOALIC**

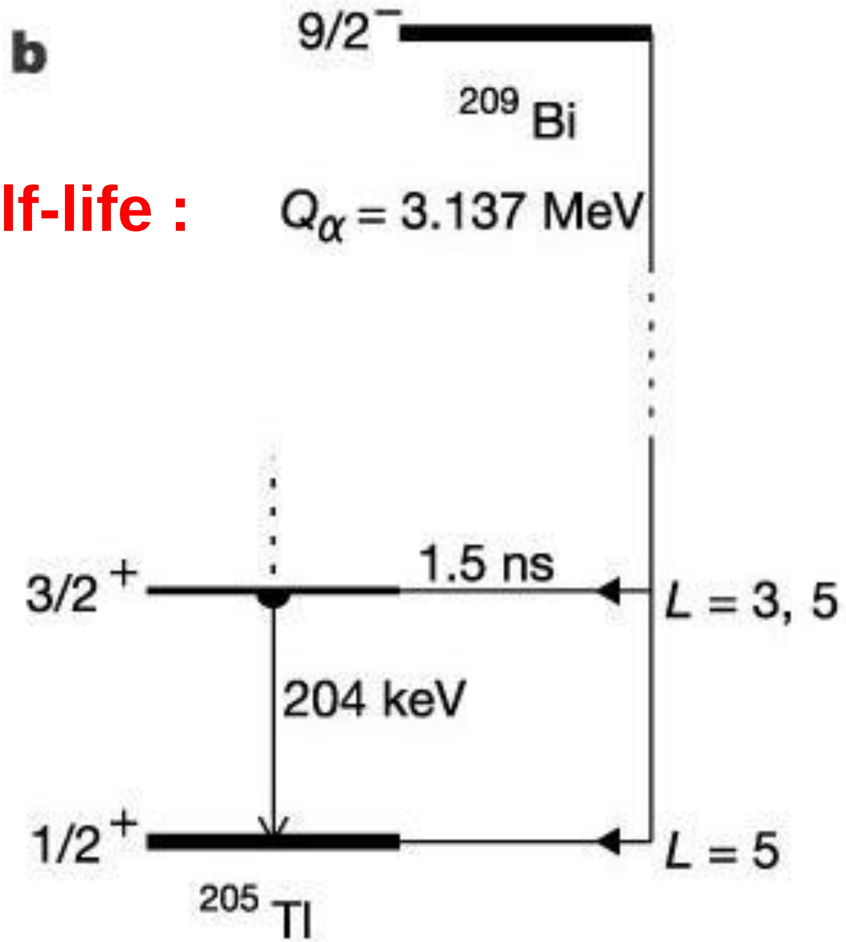
- **Institut d'Astrophysique Spatiale, CNRS & Université Paris Sud, UMR 8617, Bât. 121, 91405 Orsay Cedex, France**

α-decay scheme of ^{209}Bi

Exceptionally long half-life :

decay energy

angular momentum



我们从2003年开始对重核的alpha衰变进行研究：on 209Bi Nature

PHYSICAL REVIEW C **68**, 034319 (2003)

α decay of odd-A nuclei with an extra nucleon outside a closed shell

Chang Xu[1] and Zhongzhou Ren[1,2,*]

[1]*Department of Physics, Nanjing University, Nanjing 210008, China*

[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

(Received 19 May 2003; published 18 September 2003)

The newly discovered α decay of ^{209}Bi [Marcillac *et al.*, Nature (London) **422**, 876 (2003)] is investigated in the cluster model of α decay. It is found that the cluster model can reproduce the data of this longest-lived α emitter in all known α-decay nuclei. This decay belongs to a special class of α decays occurring in odd-A nuclei with an extra nucleon outside a closed shell. By combining the cluster model of α decay with a microscopic model of preformation α cluster, we can successfully describe the half-lives of odd-A $N=127$ isotones. The cluster model of the favored α decays is interestingly generalized to the hindered α decays of odd-A nuclei.

Preformation factor P_{α}=0.004 (Z-82): PRC1987

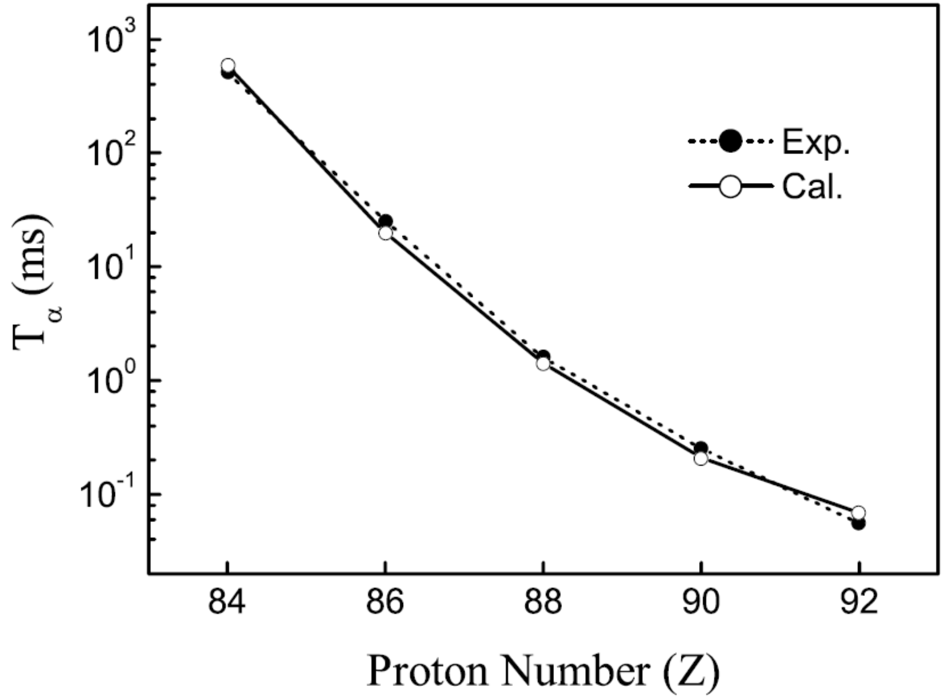


FIG. 2. The variation of theoretical half-life of α decay with proton number where the nuclear structure effect of the preformation α cluster is included. $G=23$ is chosen for $N=127$ isotones. The black circles are experimental half-lives. The hollow circles are theoretical half-lives.

Xu and Ren, PRC 73, 041301(R) 2006

建立新形变模型（DDCM）：密度依赖集团模型（ Density-Dependent Cluster Model）

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **73**, 041301(R) (2006)

New deformed model of α-decay half-lives with a microscopic potential

Chang Xu[1] and Zhongzhou Ren[1,2,3,*]

[1]*Department of Physics, Nanjing University, Nanjing 210008, China*

[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

[3]*CPNPC, Nanjing University, Nanjing 210008, China*

(Received 19 January 2006; published 6 April 2006)

The α-decay half-lives of deformed nuclei are investigated in a new version of the density-dependent cluster model. By the multipole expansion method, the deformation- and orientation-dependent double-folding potential is derived to calculate the α-decay width through a deformed Coulomb barrier. We perform systematic calculations for the ground-state α transitions of even-even nuclei with $Z = 52-104$. The theoretical results are in good agreement with the experimental data. This is, to our knowledge, the first deformed calculation of α-decay half-lives within the framework of microscopic double-folding potentials. A unified description of α-decay half-lives of both spherical and deformed nuclei is obtained by the microscopic potentials.

^{104}Te，中质量区，现在，前面PLB 2018
讲2006预言：博士生—博导---优青18

PHYSICAL REVIEW C **74**, 037302 (2006)

Half lives of α-emitters approaching the $N = Z$ line

Chang Xu[1] and Zhongzhou Ren[1,2,3]
[1]*Department of Physics, Nanjing University, Nanjing 210008, People's Republic of China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, People's Republic of China*
[3]*CPNPC, Nanjing University, Nanjing 210008, People's Republic of China*
(Received 13 July 2006; published 21 September 2006)

PHYSICAL REVIEW LETTERS **121**, 182501 (2018)

Editors' Suggestion   Featured in Physics

Superallowed α Decay to Doubly Magic ^{100}Sn

K. Auranen,[1,*] D. Seweryniak,[1] M. Albers,[1] A. D. Ayangeakaa,[1,†] S. Bottoni,[1,‡] M. P. Carpenter,[1] C. J. Chiara,[1,2,§] P. Copp,[1,3] H. M. David,[1,‖] D. T. Doherty,[4,¶] J. Harker,[1,2] C. R. Hoffman,[1] R. V. F. Janssens,[5,6] T. L. Khoo,[1] S. A. Kuvin,[1,7] T. Lauritsen,[1] G. Lotay,[8] A. M. Rogers,[1,**] J. Sethi,[1,2] C. Scholey,[9] R. Talwar,[1] W. B. Walters,[2] P. J. Woods,[4] and S. Zhu[1]
[1]*Physics Division, Argonne National Laboratory, 9700 South Cass Avenue, Lemont, Illinois 60439, USA*

suddenly. The present data are in agreement with this linear trend, and therefore with the extrapolated values of $Q_\alpha(^{104}\text{Te}) = 5.053$ MeV and $Q_\alpha(^{108}\text{Xe}) = 4.440$ MeV [29]. Furthermore, the folding potential calculations

[29] C. Xu and Z. Ren, Phys. Rev. C **74**, 037302 (2006).

现在数据与理论结果【29】一致
（文中仅引用少数理论结果）

^{212}Po，轻核结团模型思想（N=Z）到重核区

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **93**, 011306(R) (2016)

α-decay width of ^{212}Po from a quartetting wave function approach

Chang Xu,[1,*] Zhongzhou Ren,[1,2,†] G. Röpke,[3,‡] P. Schuck,[4,5,§] Y. Funaki,[6] H. Horiuchi,[7,8] A. Tohsaki,[7] T. Yamada,[9] and Bo Zhou[10]

[1]*Department of Physics and Key Laboratory of Modern Acoustics, Nanjing University, Nanjing 210093, China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[3]*Institut für Physik, Universität Rostock, D-18051 Rostock, Germany and National Research Nuclear University (MEPhI), 115409 Moscow, Russia*
[4]*Institut de Physique Nucléaire, Université Paris-Sud, IN2P3-CNRS, UMR 8608, F-91406 Orsay, France*

present computer capabilities. The approach is inspired by the THSR wave function concept that has been successfully applied to light nuclei. Shell model calculations are improved by including four-particle (α-like) correlations that are of relevance when the matter density becomes low. A closer relation of the calculation presented here to the THSR calculations is of great interest; see the calculations for ^{20}Ne [16,17]. Related calculations are performed in Ref. [18]. A comparison with THSR calculations would lead to a better understanding of the microscopic calculations, in particular the c.m. potential, the c.m. wave function, and the preformation factor.

[16] B. Zhou, Z. Ren, C. Xu, Y. Funaki, T. Yamada, A. Tohsaki, H. Horiuchi, P. Schuck, and G. Röpke, Phys. Rev. C **86**, 014301 (2012).

[17] B. Zhou, Y. Funaki, H. Horiuchi, Z. Ren, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, and T. Yamada, Phys. Rev. C **89**, 034319 (2014).

集团模型近似推广到中重核是一个大的发展，论文被同行引用及好评

同行指出我们结果和实验符合好

PHYSICAL REVIEW C **93**, 054326 (2016)

Microscopic description of superallowed α-decay transitions

Monika Patial,* R. J. Liotta, and R. Wyss
Royal Institute of Technology (KTH), Alba Nova University Center, SE-10691 Stockholm, Sweden
(Received 4 March 2016; published 26 May 2016)

larger than the corresponding experimental value. In effective theories, where the preformation probability is a parameter extracted from fittings to previous experimental values, theory and experiment agree reasonably well, as seen in Refs. [18,19].

[18] C. Xu, Z. Ren, G. Röpke, P. Schuck, Y. Funaki, H. Horiuchi, A. Tohsaki, T. Yamada, and B. Zhou, Phys. Rev. C **93**, 011306 (2016).
[19] Y. Ren and Z. Ren, Phys. Rev. C **85**, 044608 (2012).

PHYSICAL REVIEW C **97**, 064616 (2018)

Systematic studies of α and heavy-cluster emissions from superheavy nuclei

K. P. Santhosh* and C. Nithya
School of Pure and Applied Physics, Kannur University, Swami Anandatheertha Campus, Payyanur 670327, Kerala, India

It should be noted that microscopic calculations [29,30] are very important for the determination of the cluster preformation probabilities. Recently Deng *et al.* [29] calculated the α preformation factors of medium-mass nuclei as well as their behavior in the vicinity of $Z = 82$ shell closure by the cluster-formation model (CFM). The CFM was found to be effective in the evaluation of α preformation factors in the heavy-mass region and the authors claimed that the CFM is also valid for medium-mass nuclei because it reproduced reasonable features of the variation of α preformation probability, especially the $Z = 82$ shell effects, which were made evident in a recent experiment. Xu *et al.* [30] performed a microscopic calculation of α-cluster preformation probability and α-decay width in the ^{212}Po nucleus by improving a recent approach to describe α preformation in ^{212}Po [31] implementing four-nucleon correlations (quartetting). It was seen that, using the actually measured density distribution of the ^{208}Pb core, the calculated α-decay width of ^{212}Po agrees fairly well with the measured one.

[27] Z. Ren, C. Xu, and Z. Wang, Phys. Rev. C **70**, 034304 (2004).
[28] Y. Qian and Z. Ren, J. Phys. G: Nucl. Part. Phys. **39**, 015103 (2012).
[29] D. Deng and Z. Ren, Phys. Rev. C **93**, 044326 (2016).
[30] C. Xu, Z. Ren, G. Röpke, P. Schuck, Y. Funaki, H. Horiuchi, A. Tohsaki, T. Yamada, and B. Zhou, Phys. Rev. C **93**, 011306(R) (2016).
[31] G. Röpke, P. Schuck, Y. Funaki, H. Horiuchi, Z. Ren, A. Tohsaki, C. Xu, T. Yamada, and B. Zhou, Phys. Rev. C **90**, 034304 (2014).

PHYSICAL REVIEW C **94**, 024316 (2016)

Relative stability and magic numbers of nuclei deduced from behavior of cluster emission half-lives

M. Ismail,[1] W. M. Seif,[1,*] and A. Abdurrahman[2]
[1]*Department of Physics, Faculty of Science, Cairo University, Giza 12613, Egypt*

PHYSICAL REVIEW C **95**, 044303 (2017)

Systematic study of α decay half-lives of doubly odd nuclei within the two-potential approach

Xiao-Dong Sun,[1] Jun-Gang Deng,[2] Dong Xiang,[2,*] Ping Guo,[1] and Xiao-Hua Li[2,3,4,†]
[1]*School of Math and Physics, University of South China, 421001 Hengyang, People's Republic of China*

PHYSICAL REVIEW C **97**, 044322 (2018)

Systematic study of α decay of nuclei around the $Z = 82$, $N = 126$ shell closures within the cluster-formation model and proximity potential 1977 formalism

Jun-Gang Deng,[1] Jie-Cheng Zhao,[1] Peng-Cheng Chu,[2,*] and Xiao-Hua Li[1,3,4,†]
[1]*School of Nuclear Science and Technology, University of South China, 421001 Hengyang, People's Republic of China*

tailored wave function of the parent nucleus [24–28]. Röpke *et al.* [29] and Xu *et al.* [30] calculated α preformation factors using an approach of the Tohsaki-Horiuchi-Schuck-Röpke wave function, which was also successfully used to describe the cluster structure of light nuclei. In the cluster model,

[29] G. Röpke, P. Schuck, Y. Funaki, H. Horiuchi, Z. Ren, A. Tohsaki, C. Xu, T. Yamada, and B. Zhou, Phys. Rev. C **90**, 034304 (2014).
[30] C. Xu, Z. Ren, G. Röpke, P. Schuck, Y. Funaki, H. Horiuchi, A. Tohsaki, T. Yamada, and B. Zhou, Phys. Rev. C **93**, 011306 (2016).

发展轻核集团到中重核区，论文被国内外同行引用和肯定

Ni and Ren, PRC 81, 064318 (2010)…建立多道集团模型：Multi-channel cluster model (MCCM)

PHYSICAL REVIEW C **81**, 064318 (2010)

New approach for α-decay calculations of deformed nuclei

Dongdong Ni[1,2,*] and Zhongzhou Ren[1,2,3,†]
[1]*Department of Physics, Nanjing University, Nanjing 210093, China*
[2]*Kavli Institute for Theoretical Physics China, Beijing 100190, China*
[3]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
(Received 31 March 2010; published 22 June 2010)

We present a new theoretical approach to evaluate α-decay properties of deformed nuclei, namely the multichannel cluster model (MCCM). The deformed α-nucleus potential is taken into full account, and the coupled-channel Schrödinger equation with outgoing wave boundary conditions is employed for quasibound states. Systematic calculations are carried out for well-deformed even-even nuclei with $Z \geqslant 98$ and isospin dependence of nuclear potentials is included in the calculations. Fine structure observed in α decay is well described by the four-channel microscopic calculation, which is performed for the first time in α-decay studies. The good agreement between experiment and theory is achieved for both total α-decay half-lives and branching ratios to the ground-state rotational band of daughter nuclei. Predictions on the branching ratios to high-spin daughter states are presented for superheavy nuclei, which may be important to interpret future observations.

建立和发展重核衰变结团模型

1 系统性研究工作：建立和发展多道结团模型到5道和25道。

研究范围：偶偶核—奇A核—奇奇核alpha衰变精细结构

创新点：1) 4道→5道→25道，新编写更多道计算程序

2) 完成奇A核和奇奇核的耦合道模型（求解准束缚态耦合薛定谔方程），研究形变重核 alpha 衰变精细结构现象，解决了半经典近似计算的缺陷。

2 这是计算形变重核alpha衰变寿命和分支比的微观模型—多道结团模型（MCCM）。Period：2010—2015.

耦合道计算系列工作 (PRC3篇)

该系列工作第一篇 —— 偶偶核五道耦合计算

调试新程序（多级展开），并解决半经典近似的缺陷

PHYSICAL REVIEW C **83**, 067302 (2011)

Coupled-channels study of fine structure in the α decay of well deformed nuclei

Dongdong Ni[1,*] and Zhongzhou Ren[1,2,†]

[1]*Department of Physics, Nanjing University, Nanjing 210093, China*

[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

(Received 14 March 2011; revised manuscript received 8 June 2011; published 21 June 2011)

We formulate a theoretical model for the α decay of well-deformed even-even nuclei based on the coupled-channel Schrödinger equation. The α-decay half-lives and fine structures observed in α decay are well described by the five-channel microscopic calculations. Since the branching ratios to high-spin states are hard to understand in the traditional α-decay theories, this success could be important to interpret future observations of heavier nuclei. It is also found that the α transition to high-spin states is a powerful tool to probe the energy spectrum and deformation of daughter nuclei.

系列工作第二篇 —— 奇A核多道耦合计算（最多25道）

耦合道数目多，数值计算难度大（未见他人研究）

PHYSICAL REVIEW C **86**, 054608 (2012)

Systematic calculation of fine structure in the α decay of heavy odd-mass nuclei

Dongdong Ni[1,*] and Zhongzhou Ren[1,2,3,†]
[1]*Department of Physics, Nanjing University, Nanjing 210093, China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[3]*Kavli Institute for Theoretical Physics China, Beijing 100190, China*
(Received 28 October 2012; published 28 November 2012)

系列工作第三篇 —— 奇奇核多道耦合计算

实验数据稀少，理论与实验符合很好（未见他人研究）

PHYSICAL REVIEW C **87**, 027602 (2013)

Theoretical description of fine structure in the α decay of heavy odd-odd nuclei

Dongdong Ni[1,*] and Zhongzhou Ren[1,2,3,†]
[1]*Department of Physics, Nanjing University, Nanjing 210093, China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[3]*Kavli Institute for Theoretical Physics China, Beijing 100190, China*
(Received 1 February 2013; published 28 February 2013)

5道结果：偶偶核 。DD NI：博士—优青

^{242}Cm	*Exp.* (%)	*Cal.* (%)
8^+	2.0×10^{-5}	3.8×10^{-5}
6^+	0.0046	0.0053
4^+	0.035	0.077
2^+	25.92	31.04
0^+	74.08	68.87
$T_{1/2}(s)$	1.41×10^{7}	1.32×10^{7}

^{244}Cm	*Exp.* (%)	*Cal.* (%)
8^+	4.0×10^{-5}	2.8×10^{-5}
6^+	0.00352	0.00733
4^+	0.0204	0.0479
2^+	23.1	28.60
0^+	76.9	71.34
$T_{1/2}(s)$	5.72×10^{8}	5.68×10^{8}

60

PHYSICAL REVIEW C **89**, 014308 (2014)

α decay of the new neutron-deficient isotope ^{205}Ac

Z. Y. Zhang (张志远),[1] Z. G. Gan (甘再国),[1,*] L. Ma (马龙),[1,2,3] L. Yu (郁琳),[1,2] H. B. Yang (杨华彬),[1,2,3] T. H. Huang (黄天衡),[1] G. S. Li (李广顺),[1] Y. L. Tian (田玉林),[1] Y. S. Wang (王永生),[1] X. X. Xu (徐新星),[4] X. L. Wu (吴晓蕾),[1] M. H. Huang (黄明辉),[1,5] C. Luo (罗成),[1] Z. Z. Ren (任中洲),[6,7] S. G. Zhou (周善贵),[7,8] X. H. Zhou (周小红),[1] H. S. Xu (徐瑚珊),[1] and G. Q. Xiao (肖国青)[1]

[1]*Key Laboratory of High Precision Nuclear Spectroscopy and Center for Nuclear Matter Science, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*

[2]*University of Chinese Academy of Sciences, Beijing 100049, China*

[3]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*

[4]*China Institute of Atomic Energy, Beijing 102413, China*

[5]*Nishina Center for Accelerator-Based Science, RIKEN, Wako, Saitama 351-0198, Japan*

[6]*Department of Physics, Nanjing University, Nanjing 210093, China*

[7]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

[8]*State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*

(Received 1 December 2013; published 13 January 2014)

The new neutron-deficient isotope ^{205}Ac was synthesized in the complete-fusion reaction ^{169}Tm(^{40}Ca, $4n$)^{205}Ac. The evaporation residues were separated in-flight by the gas-filled recoil separator SHANS in Lanzhou and subsequently identified by the α-α position and time correlation method. The α-decay energy and half-life of ^{205}Ac were determined to be 7.935(30) MeV and 20^{+97}_{-9} ms, respectively. Previously reported decay properties of the ground state in ^{206}Ac were confirmed.

In Refs. [16,17], a new version of the Geiger-Nuttall law including the quantum numbers of α-core relative motion was proposed, which reproduces the α-decay half-lives of heavy nuclei with $N \leqslant 126$ very well. In Fig. 3(b), a calculation using this law is carried out for the favored α-decay transitions, and the results are compared with experimental values. The calculated 15-ms half-life of ^{205}Ac is in good agreement with the value measured in the present experiment.

The calculated half-life (15 ms) with the new Geiger-Nuttall law [16,17] agrees well with the measured data (20 $^{+97}_{-9}$ms).

[16] Yuejiao Ren and Zhongzhou Ren, Phys. Rev. C **85**, 044608 (2012).
[17] Yuejiao Ren and Zhongzhou Ren, Nucl. Sci. Tech. **24**, 050518 (2013), http://www.j.sinap.ac.cn/nst/EN/Y2013/V24/I5/50518.

轻—中重核：α预形成因子，中重核区计算

Physics Letters B 777 (2018) 298–302

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

New insight into α clustering of heavy nuclei via their α decay

Yibin Qian [a,b,*], Zhongzhou Ren [c,**]

[a] *Department of Applied Physics, Nanjing University of Science and Technology, Nanjing 210094, China*
[b] *School of Physics, Nanjing University, Nanjing 210093, China*
[c] *School of Physics Science and Engineering, Tongji University, Shanghai 200092, China*

Physics Letters B 786 (2018) 5–10

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Cluster-daughter overlap as a new probe of alpha-cluster formation in medium-mass and heavy even–even nuclei

Dong Bai [a], Zhongzhou Ren [b,*]

[a] *School of Physics, Nanjing University, Nanjing, 210093, China*
[b] *School of Physics Science and Engineering, Tongji University, Shanghai, 200092, China*

PRL 122, 192503 (2019) 产生一个新核素^{220}Np，
研究了*N* = 126幻数对应的闭壳效应。PRL编辑建议文章。
同济大学任中洲教授 (作者之一)

PHYSICAL REVIEW LETTERS **122,** 192503 (2019)

Editors' Suggestion

New Isotope ^{220}Np: Probing the Robustness of the $N = 126$ Shell Closure in Neptunium

Z. Y. Zhang (张志远),[1,2] Z. G. Gan (甘再国),[1,2,*] H. B. Yang (杨华彬),[1] L. Ma (马龙),[1] M. H. Huang (黄明辉),[1,2] C. L. Yang (杨春莉),[1,2] M. M. Zhang (张明明),[1,2] Y. L. Tian (田玉林),[1,2] Y. S. Wang (王永生),[1,2,3] M. D. Sun (孙明道),[1,2,3,†] H. Y. Lu (卢洪洋),[1,2] W. Q. Zhang (张文强),[1,2] H. B. Zhou (周厚兵),[4] X. Wang (王翔),[5] C. G. Wu (武晨光),[5] L. M. Duan (段利敏),[1,2] W. X. Huang (黄文学),[1,2] Z. Liu (刘忠),[1,2] Z. Z. Ren (任中洲),[6] S. G. Zhou (周善贵),[7,8] X. H. Zhou (周小红),[1,2] H. S. Xu (徐瑚珊),[1,2] Yu. S. Tsyganov,[9] A. A. Voinov,[9] and A. N. Polyakov[9]

[1]*CAS Key Laboratory of High Precision Nuclear Spectroscopy, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[2]*School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing 100049, China*
[3]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*
[4]*Guangxi Key Laboratory of Nuclear Physics and Technology, Guangxi Normal University, Guilin 541004, China*
[5]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*
[6]*School of Physics Science and Engineering, Tongji University, Shanghai 200092, China* 同济大学
[7]*CAS Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*
[8]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[9]*Joint Institute for Nuclear Research, RU-141980 Dubna, Russian Federation*

(Received 9 January 2019; revised manuscript received 10 April 2019; published 16 May 2019)

PRL 125, 032502 (2020) 在兰州产生另一个新核素 ^{222}Np，深入研究*N* = 126闭壳附近阿尔法衰变。同济大学任中洲教授 (作者之一)

PHYSICAL REVIEW LETTERS **125,** 032502 (2020)

Short-Lived α-Emitting Isotope ^{222}Np and the Stability of the $N = 126$ Magic Shell

L. Ma (马龙),[1] Z. Y. Zhang (张志远),[1,2,*] Z. G. Gan (甘再国),[1,2] X. H. Zhou (周小红),[1,2,†] H. B. Yang (杨华彬),[1] M. H. Huang (黄明辉),[1] C. L. Yang (杨春莉),[1] M. M. Zhang (张明明),[1,2] Y. L. Tian (田玉林),[1] Y. S. Wang (王永生),[1,2,3] H. B. Zhou (周厚兵),[4] X. T. He (贺晓涛),[5] Y. C. Mao (毛英臣),[6] W. Hua (滑伟),[7] L. M. Duan (段利敏),[1,2] W. X. Huang (黄文学),[1,2] Z. Liu (刘忠),[1,2] X. X. Xu (徐新星),[1,2] Z. Z. Ren (任中洲),[8] S. G. Zhou (周善贵),[9,10,11,12] and H. S. Xu (徐瑚珊)[1,2]

任中洲

[1]*CAS Key Laboratory of High Precision Nuclear Spectroscopy, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[2]*School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing 100049, China*
[3]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*
[4]*Guangxi Key Laboratory of Nuclear Physics and Technology, Guangxi Normal University, Guilin 541004, China*
[5]*College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*
[6]*Department of Physics, Liaoning Normal University, Dalian 116029, China*
[7]*Sino-French Institute of Nuclear Engineering and Technology, Sun Yat-Sen University, Zhuhai 519082, China*
[8]*School of Physics Science and Engineering, Tongji University, Shanghai 200092, China* 同济大学
[9]*CAS Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*
[10]*School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China*
[11]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator, Lanzhou 730000, China*
[12]*Synergetic Innovation Center for Quantum Effects and Application, Hunan Normal University, Changsha 410081, China*

(Received 8 May 2020; revised 22 June 2020; accepted 26 June 2020; published 13 July 2020)

2020年一篇研究工作

理论----实验----理论：互动, ^{220}Np, ^{219}Np

PHYSICAL REVIEW C **101**, 054310 (2020)

Theoretical studies on α-decay half-lives of $N = 125$, 126, and 127 isotones

Zhen Wang,[1] Zhongzhou Ren,[1,2,*] and Dong Bai[1]

[1] *School of Physics Science and Engineering, Tongji University, Shanghai 200092, China*

[2] *Key Laboratory of Advanced Micro-Structure Materials, Ministry of Education, Shanghai 200092, China*

(Received 14 January 2020; revised manuscript received 30 March 2020; accepted 27 April 2020; published 15 May 2020)

The α decays of exotic $N = 125$, 126, and 127 isotones, including two new isotopes ^{219}Np [Phys. Lett. B **777**, 212 (2018)] and ^{220}Np [Phys. Rev. Lett. **122**, 192503 (2019)], are studied by using the improved Buck-Merchant-Perez cluster model with the charge-dependent α-preformation factors. The experimental half-lives of α decays varying from 2.50×10^{-5} to 6.00×10^{26} s are reproduced within a factor of ≈ 2. Noticeably, the theoretical α-decay half-lives of the new isotopes ^{219,220}Np are also in good agreement with the experimental data. Furthermore, the α-decay half-lives of some undiscovered $N = 125$, 126 and 127 isotones are predicted, which could be useful for future experimental studies on the robustness of the magic number $N = 126$.

PHYSICAL REVIEW C
covering nuclear physics

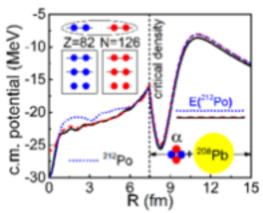
Highlights Recent Accepted Collections Authors Referees Search Press About Staff

Editors' Suggestion

α decay to a doubly magic core in the quartetting wave function approach

Shuo Yang, Chang Xu, Gerd Röpke, Peter Schuck, Zhongzhou Ren, Yasuro Funaki, Hisashi Horiuchi, Akihiro Tohsaki, Taiichi Yamada, and Bo Zhou

Phys. Rev. C **101**, 024316 (2020) – Published 28 February 2020



This microscopic calculation for the α decay of heavy nuclei provides a solution to what has long been an outstanding problem. In the authors' model, the α particle exists only below about one-fifth of saturation density, corresponding to a large radius, inside of which the α particle transitions into an unbound four-nucleon shell-model state. The model reproduces the half-life of ^{212}Po (a classic test case) as well as some neighboring nuclei, and calculations are also made for ^{104}Te.

编辑推荐并评价为“该微观衰变模型为这一长期难点问题提供了解决办法”

S. Yang, C. Xu, G. Roepke, P. Schuck, Z. Ren et al., PRC101, 024316 (2020)

Shen,Guo…PLB， 2019，原子能院+…+同济大学+中大

Physics Letters B 797 (2019) 134820

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

First experimental constraint of the spectroscopic amplitudes for the α-cluster in the ^{11}B ground state

Y.P. Shen (谌阳平)[a], B. Guo (郭冰)[a,*], T.L. Ma (马田丽)[a], D.Y. Pang (庞丹阳)[b,c], D.D. Ni (倪冬冬)[d], Z.Z. Ren (任中洲)[e], Y.J. Li (李云居)[a], Z.D. An (安振东)[f], J. Su (苏俊)[a], J.C. Liu (刘建成)[a], Q.W. Fan (樊启文)[a], Z.Y. Han (韩治宇)[a], X.Y. Li (李鑫悦)[a], Z.H. Li (李志宏)[a], G. Lian (连钢)[a], Y. Su (苏毅)[a], Y.B. Wang (王友宝)[a], S.Q. Yan (颜胜权)[a], S. Zeng (曾晟)[a], W.P. Liu (柳卫平)[a]

[a] China Institute of Atomic Energy, P. O. Box 275(10), Beijing 102413, China
[b] School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[c] Beijing Key Laboratory of Advanced Nuclear Materials and Physics, Beihang University, Beijing 100191, China
[d] Space Science Institute, Macao University of Science and Technology, Macao, China
[e] School of Physics Science and Engineering, Tongji University, Shanghai 200092, China
[f] School of Physics and Astronomy, Sun Yat-Sen University, Zhuhai 519082, China

ARTICLE INFO

Article history:
Received 30 November 2018

ABSTRACT

We present the first experimental determination on the spectroscopic amplitudes (SAs) for the α-cluster in the ^{11}B ground state via the ^{7}Li(^{6}Li, d)^{11}B reaction using a high-precision magnetic spectrograph. This

三. 小 结

首先，回顾了国内外核集团态理论研究的一些新成果，特别是发表在Nature和PRL上的重要论文。

对原子核集团态的研究少，国内2013.6-2014.7有三篇关于集团态的PRL论文（轻核区集团态）。还回顾了重核的alpha衰变和集团放射性等的模型, 209Bi。新核素220Np。

不稳定原子核做为复杂的量子多体系统，会有不少结团有关新现象和新规律有待研究。

轻核集团研究：1青千。

重核集团研究：2优青。

谢谢吴雪峰老师的邀请！

祝愿紫金山天文台取得更多新成果！

很高兴访问紫金山天文台新的园区（仙林），进行科研交流！

Variation of reduced alpha transfer rates with valence protons and neutrons

$$B_0(Z,N\rightarrow Z-2,N-2)=B_0(Z-2,N-2\rightarrow Z,N)$$

$$=(N_{\tilde{\pi}}+2)\left[1-\frac{N_{\tilde{\pi}}}{2[2l(-)+1]}\right]N_{\nu}\left[1-\frac{N_{\nu}-2}{2[2l(+)+1]}\right]$$

$$\times\frac{1}{3}\lambda_1^2\left[\frac{1}{\Delta E_{\alpha}(N_{\tilde{\pi}},N_{\nu})}\left[1+\frac{2}{2l(+)+1}\right]+\frac{1}{\Delta E_{\tilde{\alpha}}(N_{\tilde{\pi}}+2,N_{\nu}-2)}\left[1+\frac{2}{2l(-)+1}\right]\right]$$

where

$$\Delta E_{\alpha}(N_{\tilde{\pi}},N_{\nu})=4(\epsilon-\lambda_0)-\frac{8\lambda_0}{2l(+)+1}+\frac{12\lambda_0}{2l(-)+1}+\frac{2\lambda_0 N_{\tilde{\pi}}}{2l(-)+1}$$

$$\Delta E_{\tilde{\alpha}}(N_{\tilde{\pi}},N_{\nu})=4(\epsilon-\lambda_0)+\frac{4\lambda_0}{2l(-)+1}+\frac{2\lambda_0 N_{\nu}}{2l(+)+1}\ .$$

Ren and Xu, PRC 1988: alpha correlation

任中洲　南京大学物理系
徐躬耦　南京大学物理系
兰州大学现代物理系

PHYSICAL REVIEW C　VOLUME 38, NUMBER 2　AUGUST 1988

Evidence of α correlation from binding energies in medium and heavy nuclei

Ren Zhong-zhou
Department of Physics, Nanjing University, Nanjing, China

Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
and Department of Modern Physics, Lanzhou University, Lanzhou, China

(Received 23 March 1988)

If the effect of α clustering due to the interaction of the excited correlated proton pair with correlated neutron pairs in medium and heavy nuclei were taken into consideration, quasiparticle energies would not be simply additive. The empirical values of the extra term $\delta(\alpha)$ indicate that α correlations exist to a certain extent in these nuclei.

系统研究奇Z超重核的基态性质，
预言未知超重核衰变能和寿命.

PHYSICAL REVIEW C **67**, 064302 (2003)

Ground state properties of odd-*Z* superheavy nuclei

Zhongzhou Ren,[1,2,*] Ding-Han Chen,[1] Fei Tai,[1] H. Y. Zhang,[3] and W. Q. Shen[3]
[1]*Department of Physics, Nanjing University, Nanjing 210008, People's Republic of China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator at Lanzhou, Lanzhou 730000, People's Republic of China*
[3]*Shanghai Institute of Nuclear Research, Shanghai 201800, People's Republic of China*
(Received 21 January 2003; published 5 June 2003)

The ground state properties of odd-*Z* superheavy nuclei in the mass range of $Z=97$–115 and $N=140$–190 are systematically investigated in deformed relativistic mean-field (RMF) theory. Special emphasis is placed on nuclear shell effect around $N=184$. Calculations clearly show that the RMF model can reliably reproduce the data of binding energy and α decay energy of known nuclei and can also be used to predict the binding energy of unknown nuclei. It is found that deformation plays an important role for many superheavy nuclei. For $N=184$ isotones, the lighter ones are approximately spherical but the heavier ones are deformed. The α-decay energies of $N=184$ isotones are lower than those of neighboring nuclei in some cases and higher in other cases. This demonstrates that there is a complicated structural behavior for $N=184$ isotones.

Oganessian et al, PRC72 2005

PHYSICAL REVIEW C **72**, 034611 (2005)

Synthesis of elements 115 and 113 in the reaction ^{243}Am + ^{48}Ca

Yu. Ts. Oganessian, V. K. Utyonkov, S. N. Dmitriev, Yu. V. Lobanov, M. G. Itkis, A. N. Polyakov, Yu. S. Tsyganov, A. N. Mezentsev, A. V. Yeremin, A. A. Voinov, E. A. Sokol, G. G. Gulbekian, S. L. Bogomolov, S. Iliev, V. G. Subbotin, A. M. Sukhov, G. V. Buklanov, S. V. Shishkin, V. I. Chepygin, G. K. Vostokin, N. V. Aksenov, M. Hussonnois, K. Subotic, and V. I. Zagrebaev
Joint Institute for Nuclear Research, RU-141980 Dubna, Russian Federation

K. J. Moody, J. B. Patin, J. F. Wild, M. A. Stoyer, N. J. Stoyer, D. A. Shaughnessy, J. M. Kenneally, P. A. Wilk, and R. W. Lougheed
University of California, Lawrence Livermore National Laboratory, Livermore, California 94551, USA

H. W. Gäggeler, D. Schumann, H. Bruchertseifer, and R. Eichler
Paul Scherrer Institute, Villigen CH-5232, Switzerland

(Received 21 March 2005; published 29 September 2005)

The results of two experiments designed to synthesize element 115 isotopes in the ^{243}Am + ^{48}Ca reaction are presented. Two new elements with atomic numbers 113 and 115 were observed for the first time. With 248-MeV ^{48}Ca projectiles, we observed three similar decay

Predictions of SHF and RMF compare well with MM results [12,13]

[13] Z. Ren *et al.*, Phys. Rev. C **67**, 064302 (2003).

In our experiments, α-decay properties proposed by the MM nuclear model [6,7] were used for setting the initial experimental parameters. One should note that the predictions of other models within the Skyrme-Hartree-Fock-Bogoliubov (SHFB) and the relativistic mean-field (RMF) approaches compare well with the MM results (see, e.g., [12,13]). Unfortunately, calculations of the probability of spontaneous fission and electron capture for odd nuclei are rather scarce.

Oganessian et al, PRC72 2005

V. DISCUSSION

The experimental α-decay energies Q_α^{exp} of the synthesized isotopes and previously known odd-Z nuclei with $Z \geqslant 103$ are plotted in Fig. 9(a). The Q_α^{exp} of even-Z nuclei, including those produced in our experiments [1,2,20], are plotted in Fig. 9(b) for comparison. The α-decay energies attributed to the isotopes of Mt and Bh coincide well with theoretical values [7], also plotted in the figures. The same can be seen for the last nuclei in the decay chain ^{275}Hs → ^{271}Sg → ^{267}Rf.

The trend of the $Q_\alpha(N)$ systematics predicted by the MM model [6,7] and confirmed by experimental data for odd-Z isotopes of Mt and Bh along with even-Z isotopes of Ds can

SHF [12, 49-51] and RMF [13, 52-57] compare well with the experimental results

considerable increase in T_α for the new heavier isotopes ... Db

[54] Z. Ren, Phys. Rev. C **65**, 051304(R) (2002).

[55] S. Das and G. Gangopadhyay, J. Phys. G **30**, 957 (2004).

[56] Z. Ren *et al.*, Phys. Rev. C **67**, 064302 (2003).

For the isotopes ^{279,280}Rg and ^{283,284}113 the difference between theoretical and experimental Q_α values is 0.6–0.9 MeV. Some part of this energy can be accounted for by γ-ray emission from excited levels populated during α decay. For the even-Z nuclei as well, the agreement between theory and experiment becomes somewhat worse as one moves from the deformed nuclei in the vicinity of neutron shells $N = 152$ and $N = 162$ to the more neutron-rich nuclides with $N \geqslant 169$. In this region, experimentally measured values of Q_α are less than the values calculated from the model by $\leqslant 0.5$ MeV. Although the predicted Q_α values for the heaviest nuclei observed in our experiments are systematically larger than the experimental data as a whole, the trends of the predictions are in good agreement for the 23 nuclides with $Z = 106$–118 and $N = 165$–177, especially considering that the theoretical predictions of the MM model match the experimental data over a broad previously unexplored region of nuclides.

One should note that the predictions of other models for even-Z and odd-Z nuclei within the Skyrme-Hartree-Fock-Bogoliubov [12,49–51] and the relativistic mean-field [13,52–57] methods also compare well with the experimental results. These models predict the same spherical neutron shell at $N = 184$, but different proton shells, $Z = 114$ (MM) and $Z = 120$, 124, or 126 (SHFB, RMF), yet all describe the experimental data equally well. Such insensitivity with respect

Letters to

Nature 422, 876

重核alpha衰变：^{209}Bi。

典型的壳模型核(Z=83)，但有alpha衰变（集团）

- Experimental detection of α-particles from the radioactive decay of natural bismuth

- PIERRE DE MARCILLAC, NOËL CORON, GÉRARD DAMBIER, JACQUES LEBLANC & JEAN-PIERRE MOALIC

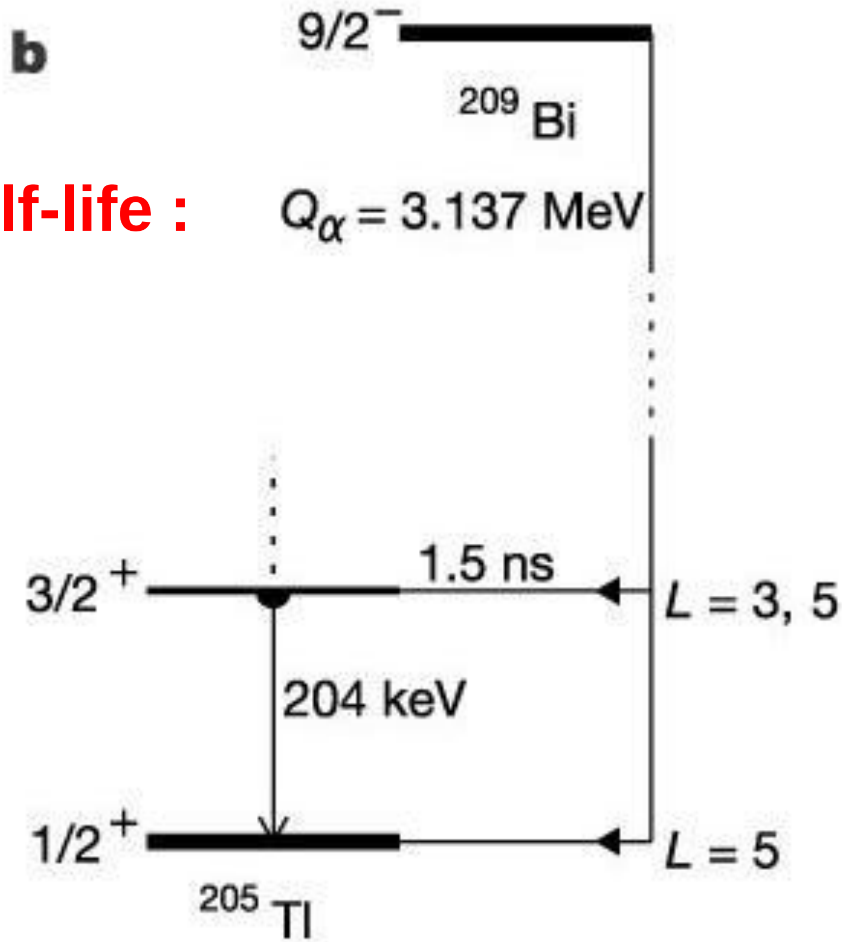
- Institut d'Astrophysique Spatiale, CNRS & Université Paris Sud, UMR 8617, Bât. 121, 91405 Orsay Cedex, France

α-decay scheme of ^{209}Bi

Exceptionally long half-life :

decay energy

angular momentum



我们从2003年开始对重核的alpha衰变进行研究：on 209Bi Nature

PHYSICAL REVIEW C **68**, 034319 (2003)

α decay of odd-A nuclei with an extra nucleon outside a closed shell

Chang Xu[1] and Zhongzhou Ren[1,2,*]
[1]*Department of Physics, Nanjing University, Nanjing 210008, China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
(Received 19 May 2003; published 18 September 2003)

The newly discovered α decay of ^{209}Bi [Marcillac *et al.*, Nature (London) **422**, 876 (2003)] is investigated in the cluster model of α decay. It is found that the cluster model can reproduce the data of this longest-lived α emitter in all known α-decay nuclei. This decay belongs to a special class of α decays occurring in odd-A nuclei with an extra nucleon outside a closed shell. By combining the cluster model of α decay with a microscopic model of preformation α cluster, we can successfully describe the half-lives of odd-A $N=127$ isotones. The cluster model of the favored α decays is interestingly generalized to the hindered α decays of odd-A nuclei.

Preformation factor P_α=0.004 (Z-82): PRC1987

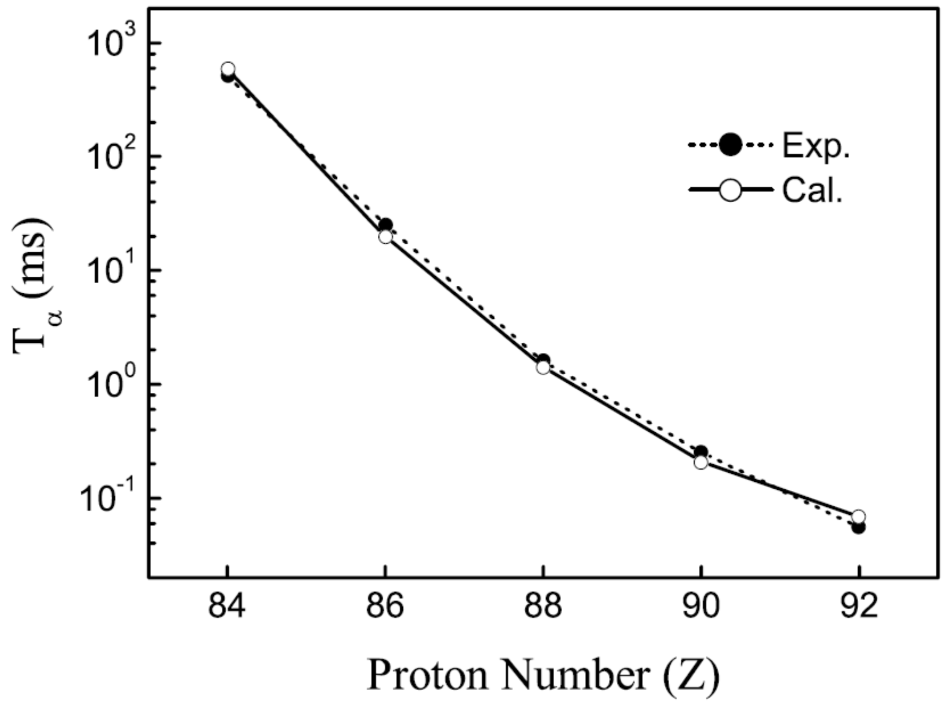


FIG. 2. The variation of theoretical half-life of α decay with proton number where the nuclear structure effect of the preformation α cluster is included. $G=23$ is chosen for $N=127$ isotones. The black circles are experimental half-lives. The hollow circles are theoretical half-lives.

Xu and Ren, PRC 73, 041301(R) 2006

建立新形变模型（DDCM）：密度依赖集团模型（ Density-Dependent Cluster Model）

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **73**, 041301(R) (2006)

New deformed model of α-decay half-lives with a microscopic potential

Chang Xu[1] and Zhongzhou Ren[1,2,3,*]

[1]*Department of Physics, Nanjing University, Nanjing 210008, China*

[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

[3]*CPNPC, Nanjing University, Nanjing 210008, China*

(Received 19 January 2006; published 6 April 2006)

The α-decay half-lives of deformed nuclei are investigated in a new version of the density-dependent cluster model. By the multipole expansion method, the deformation- and orientation-dependent double-folding potential is derived to calculate the α-decay width through a deformed Coulomb barrier. We perform systematic calculations for the ground-state α transitions of even-even nuclei with $Z = 52-104$. The theoretical results are in good agreement with the experimental data. This is, to our knowledge, the first deformed calculation of α-decay half-lives within the framework of microscopic double-folding potentials. A unified description of α-decay half-lives of both spherical and deformed nuclei is obtained by the microscopic potentials.

Ni and Ren, PRC 81, 064318 (2010)…建立多道集团模型：Multi-channel cluster model (MCCM)

PHYSICAL REVIEW C **81**, 064318 (2010)

New approach for α-decay calculations of deformed nuclei

Dongdong Ni[1,2,*] and Zhongzhou Ren[1,2,3,†]

[1]*Department of Physics, Nanjing University, Nanjing 210093, China*

[2]*Kavli Institute for Theoretical Physics China, Beijing 100190, China*

[3]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

(Received 31 March 2010; published 22 June 2010)

We present a new theoretical approach to evaluate α-decay properties of deformed nuclei, namely the multichannel cluster model (MCCM). The deformed α-nucleus potential is taken into full account, and the coupled-channel Schrödinger equation with outgoing wave boundary conditions is employed for quasibound states. Systematic calculations are carried out for well-deformed even-even nuclei with $Z \geqslant 98$ and isospin dependence of nuclear potentials is included in the calculations. Fine structure observed in α decay is well described by the four-channel microscopic calculation, which is performed for the first time in α-decay studies. The good agreement between experiment and theory is achieved for both total α-decay half-lives and branching ratios to the ground-state rotational band of daughter nuclei. Predictions on the branching ratios to high-spin daughter states are presented for superheavy nuclei, which may be important to interpret future observations.

建立和发展重核衰变结团模型

1 系统性研究工作：建立和发展多道结团模型到**5道和25道。**

研究范围：偶偶核—奇A核—奇奇核alpha衰变精细结构

创新点：1) 4道→5道→25道，新编写更多道计算程序

2) 完成奇A核和奇奇核的耦合道模型（求解准束缚态耦合薛定谔方程），研究形变重核 alpha 衰变精细结构现象，解决了半经典近似计算的缺陷。

2 这是计算形变重核alpha衰变寿命和分支比的微观模型—多道结团模型（MCCM）。Period：2010—2015.

耦合道计算系列工作 (PRC3篇)

该系列工作第一篇 —— 偶偶核五道耦合计算

调试新程序（多级展开），并解决半经典近似的缺陷

PHYSICAL REVIEW C **83**, 067302 (2011)

Coupled-channels study of fine structure in the α decay of well deformed nuclei

Dongdong Ni[1,*] and Zhongzhou Ren[1,2,†]

[1]*Department of Physics, Nanjing University, Nanjing 210093, China*

[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

(Received 14 March 2011; revised manuscript received 8 June 2011; published 21 June 2011)

We formulate a theoretical model for the α decay of well-deformed even-even nuclei based on the coupled-channel Schrödinger equation. The α-decay half-lives and fine structures observed in α decay are well described by the five-channel microscopic calculations. Since the branching ratios to high-spin states are hard to understand in the traditional α-decay theories, this success could be important to interpret future observations of heavier nuclei. It is also found that the α transition to high-spin states is a powerful tool to probe the energy spectrum and deformation of daughter nuclei.

系列工作第二篇 —— 奇A核多道耦合计算（最多25道）

耦合道数目多，数值计算难度大（未见他人研究）

PHYSICAL REVIEW C **86**, 054608 (2012)

Systematic calculation of fine structure in the α decay of heavy odd-mass nuclei

Dongdong Ni[1,*] and Zhongzhou Ren[1,2,3,†]

[1]*Department of Physics, Nanjing University, Nanjing 210093, China*

[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

[3]*Kavli Institute for Theoretical Physics China, Beijing 100190, China*

(Received 28 October 2012; published 28 November 2012)

系列工作第三篇 —— 奇奇核多道耦合计算

实验数据稀少，理论与实验符合很好（未见他人研究）

PHYSICAL REVIEW C **87**, 027602 (2013)

Theoretical description of fine structure in the α decay of heavy odd-odd nuclei

Dongdong Ni[1,*] and Zhongzhou Ren[1,2,3,†]

[1]*Department of Physics, Nanjing University, Nanjing 210093, China*

[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

[3]*Kavli Institute for Theoretical Physics China, Beijing 100190, China*

(Received 1 February 2013; published 28 February 2013)

5道计算结果：偶偶Cm核（PRC2011）

^{242}Cm	Exp. (%)	Cal. (%)
8^+	2.0×10^{-5}	3.8×10^{-5}
6^+	0.0046	0.0053
4^+	0.035	0.077
2^+	25.92	31.04
0^+	74.08	68.87
$T_{1/2}$(s)	1.41×10^{7}	1.32×10^{7}

^{244}Cm	Exp. (%)	Cal. (%)
8^+	4.0×10^{-5}	2.8×10^{-5}
6^+	0.00352	0.00733
4^+	0.0204	0.0479
2^+	23.1	28.60
0^+	76.9	71.34
$T_{1/2}$(s)	5.72×10^{8}	5.68×10^{8}

89

PHYSICAL REVIEW C **89**, 014308 (2014)

α decay of the new neutron-deficient isotope ^{205}Ac

Z. Y. Zhang (张志远),[1] Z. G. Gan (甘再国),[1,*] L. Ma (马龙),[1,2,3] L. Yu (郁琳),[1,2] H. B. Yang (杨华彬),[1,2,3]
T. H. Huang (黄天衡),[1] G. S. Li (李广顺),[1] Y. L. Tian (田玉林),[1] Y. S. Wang (王永生),[1] X. X. Xu (徐新星),[4]
X. L. Wu (吴晓蕾),[1] M. H. Huang (黄明辉),[1,5] C. Luo (罗成),[1] Z. Z. Ren (任中洲),[6,7] S. G. Zhou (周善贵),[7,8]
X. H. Zhou (周小红),[1] H. S. Xu (徐瑚珊),[1] and G. Q. Xiao (肖国青)[1]

[1]*Key Laboratory of High Precision Nuclear Spectroscopy and Center for Nuclear Matter Science, Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[2]*University of Chinese Academy of Sciences, Beijing 100049, China*
[3]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*
[4]*China Institute of Atomic Energy, Beijing 102413, China*
[5]*Nishina Center for Accelerator-Based Science, RIKEN, Wako, Saitama 351-0198, Japan*
[6]*Department of Physics, Nanjing University, Nanjing 210093, China*
[7]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[8]*State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*

(Received 1 December 2013; published 13 January 2014)

The new neutron-deficient isotope ^{205}Ac was synthesized in the complete-fusion reaction ^{169}Tm(^{40}Ca, $4n$)^{205}Ac. The evaporation residues were separated in-flight by the gas-filled recoil separator SHANS in Lanzhou and subsequently identified by the α-α position and time correlation method. The α-decay energy and half-life of ^{205}Ac were determined to be 7.935(30) MeV and 20^{+97}_{-9} ms, respectively. Previously reported decay properties of the ground state in ^{206}Ac were confirmed.

In Refs. [16,17], a new version of the Geiger-Nuttall law including the quantum numbers of α-core relative motion was proposed, which reproduces the α-decay half-lives of heavy nuclei with $N \leqslant 126$ very well. In Fig. 3(b), a calculation using this law is carried out for the favored α-decay transitions, and the results are compared with experimental values. The calculated 15-ms half-life of ^{205}Ac is in good agreement with the value measured in the present experiment.

The calculated half-life (15 ms) with the new Geiger-Nuttall law [16,17] agrees well with the measured data (20 $^{+97}_{-9}$ms).

[16] Yuejiao Ren and Zhongzhou Ren, Phys. Rev. C **85**, 044608 (2012).

[17] Yuejiao Ren and Zhongzhou Ren, Nucl. Sci. Tech. **24**, 050518 (2013), http://www.j.sinap.ac.cn/nst/EN/Y2013/V24/I5/50518.

三. 小 结

首先，回顾了国内外核集团态理论研究的一些新成果，特别是发表在Nature和PRL上的重要论文。

对原子核集团态的研究少，国内2013.6-2014.7有三篇关于集团态的PRL论文（轻核区集团态）。还回顾了重核的alpha衰变和集团放射性等的模型,209Bi。

不稳定原子核做为复杂的量子多体系统，会有不少结团有关新现象和新规律有待研究。

谢谢各位同行！

祝愿 兰州大学核学院更大发展！

南京大学
Nanjing University

原子核结团研究新进展

任中洲

南京大学 物理学院

2017年4月27日， 兰州大学 核学院

Microscopic calculation of preformation factor in a two level model

Ren and Xu, PRC 36, 456,1987…

PHYSICAL REVIEW C VOLUME 36, NUMBER 1 JULY 1987

Reduced alpha transfer rates in a schematic model

Ren Zhong-zhou and Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
(Received 27 January 1987)

The reduced alpha transfer rates are studied microscopically with a schematic model. Results for ground state to ground state alpha transfer reactions are given.

Outline

(1) A brief review of researches on alpha cluster …

(2) Alpha decay emitters with proton numbers 52<=Z<=118

Three typical regions of alpha emitters

"Light island" : near doubly magic nucleus ^{100}Sn

Alpha emitters: near doubly magic nuclei ^{208}Pb

"Superheavy island": next doubly magic nucleus $^{298}114$?

(3) Microscopic calculations with a quartetting wave function approach

(4) Summary

任中洲，徐躬耦，PRC 36 (1987) 456

PHYSICAL REVIEW C VOLUME 36, NUMBER 1 JULY 1987

Reduced alpha transfer rates in a schematic model

Ren Zhong-zhou and Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
(Received 27 January 1987)

The reduced alpha transfer rates are studied microscopically with a schematic model. Results for ground state to ground state alpha transfer reactions are given.

The model Hamiltonian is as follows:

$$H = H_0(+) + H_0(-) + H_1(+,-) , \tag{1}$$

where

$$H_0(\pm) = \pm\epsilon A(\pm) - 2\lambda_0 \left[\sum_\alpha B_\alpha^\dagger(\sigma,\pm) B_\alpha(\sigma,\pm) + \sum_\mu B_\mu^\dagger(\tau,\pm) B_\mu(\tau,\pm) \right] , \tag{2a}$$

任中洲，徐躬耦，PRC 36 (1987) 456

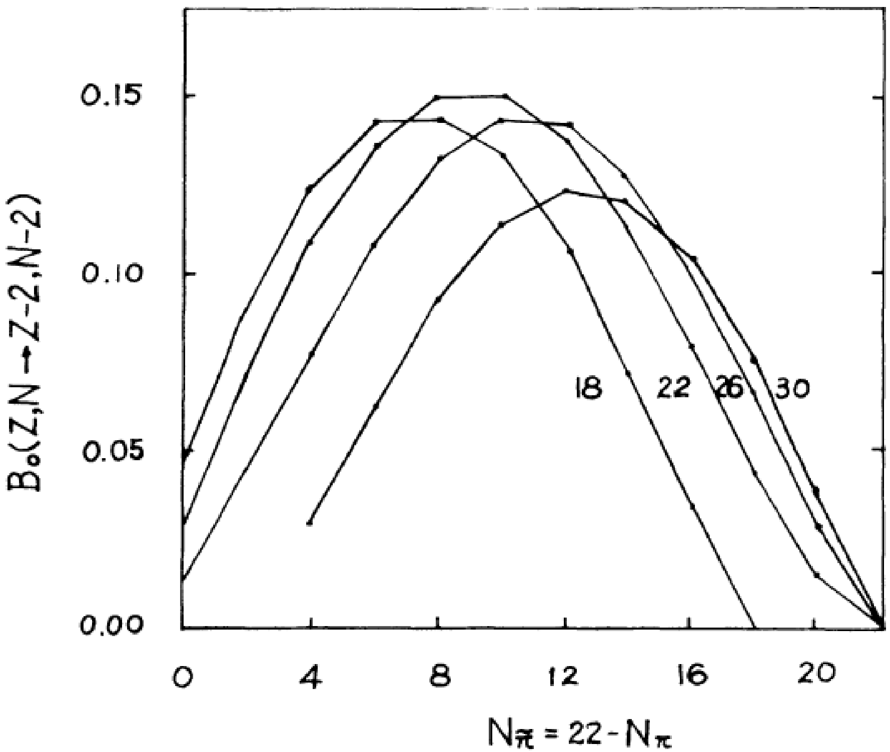


FIG. 2. Reduced α-transfer rates $B(Z,N \to Z-2,N-2)$ between ground states of nuclei with same value of $N_\nu - N_\pi$ as indicated in the figure, $N_\pi < 4l(-)+2$, $N_\nu > 4l(-)+2$. $\epsilon = 3.5$ MeV, $\lambda_0 = 1.0$ MeV, $\lambda_1 = 0.5$ MeV, $l(-)=5$, $l(+)=6$.

- 约化Alpha转移率

任中洲，徐躬耦， PRC 38 (1988) 1078

PHYSICAL REVIEW C VOLUME 38, NUMBER 2 AUGUST 1988

Evidence of α correlation from binding energies in medium and heavy nuclei

Ren Zhong-zhou
Department of Physics, Nanjing University, Nanjing, China

Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
and Department of Modern Physics, Lanzhou University, Lanzhou, China

(Received 23 March 1988)

If the effect of α clustering due to the interaction of the excited correlated proton pair with correlated neutron pairs in medium and heavy nuclei were taken into consideration, quasiparticle energies would not be simply additive. The empirical values of the extra term $\delta(\alpha)$ indicate that α correlations exist to a certain extent in these nuclei.

$$\delta B = \begin{cases} \Delta & \text{even-even nuclei} \\ 0 & \text{even-odd or odd-even nuclei} \\ -\Delta & \text{odd-odd nuclei} \end{cases} \qquad (3)$$

$$\delta B = \begin{cases} \Delta + \delta(\alpha) & \text{even-even nuclei} \\ 0 & \text{even-odd or odd-even nuclei} \\ -\Delta & \text{odd-odd nuclei} \end{cases} \qquad (4)$$

任中洲，徐躬耦，PRC 38 (1988) 1078

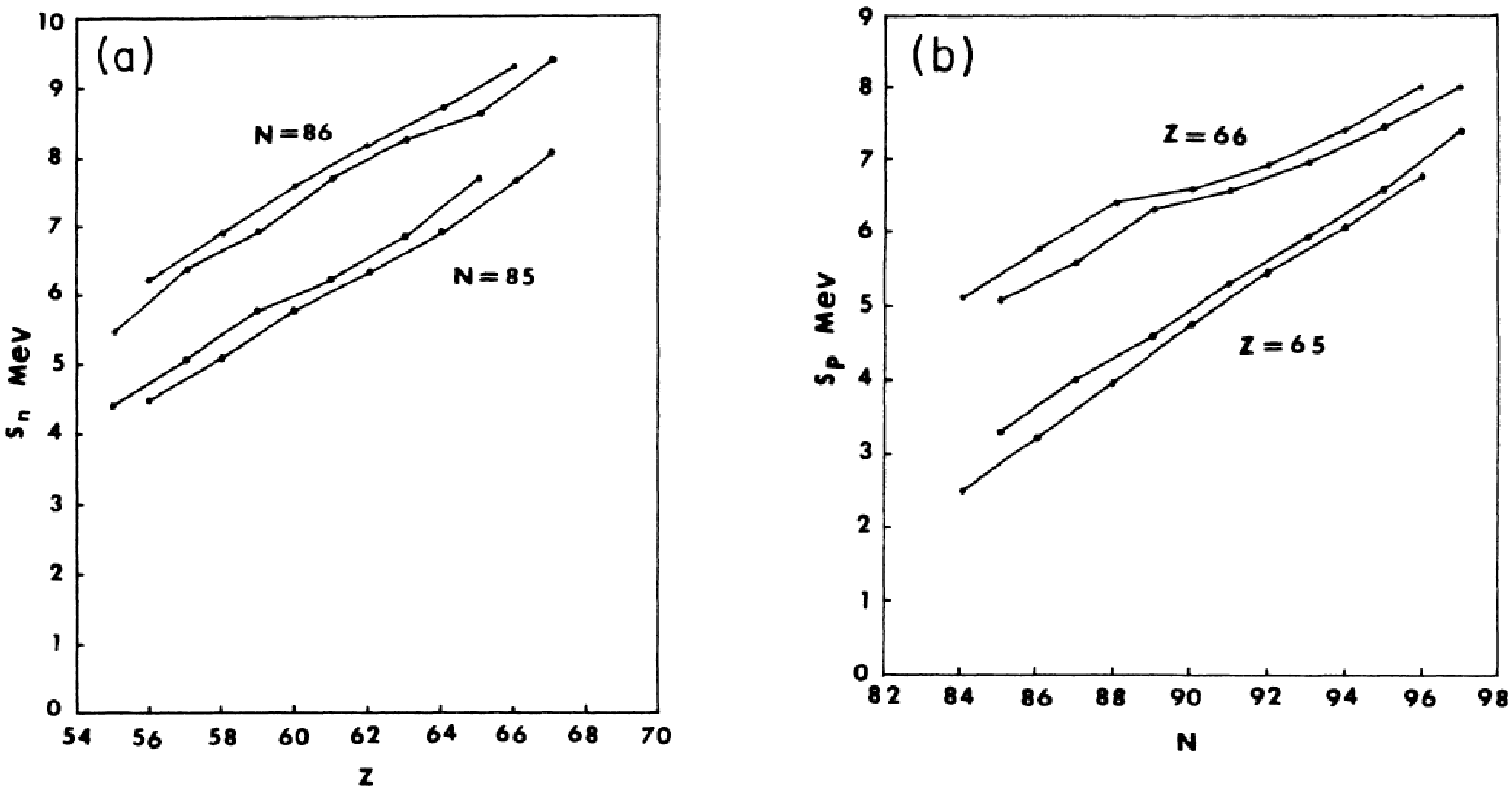


FIG. 1. (a) Neutron separation energies for nuclei with fixed *N*; (b) proton separation energies for nuclei with fixed *Z*.

任中洲，徐躬耦， JPG 15 (1989) 465

J. Phys. G: Nucl. Part. Phys. **15** (1989) 465–472. Printed in the UK

Shell and blocking effects in α-transfer reactions†

Ren Zhong-zhou‡ and Xu Gong-ou§

‡ Department of Physics, Nanjing University, Nanjing, China
§ Department of Physics, Nanjing University, Nanjing, China and Department of Modern Physics, Lanzhou University, Lanzhou, China

Received 18 July 1988

Abstract. Using a two-level pairing force model and assuming that α-clustering in ground states of medium and heavy nuclei is mainly the result of configuration mixing of cross-shell excitation of correlated pairs, shell and blocking effects in α-transfer reactions can be reasonably explained.

任中洲，徐躬耦， JPG 15 (1989) 465

2. The two-level pairing force model and the reduced pair transfer rates

The two levels of the model are introduced for representing the energy levels around proton and neutron Fermi energies in neighbouring shells. Nucleons in these two levels are interacting with each other with pairing forces. The model Hamiltonian is

$$H = H_0(+) + H_0(-) + H_1(+,-) \tag{1}$$

where

$$H_0(\pm) = \pm \varepsilon N_F(\pm) - \lambda_0 \sum_{\nu=0,\pm1} B_\nu^\dagger(\pm) B_\nu(\pm) \tag{2}$$

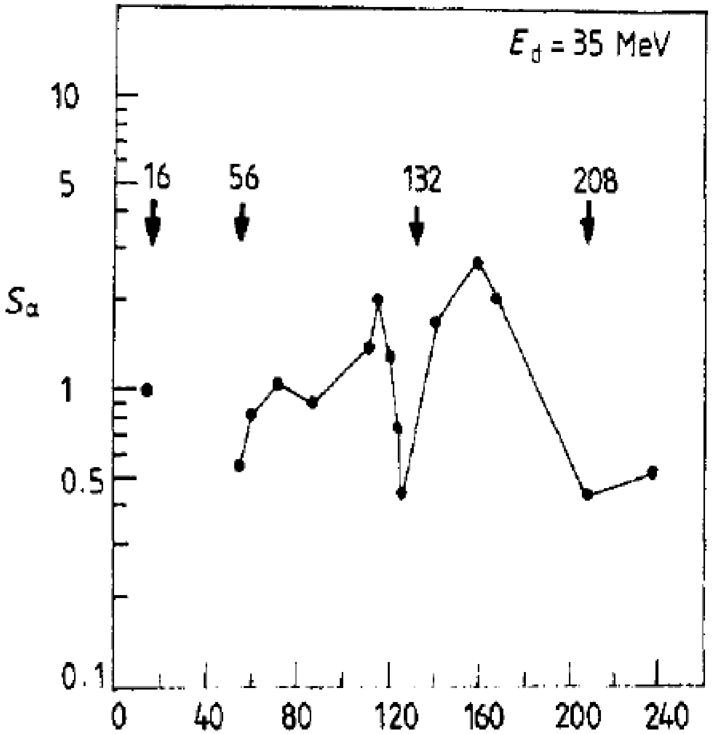
$$H_1(+,-) = -\lambda_1 \sum_{\nu=0,\pm1} B_\nu^\dagger(+) B_\nu(-) + \mathrm{HC} \tag{3}$$

$\pm\varepsilon$ represent the single-particle energies of upper and lower levels; λ_0, λ_1 represent the intensities of pairing forces related to the same level and to different levels; and

$$N_F(\pm) = \sum_{m,m_t} a_{m,m_t}^\dagger(\pm) a_{m,m_t}(\pm) \tag{4}$$

$$B_\nu^\dagger(\pm) = \frac{1}{\sqrt{2}} [a^\dagger(\pm) a^\dagger(\pm)]^{J=0}_{M=0}\,{}^{T=1}_{M_T=\nu} \qquad B_\nu(\pm) = (B_\nu^\dagger(\pm))^\dagger \tag{5}$$

任中洲，徐躬耦， JPG 15 (1989) 465



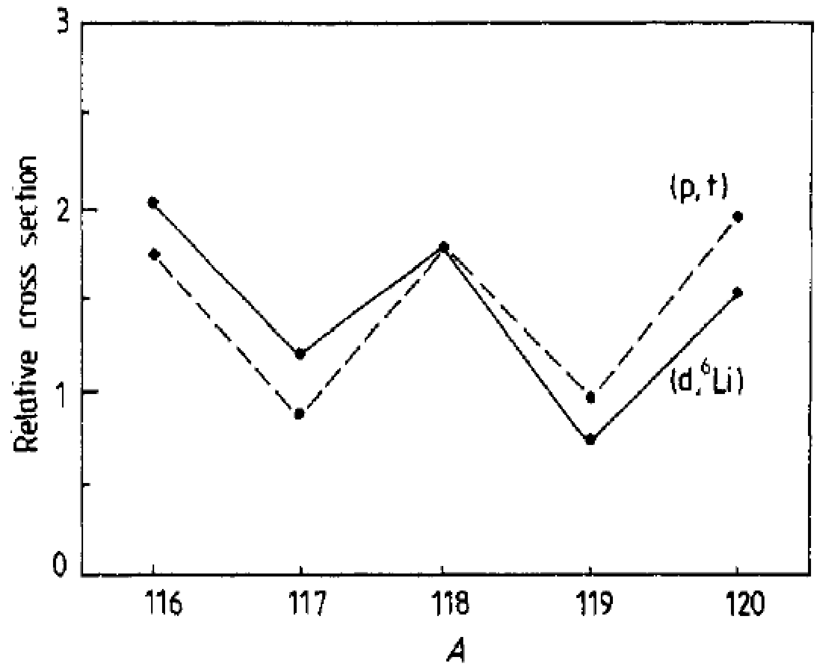
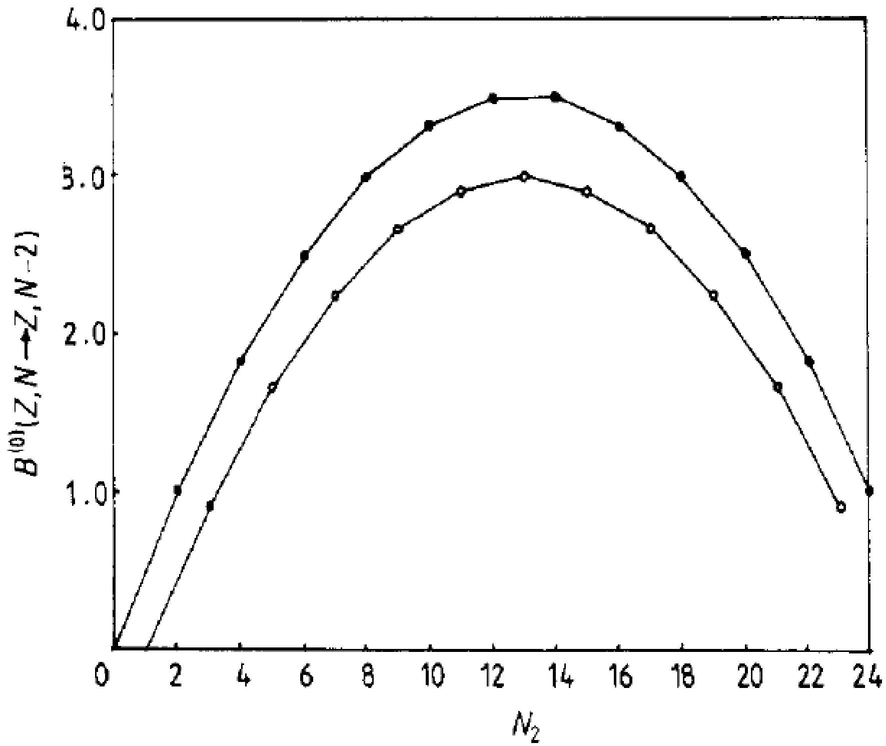


Figure 1. Alpha-particle spectroscopic factor S_α obtained from analysis of (d, Li) reactions normalised to unity at ^{16}O and plotted as a function of target mass (Becchetti *et al* 1975 *Phys. Rev. Lett.* **34** 225).

Figure 2. Comparison between the relative cross section of (p, t) and (d, Li) reactions as a function of *A* for some tin isotopes (Becchetti *et al* 1975 *Phys. Rev. Lett.* **35** 268).

任中洲，徐躬耦， JPG 15 (1989) 465



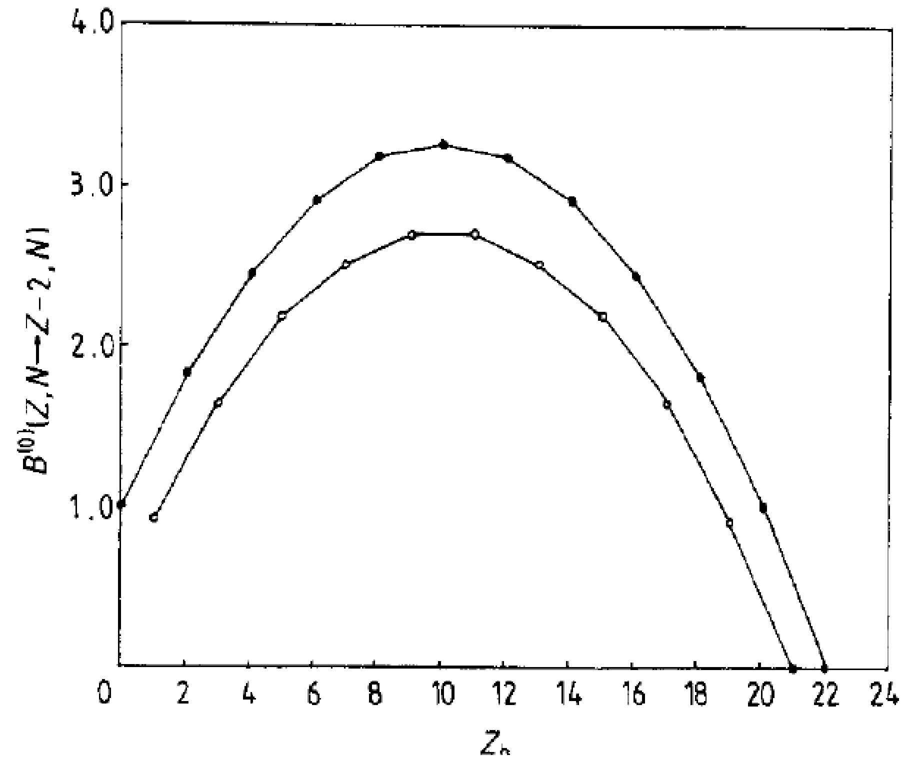
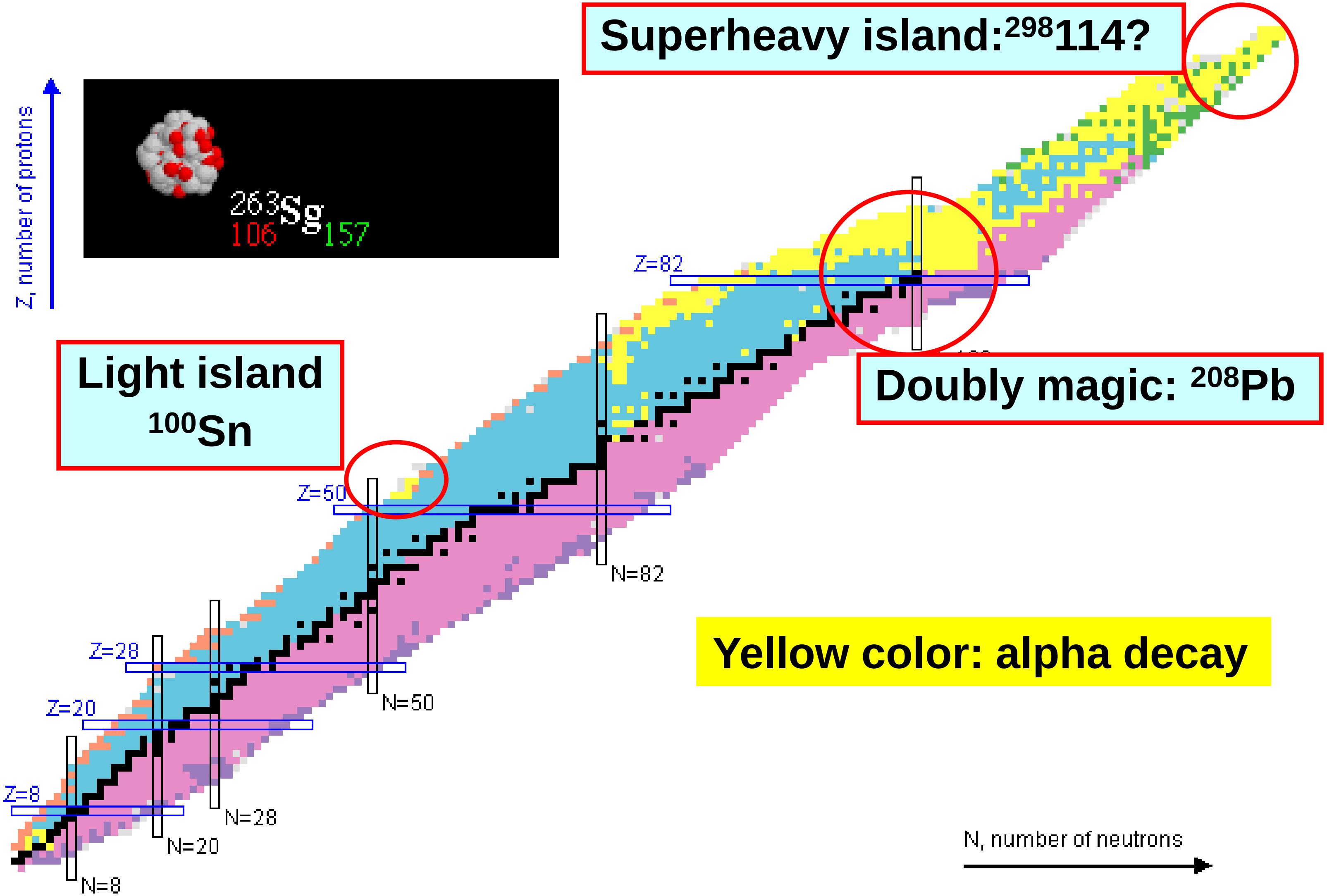


Figure 3. Reduced neutron-pair transfer rates $B^{(0)}(Z, N \rightarrow Z, N-2)$ as a function of N_2 for $Z < \Omega_1$: ○, odd N; ●, even N.

Figure 4. Reduced proton-pair transfer rates $B^{(0)}(Z, N \rightarrow Z, N-2, N)$ as a function of Z_h for $N > \Omega_1$: ○, odd Z; ●, even Z.

(1) A brief review of alpha cluster decay

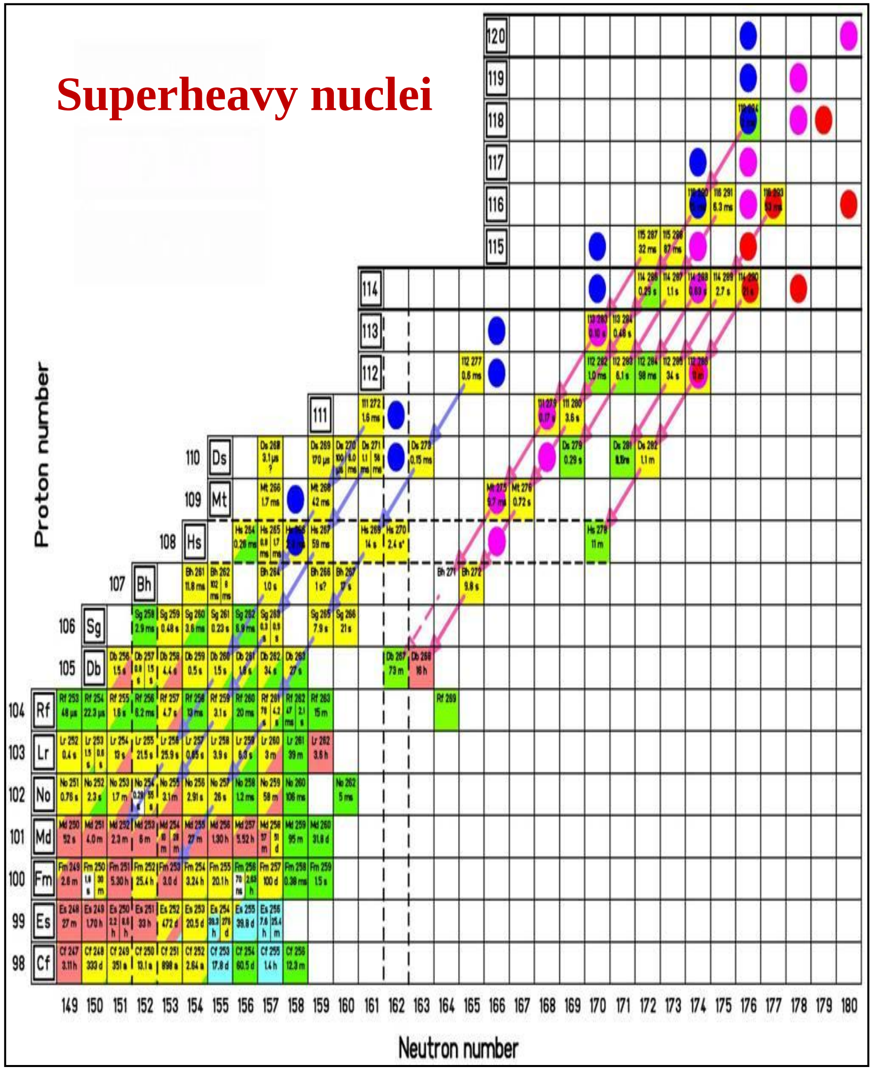


(1) A brief review of alpha cluster decay

- **Alpha decay: an old problem with renewed interest in recent years, still not fully solved**

- **Nuclear properties:**
  - **Energy and Lifetime**
  - **Spin and parity**
  - **Nuclear interaction**
  - **Shell effect**
  - **Superheavy nuclei**

- **Alpha clustering (most difficult)**



Alpha decay : theoretical calculations

1. Phenomenological Formulas:

(1) The Geiger-Nuttall law

(2) The Viola-Seaborg formula

(3) Other alpha-decay formulas

2. Theoretical Approaches:

(1) Shell model

(2) Cluster model

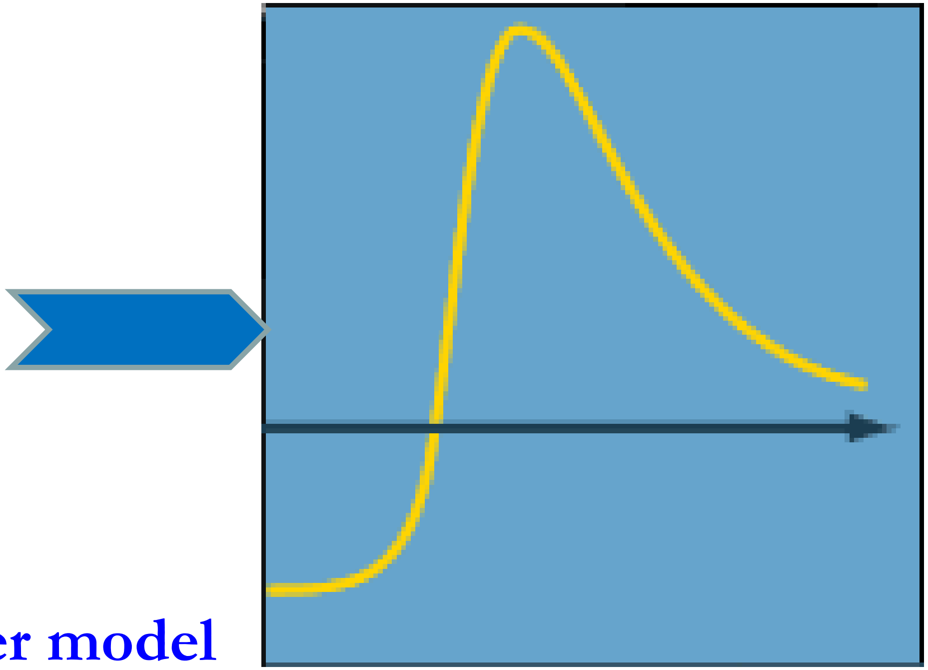
(3) Fission-like model

(4) A mixture of shell and cluster model

(5) A density-dependent cluster model

(6) A quartetting wave function approach

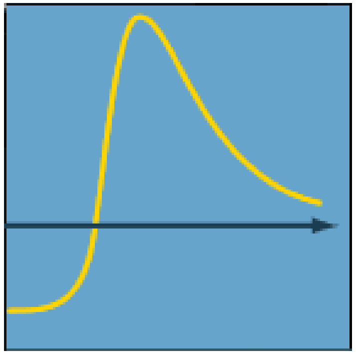
(7) ……



Alpha-decay theory in nuclear textbooks

(1) Preformation probability
(2) Frequency
(3) Penetration probability

p_α, ν, and $\mathcal{T}$



Energy and mass dependence. Using p_α, ν, and $\mathcal{T}$ obtained above, we can write the transition probability as

$$\mathcal{W} = p_\alpha \nu \mathcal{T}$$

To put this expression into a form so that it can be compared with the Geiger-Nuttall law of Eq. (4-61), we take the logarithm in the base 10 for both sides and obtain the result

$$\begin{aligned} \log_{10} \mathcal{W} &= \log_{10} p_\alpha + \log_{10} \nu + \log_{10} \mathcal{T} \\ &= 20.46 + \log_{10} \frac{\sqrt{E_\alpha}}{A^{1/3}} + 1.42\sqrt{ZA^{1/3}} - 1.72\frac{Z}{\sqrt{E_\alpha}} \end{aligned} \qquad (4\text{-}65)$$

The dominant energy dependence comes from the last term, in agreement with the empirical result of the Geiger-Nuttall law.

Alpha-decay theory in textbooks

(1)Preformation probability (open problem)

The probability W for α-particle emission from a heavy nucleus by tunneling may be separated into a product of three factors. The first is the probability p_α to find an α-particle inside the nucleus. In a heavy nucleus, there is a good chance for two protons and two neutrons to form an α-like entity. We shall call such an object an α-cluster. However, this is only one of the many possible components of the wave function for such a nucleus. As a result, it is not easy to make an estimate for the value of p_α. A crude way is to say that it must be essentially of the same order of magnitude for all heavy nuclei, as there are only small fractional differences in their masses and we shall take $p_\alpha \sim 0.1$ as a rough guide.

This is only a rough guide!!!

Phenomenological

Alpha-decay theory in textbooks

(2) Frequency (Pre-exponential factor)

Once an α-cluster is formed inside the nucleus, it must come to the surface before it can tunnel through the barrier. The frequency ν with which it appears at the edge of the potential well depends on the velocity v it travels and the size of the potential well. A reasonable way to estimate ν is to take the well size as twice the nuclear radius R. With this assumption we obtain the result,

$$\nu = \frac{v}{2R} = \frac{\sqrt{2K/M_\alpha}}{2R}$$

Phenomenological

where K is the kinetic energy of the α-cluster inside the well and M_α its mass. The precise value of K depends on the depth of the potential well and is not well known.

$E_\alpha = 5.6$ MeV. It is about an order of magnitude larger than the best values deduced from measurements. Part of the reason for the poor agreement comes from the fact that heavy nuclei do not have the simple spherical shape assumed here. Furthermore, the replacement of K by E_α may also have cost some loss of accuracy.

Microscopic calculation of “frequency”

VOLUME 59, NUMBER 3 PHYSICAL REVIEW LETTERS 20 JULY 1987

Decay Width and Shift of a Quasistationary State

S. A. Gurvitz
Weizmann Institute of Science, 76 100 Rehovot, Israel

and

G. Kalbermann
The Hebrew University of Jerusalem, 91 904 Jerusalem, Israel

The decay width of a metastable state in the quasiclassical limit was found long ago by Gamow.[3] Even in this treatment the preexponential factor appearing in the width formula was hard to estimate except for the case of high-lying states. Since then, little progress has been made towards finding a general formula that embodies the quasiclassical result of Gamow including the energy shift in closed form.

$$N = \left[\int_{r_0}^{r_1} \frac{1}{p(r)} \cos^2 \left[\int_{r_0}^{r} p(r')dr' - \frac{\pi}{4} \right] dr \right]^{-1} . \qquad (3.7)$$

If the contribution from the classically forbidden regions is not small, these regions should also be taken into account in Eq. (3.7). Substituting Eq. (3.6) into Eqs. (3.3) and (3.4) we obtain for the quasiclassical width and shift

$$\Gamma = \frac{\hbar^2 N}{4m} \exp\left[-2 \int_{r_1}^{r_2} |p(r)|\, dr \right] , \qquad (3.8)$$

Frequency
Vs

Well defined

pre-factor

For the high-lying states where $\varphi_0(r)$ oscillates strongly, one can replace the cosine term in Eq. (3.7) by $\frac{1}{2}$. Then

$$N^{-1} = \frac{1}{2m} \int_{r_0}^{r_1} \frac{m}{p(r)} dr = \frac{T\hbar}{4m} , \qquad (3.10)$$

where T is the classical period of motion. Substituting Eq. (3.10) into Eq. (3.8) we obtain the famous Gamow formula for the width of the quasistationary state with preexponential Gamow factor $\hbar/T$. However, our prefactor factor $N\hbar^2/4$ in Eq. (3.8) is more general and can also be used as soon as the quasiclassical approximation is applicable to the bound-state wave function in a classically forbidden region, which is correct even for low-lying bound states.

Alpha-decay theory in textbooks

(3) Exponential factor

$$\Gamma = \nu \times \mathcal{T} = \frac{4\hbar^2\alpha^2}{\mu k} |\Phi(r_{\rm sep})\chi_k(r_{\rm sep})|^2,$$

to calculate. In this limit, $\kappa b \to \infty$, and $\sinh \kappa b \longrightarrow e^{\kappa b}$. The transmission coefficient in Eq. (4-62) simplifies to the form

$$\mathcal{T} \longrightarrow e^{-2\kappa b} \tag{4-63}$$

The factor $e^{-\kappa b}$ expresses the attenuation of the amplitude of the wave in going through the barrier, and it is quite reasonable to expect that the transmission coefficient is essentially given by the square of this factor. For our case of $V_0 \approx 30$ MeV and E_α in

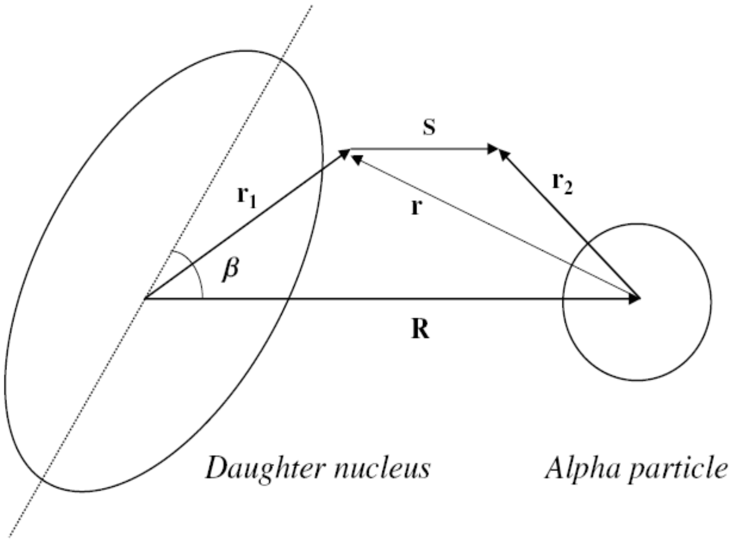
The form of the solution, however, remains very similar to that given in Eq. (4-63) if we make the replacement

$$\kappa b \longrightarrow \int_R^{R_1} \sqrt{\frac{2\mu}{\hbar^2}} \left\{V_b(r) - E_\alpha\right\}^{1/2} dr$$

A density-dependent cluster model: all alpha emitters

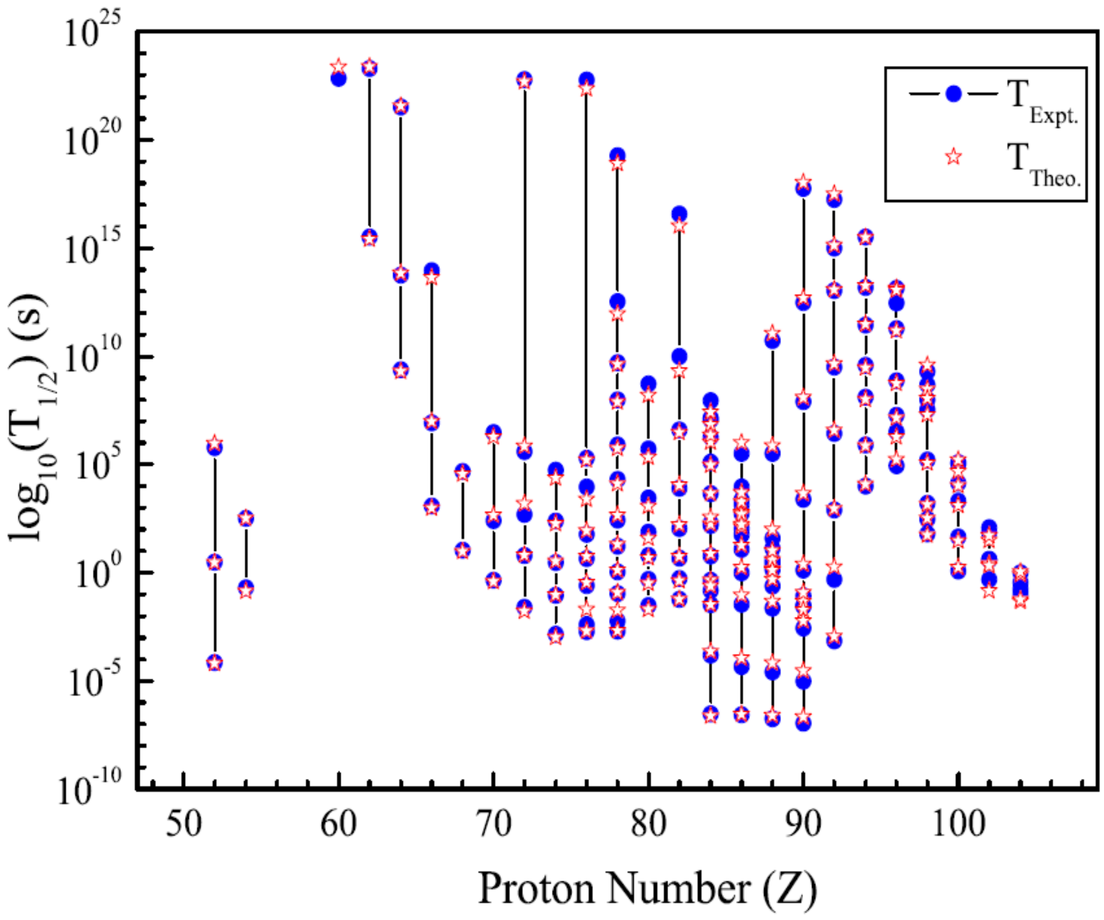
Preformation probability
Pre-exponential factor
Exponential factor

p_α, ν, and $\mathcal{T}$



- **Potential with doubly folding procedure**
- **Finite-size of the alpha particle and core**
- **Nuclear deformation**
- **Centrifugal potential**
- **Bohr-Sommerfeld quantization condition**
- **……**

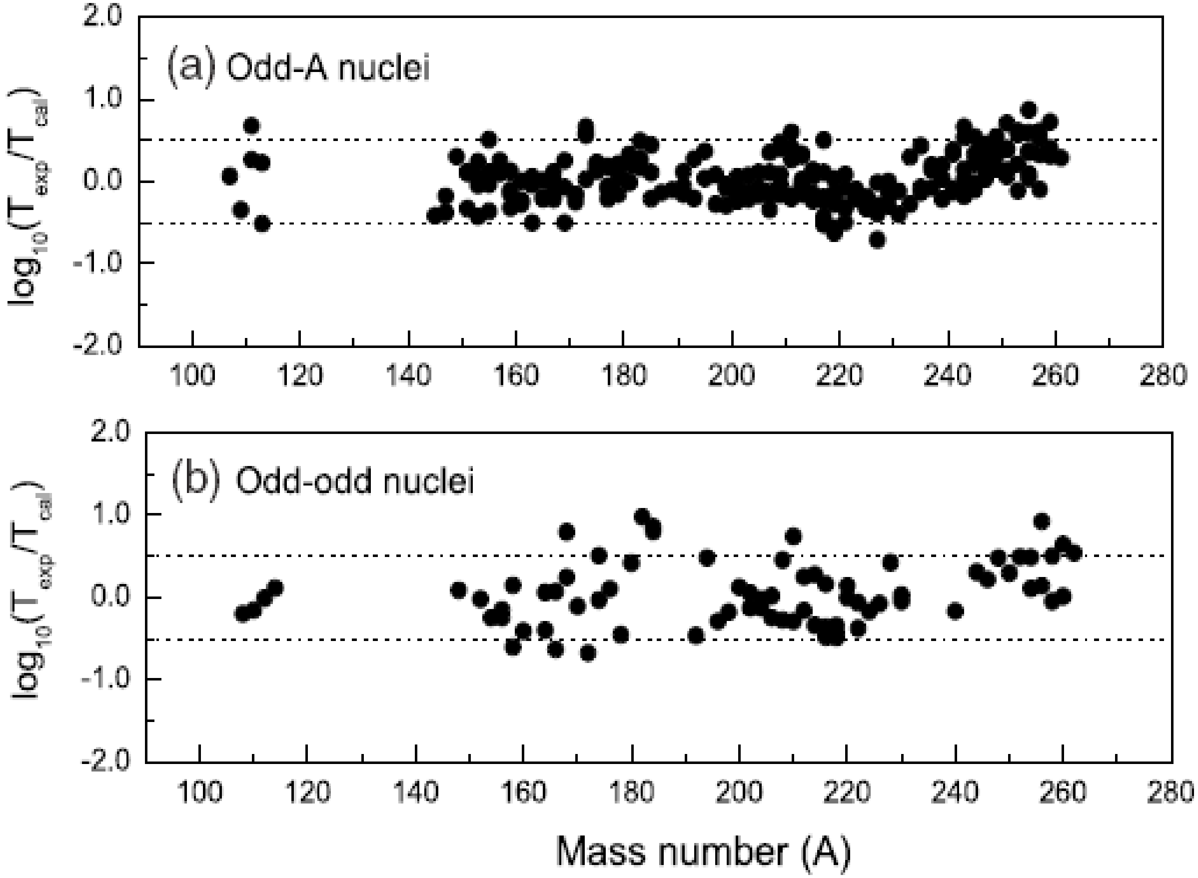
Alpha-decay half-lives of even-even nuclei of ground-state transitions (Z=52-104)



Circles : Experiment

Stars : Theory

The factor of agreement for odd nuclei of ground-state transitions (Z=52-105)



Circles :

HF=Texp / Tcal between experiment and theory

TABLE I. Comparison of average and rms deviations of DDCM and GLDM.

Nuclide	Number	Average deviation	rms deviation
Even-even	157 (131)	0.209	0.267(0.35)
Odd-*A*	231 (192)	0.229	0.285(0.57/0.71)
Odd-odd	79 (50)	0.318	0.435(0.99)

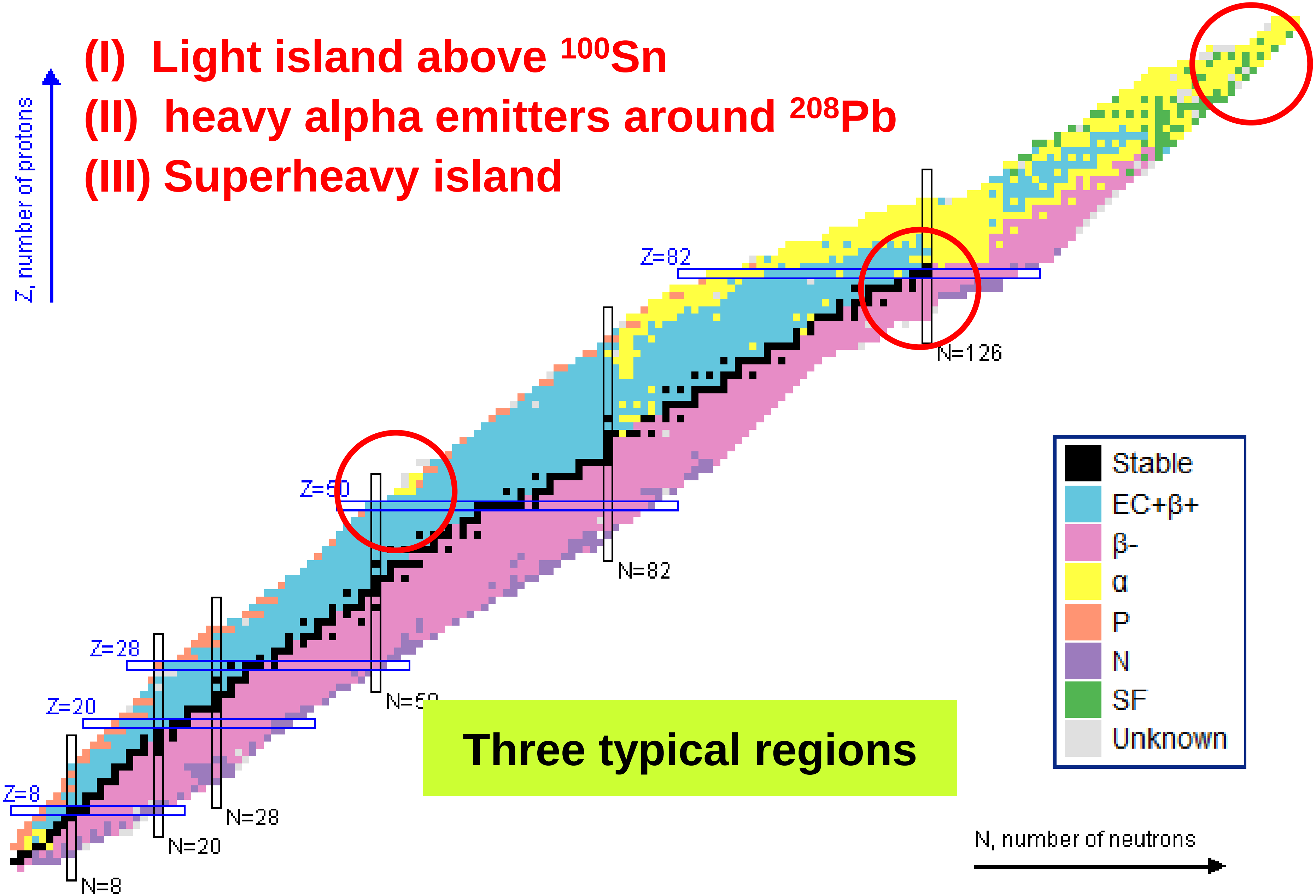
To further improve the agreement, microscopic calculations of preformation factors are needed.

A constant alpha preformation factor is OK for open shell nuclei, but not for shell region nuclei!

(I) Light island above ^{100}Sn

(II) heavy alpha emitters around ^{208}Pb

(III) Superheavy island



Three typical regions

(I) Light island: Theory and Experiment

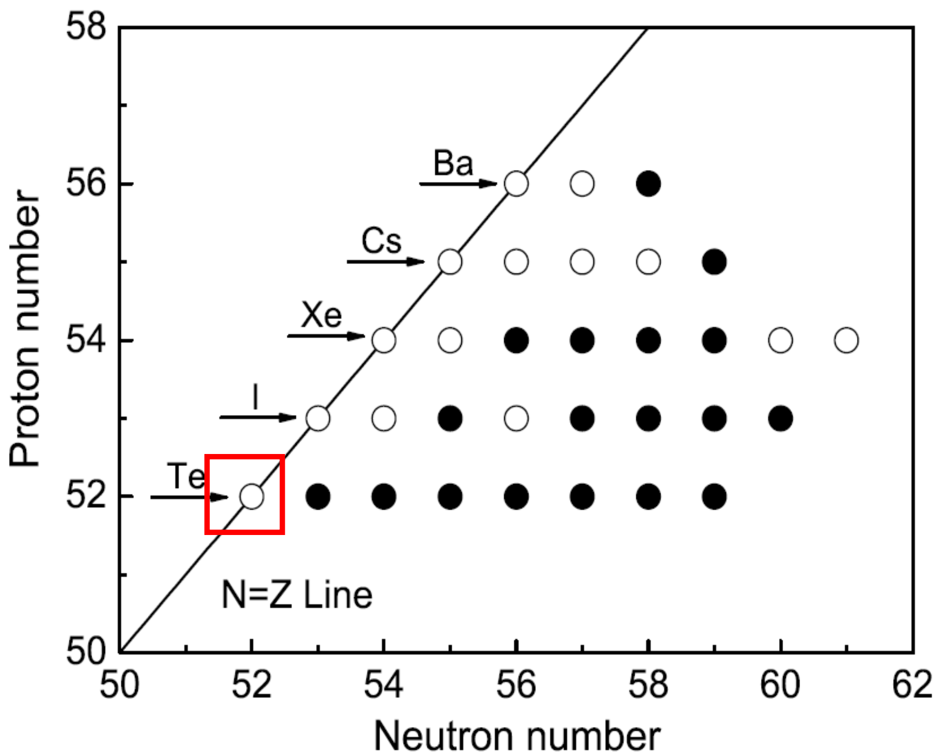


FIG. 1: Alpha emitters close to the N=Z line.

^{104}Te: alpha particle on top of doubly magic core ^{100}Sn

***α* decay of ^{105}Te**

PHYSICAL REVIEW C **73**, 061301(R) (2006)

closest to the N=Z line

Extrapolated alpha-decay energy for ^{104}Te

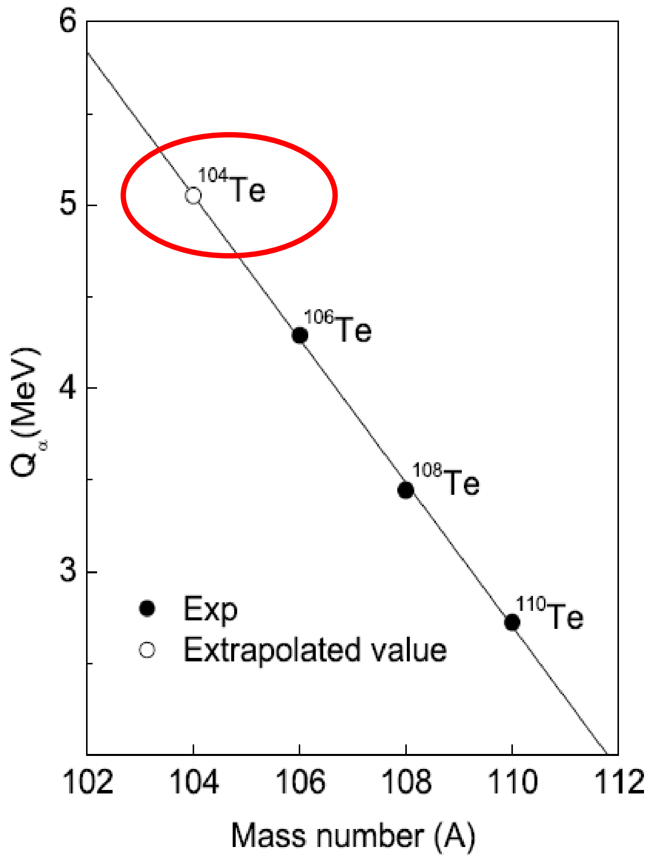
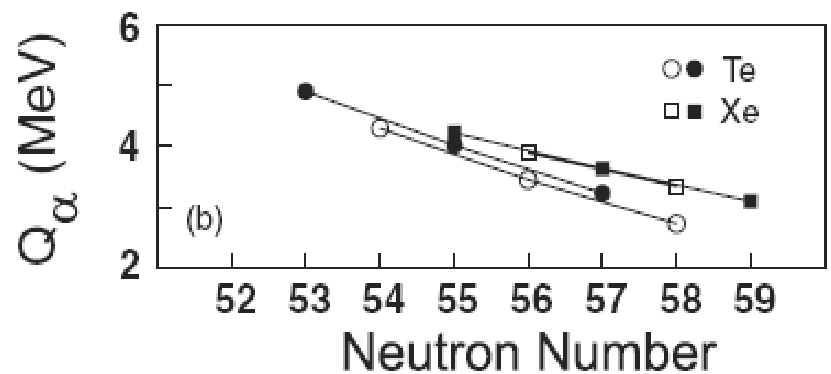


FIG. 2: Extrapolation of α-decay energy for ^{104}Te.

Nuclei	Q_α(MeV)
$^{104}Te \rightarrow ^{100}Sn + \alpha$	5.053*
$^{105}Te \rightarrow ^{101}Sn + \alpha$	4.900
$^{106}Te \rightarrow ^{102}Sn + \alpha$	4.290
$^{107}Te \rightarrow ^{103}Sn + \alpha$	4.008
$^{108}Te \rightarrow ^{104}Sn + \alpha$	3.445
$^{109}Te \rightarrow ^{105}Sn + \alpha$	3.230
$^{110}Te \rightarrow ^{106}Sn + \alpha$	2.723
$^{111}Te \rightarrow ^{107}Sn + \alpha$	2.576



Preformation probability: important

of α clusterization in the DDCM. Delion and co-workers systematically analyzed the α-clustering effect in heavy and superheavy nuclei [6,7] and they pointed out the suppression of the α-clusterization process with increasing proton-neutron asymmetry along the isotopic chains [7]. To improve the agreement between experiment and theory, we therefore use the isospin-dependent preformation factor $P_\alpha = c_1 + c_2(N - Z)$ instead of the constant one [19] for each kind of nuclei [e.g., a linear dependence $P_\alpha^{\mathrm{ee}} = 0.73 - 0.09 \times (N - Z)$ for the even-even nuclei]. As expected, the corresponding theoretical lifetimes [T_α(Cal2)] show a significantly better agreement with the experimental data. The root-mean-square deviation is reduced from 0.319 to 0.242 for the available α-emitters. Thus

(II) Shape Coexistence : Pb and Po isotopes

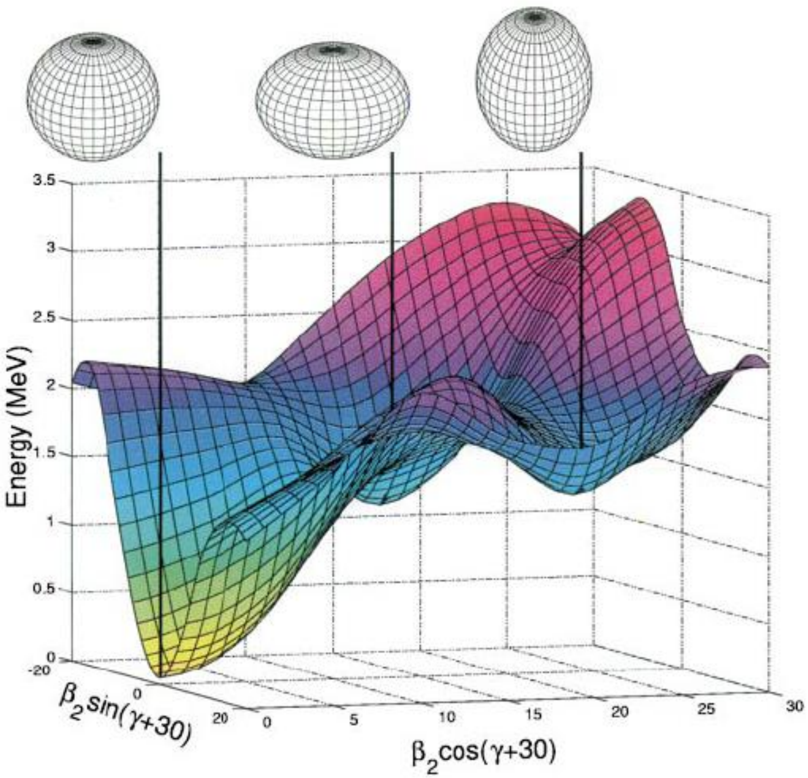
Preformation factor is also important!

letters to nature

A triplet of differently shaped spin-zero states in the atomic nucleus ^{186}Pb

A. N. Andreyev*, M. Huyse*, P. Van Duppen*, L. Weissman*, D. Ackermann†, J. Gerl†, F. P. Heßberger†, S. Hofmann†, A. Kleinböhl†, G. Münzenberg†, S. Reshitko†, C. Schlegel†, H. Schaffner†, P. Cagarda‡, M. Matos‡, S. Saro‡, A. Keenan§, C. Moore§, C. D. O'Leary§, R. D. Page§, M. Taylor§, H. Kettunen||, M. Leino||, A. Lavrentiev¶, R. Wyss# & K. Heyde☆

* Instituut voor Kern- en Stralingsfysica, University of Leuven, Celestijnenlaan 200 D, B-3001 Leuven, Belgium
† Gesellschaft fur Schwerionenforschung Darmstadt, Postfach 110541, D-6100 Darmstadt, Germany
‡ Department of Nuclear Physics, Comenius University, Bratislava, Slovakia
§ Department of Physics, Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, UK
|| Department of Physics, University of Jyväskylä, FIN-40351 Jyväskylä, Finland
¶ Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, 141980 Dubna, Russia
# Department of Physics, Royal Institute of Technology, 104 05 Stockholm, Sweden, and Department of Technology, Kalmar University, Box 905, 391 29 Kalmar, Sweden
☆ Vakgroep Subatomaire en Stralingsfysica, Institute for Theoretical Physics, B-9000 Gent, Belgium



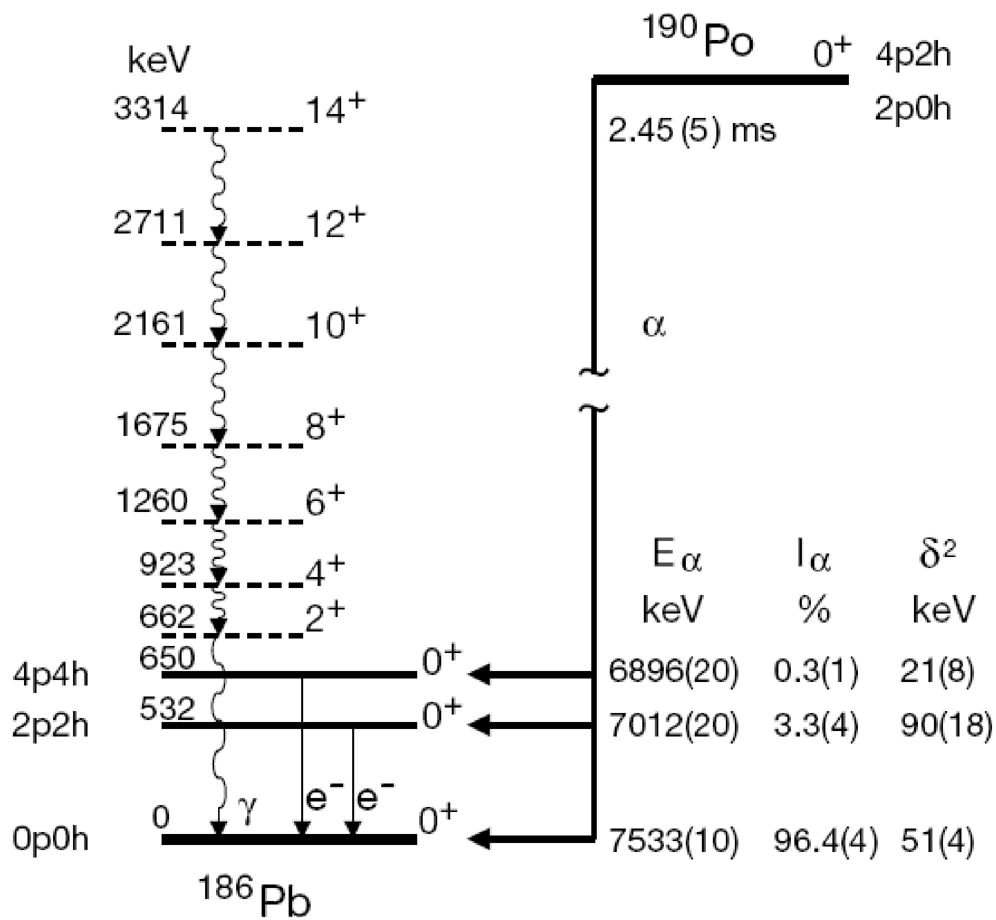
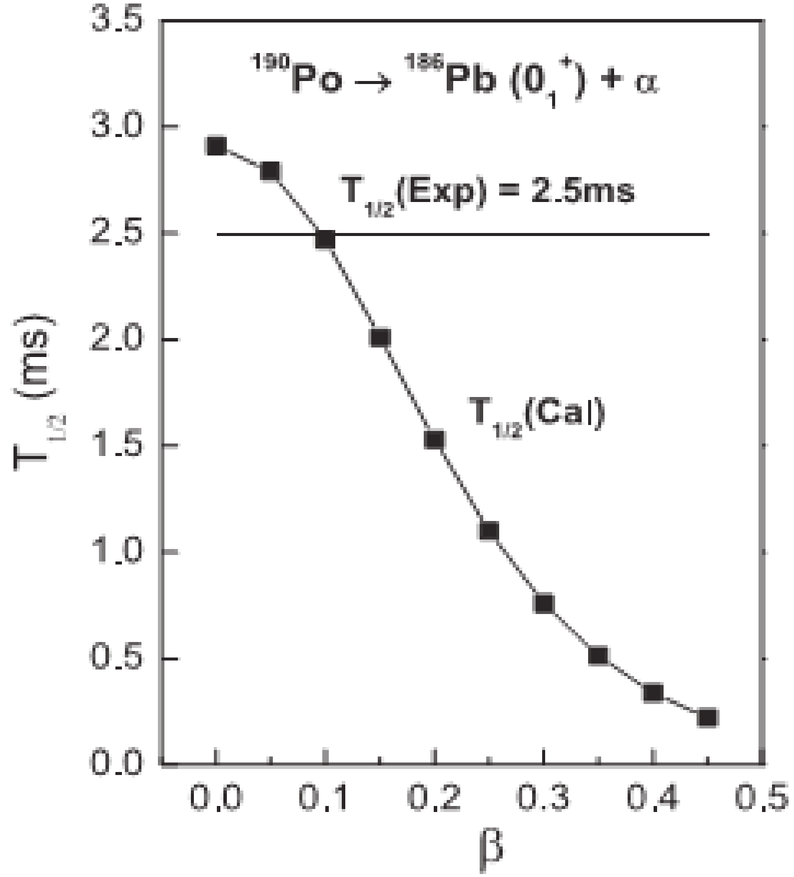
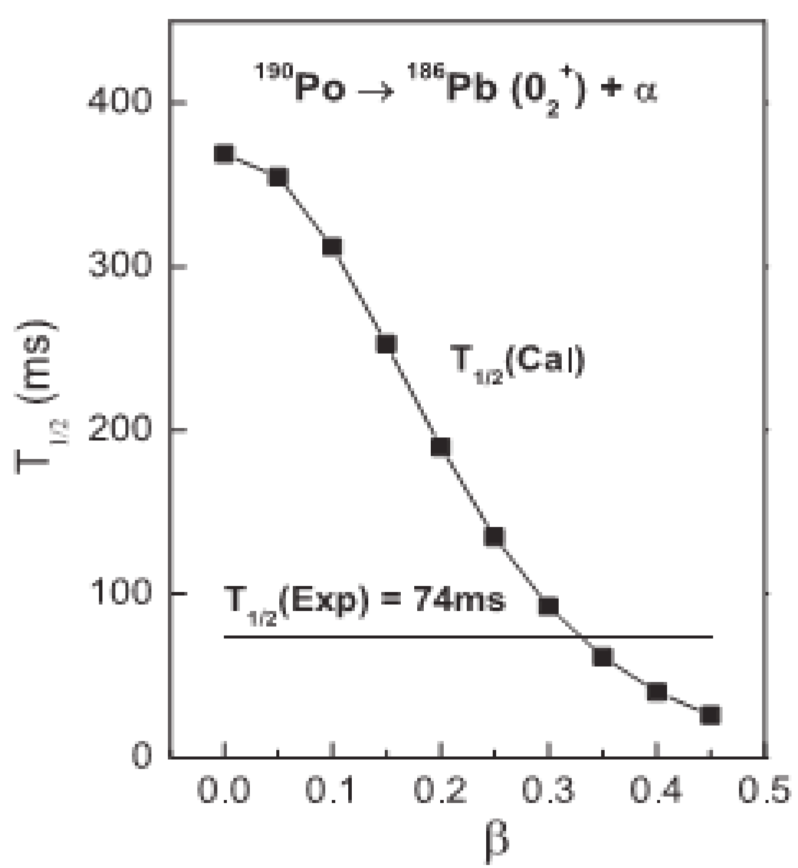


Figure 4 The decay pattern of ^{190}Po and the level scheme of ^{186}Pb. Indicated are α-decay energies E_α, intensities I_α, reduced α-widths δ^2, and configuration assignments. As

Alpha-transitions to coexisting 0+ states





Preformation probability: important

are involved. This is also evidenced by our previous analysis of α-decay branching ratios where the excitation probabilities of the daughter nucleus after disintegration were found to obey the Boltzmann distribution approximately [36]

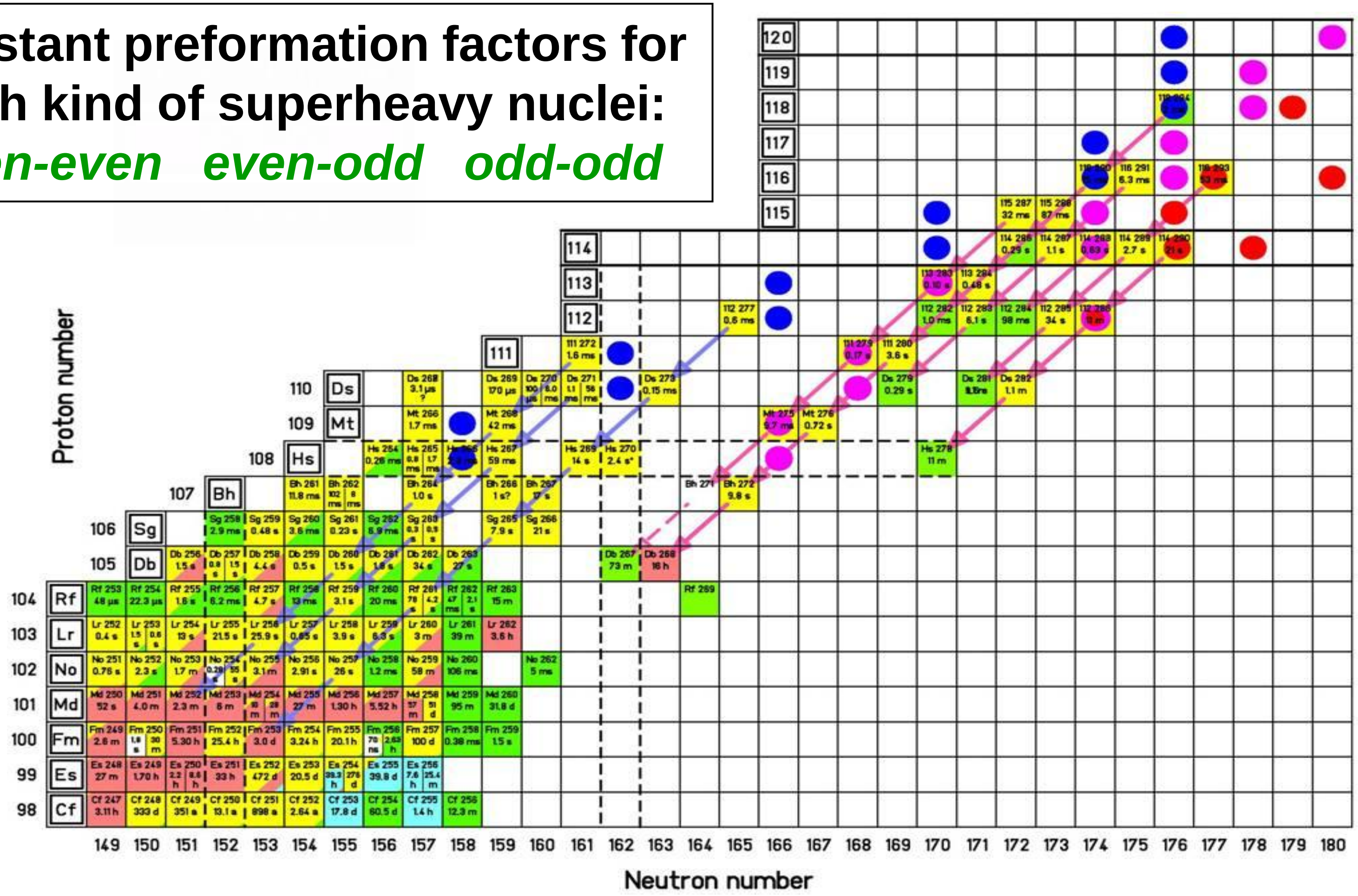
$$w_\ell(\mathrm{E}_\ell^*) = \exp[-c\mathrm{E}_\ell^*], \tag{9}$$

where E_ℓ^* is the excitation energy of ℓ state in the daughter nucleus and c is a free parameter. The excitation probability

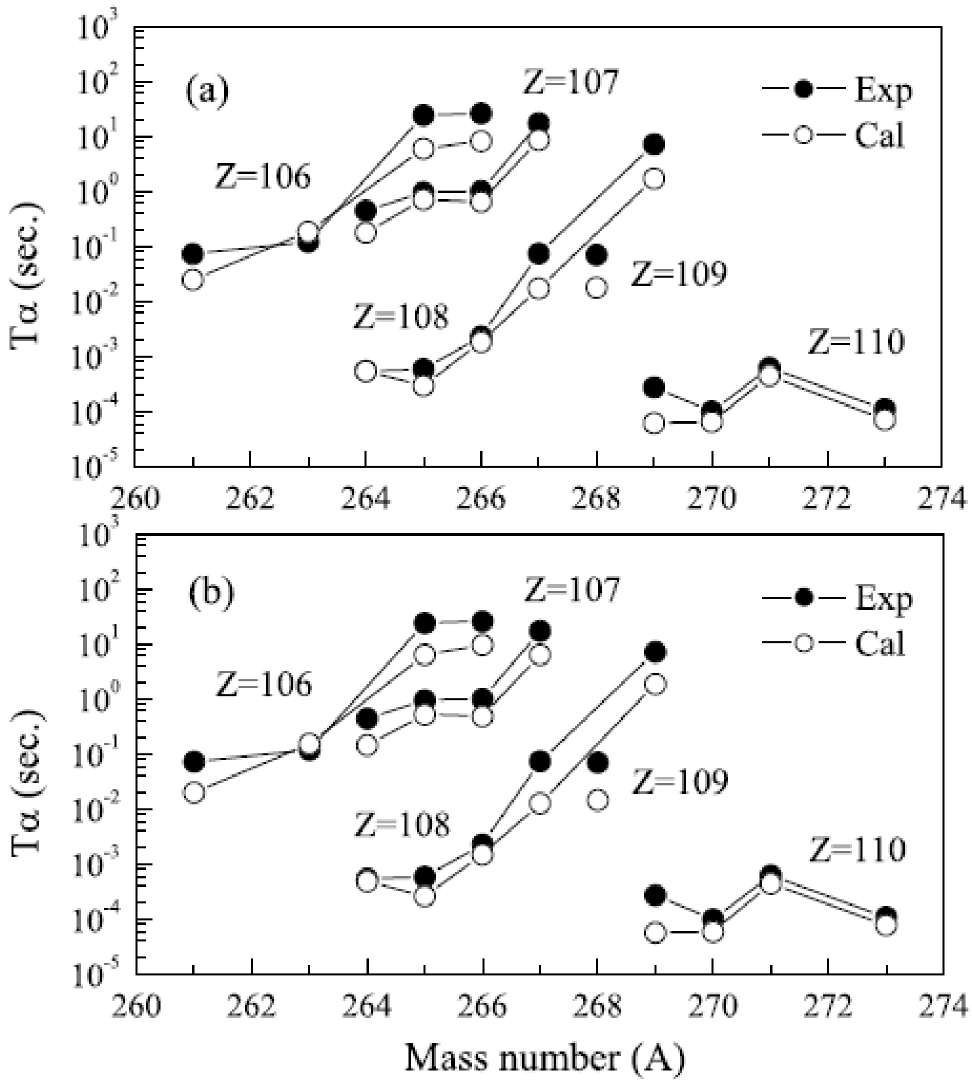
α-decay branching ratios [36]. In present study, we describe the α-cluster preformation probabilities for different α-transitions by the product of the constant formation factor and the Boltzmann distribution function $[\mathrm{P}_\alpha \times w_\ell(\mathrm{E}_\ell^*)]$. It is easy to find that the preformation factor of the α-particle is fixed to a constant value of 0.38 for the ground-state transitions ($0^+ \rightarrow 0_1^+$). For α-transitions to the excited 0^+ states, a smaller value

(III) Superheavy island: Theory and Experiment

Constant preformation factors for each kind of superheavy nuclei:
even-even even-odd odd-odd



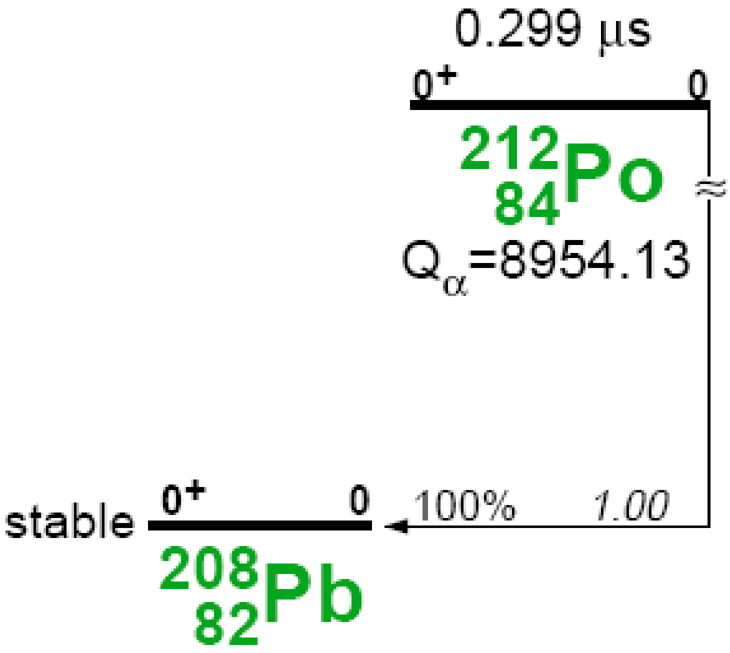
The experimental and calculated alpha-decay half-lives of nuclei with Z=106-110



Deformation: the macroscopic-microscopic model (MM)

Deformation: RMF

Preformation probability and Penetration probability of ^{212}Po



Spherical
Doubly magic
Only one decay channel
Accurate experimental data
……

Microscopic calculation of the preformation and penetration probability simultaneously

Alpha decay: a quartetting wave function approach

PHYSICAL REVIEW C **93**, 011306(R) (2016)

α-decay width of ^{212}Po from a quartetting wave function approach

Chang Xu,[1,*] Zhongzhou Ren,[1,2,†] G. Röpke,[3,‡] P. Schuck,[4,5,§] Y. Funaki,[6] H. Horiuchi,[7,8] A. Tohsaki,[7] T. Yamada,[9] and Bo Zhou[10]

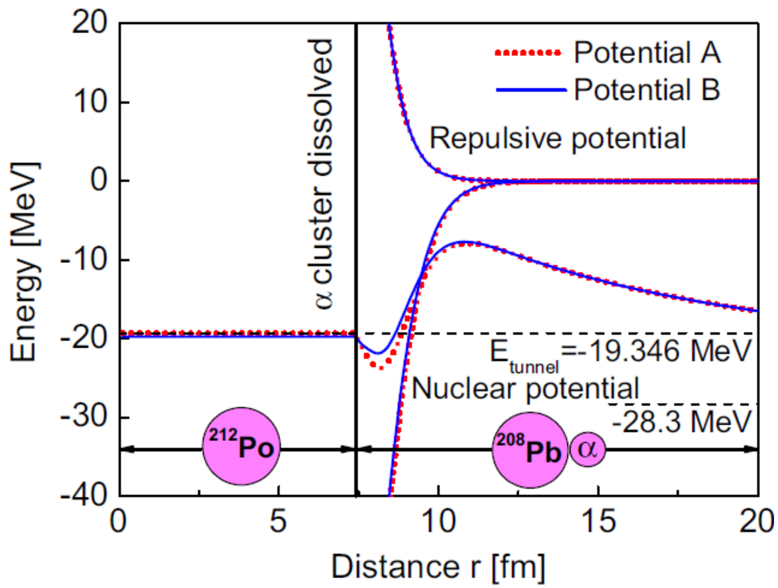
[1]*Department of Physics and Key Laboratory of Modern Acoustics, Nanjing University, Nanjing 210093, China*
[2]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*
[3]*Institut für Physik, Universität Rostock, D-18051 Rostock, Germany and National Research Nuclear University (MEPhI), 115409 Moscow, Russia*
[4]*Institut de Physique Nucléaire, Université Paris-Sud, IN2P3-CNRS, UMR 8608, F-91406 Orsay, France*
[5]*Laboratoire de Physique et Modélisation des Milieux Condensés, CNRS- UMR 5493, F-38042 Grenoble Cedex 9, France*
[6]*RIKEN Nishina Center, Wako 351-0198, Japan*
[7]*Research Center for Nuclear Physics (RCNP), Osaka University, Osaka 567-0047, Japan*
[8]*International Institute for Advanced Studies, Kizugawa 619-0225, Japan*
[9]*Laboratory of Physics, Kanto Gakuin University, Yokohama 236-8501, Japan*
[10]*Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan*

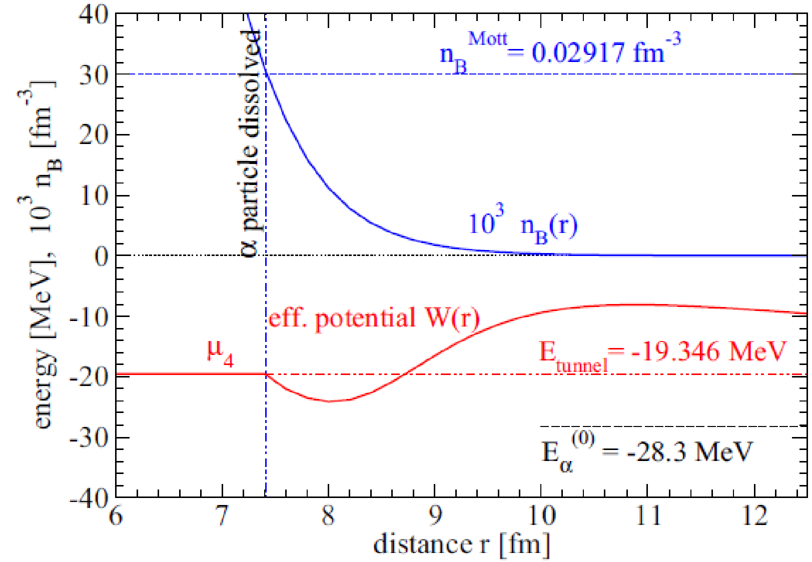
A microscopic calculation of α-cluster preformation probability and α-decay width in the typical α emitter ^{212}Po is presented. Results are obtained by improving a recent approach to describe α preformation in ^{212}Po [Phys. Rev. C **90**, 034304 (2014)] implementing four-nucleon correlations (quartetting). Using the actually measured density distribution of the ^{208}Pb core, the calculated α-decay width of ^{212}Po agrees fairly well with the measured one.

PHYSICAL REVIEW C **93**, 011306(R) (2016) **RAPID COMMUNICATIONS**

α-decay width of ^{212}Po from a quartetting wave function approach

Chang Xu,[1,*] Zhongzhou Ren,[1,2,†] G. Röpke,[3,‡] P. Schuck,[4,5,§] Y. Funaki,[6] H. Horiuchi,[7,8] A. Tohsaki,[7] T. Yamada,[9] and Bo Zhou[10]





Potential A: Thomas-Fermi model for the core region.

Potential B: Discrete energy level structure of the core nucleus.

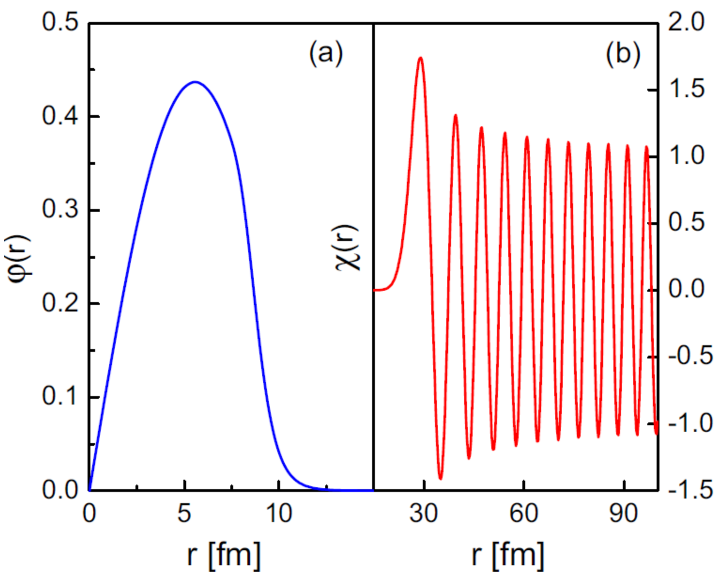
$$P_\alpha = \int_0^\infty d^3r|\Phi(r)|^2\Theta[n_B^{\mathrm{Mott}} - n_B(r)].$$

$$\Gamma = \nu \times \mathcal{T} = \frac{4\hbar^2\alpha^2}{\mu k}|\Phi(r_{\mathrm{sep}})\chi_k(r_{\mathrm{sep}})|^2,$$

PHYSICAL REVIEW C **93**, 011306(R) (2016) **RAPID COMMUNICATIONS**

α-decay width of ^{212}Po from a quartetting wave function approach

Chang Xu,[1,*] Zhongzhou Ren,[1,2,†] G. Röpke,[3,‡] P. Schuck,[4,5,§] Y. Funaki,[6] H. Horiuchi,[7,8] A. Tohsaki,[7]
T. Yamada,[9] and Bo Zhou[10]



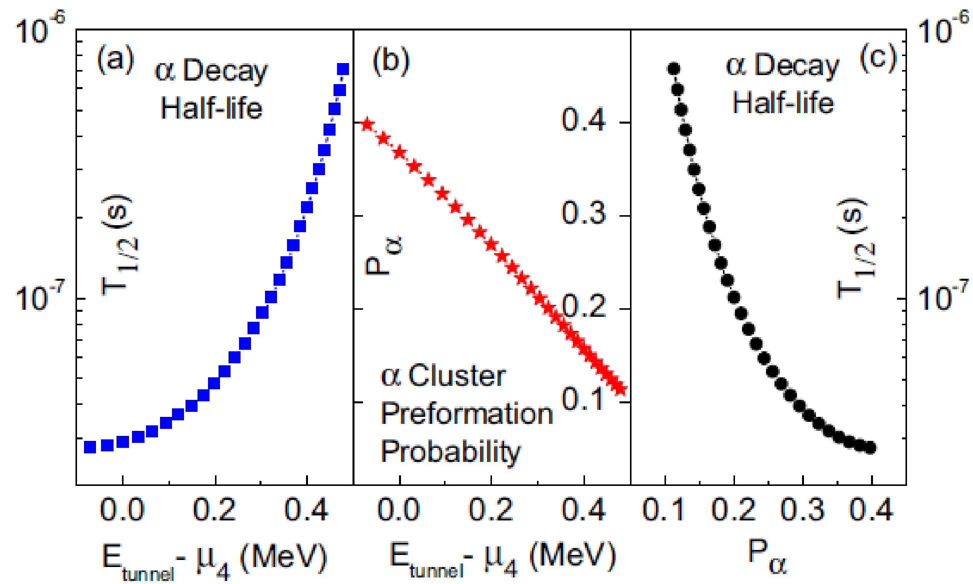


TABLE I. The calculated preformation probability and decay half-life of ^{212}Po using different sets of effective c.m. potentials.

Potential	c (MeV fm)	d (MeV fm)	E_{tunnel} (MeV)	Fermi energy μ_4 (MeV)	$E_{\mathrm{tunnel}} - \mu_4$ (MeV)	Preform. factor P_α	Decay half-life $T_{1/2}$ (s)
A	13866.30	4090.51	−19.346	−19.346	0	0.367	2.91×10^{-8}
B	11032.08	3415.56	−19.346	−19.771	0.425	0.142	2.99×10^{-7}

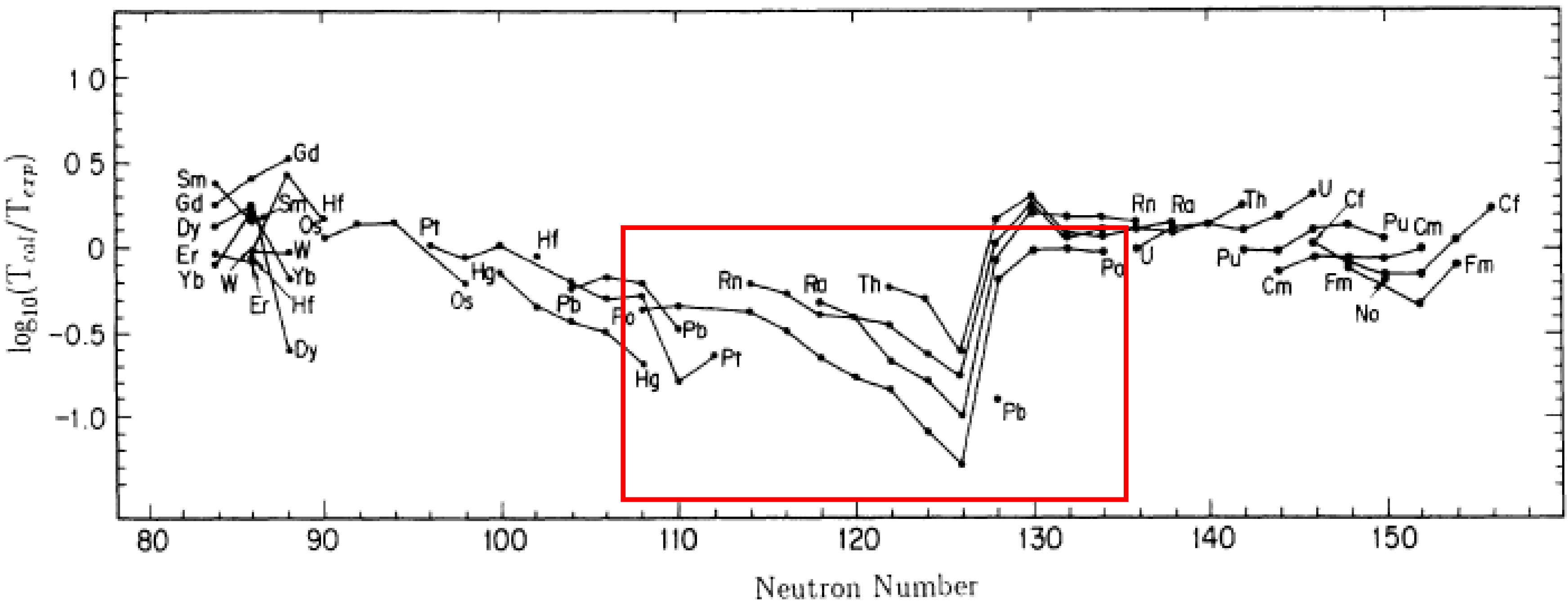
PHYSICAL REVIEW C VOLUME 42, NUMBER 2 AUGUST 1990

Systematics of alpha decay half-lives

Yuichi Hatsukawa
Department of Radioisotopes, Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-11, Japan

Hiromichi Nakahara
Department of Chemistry, Tokyo Metropolitan University, Setagaya, Tokyo 158, Japan

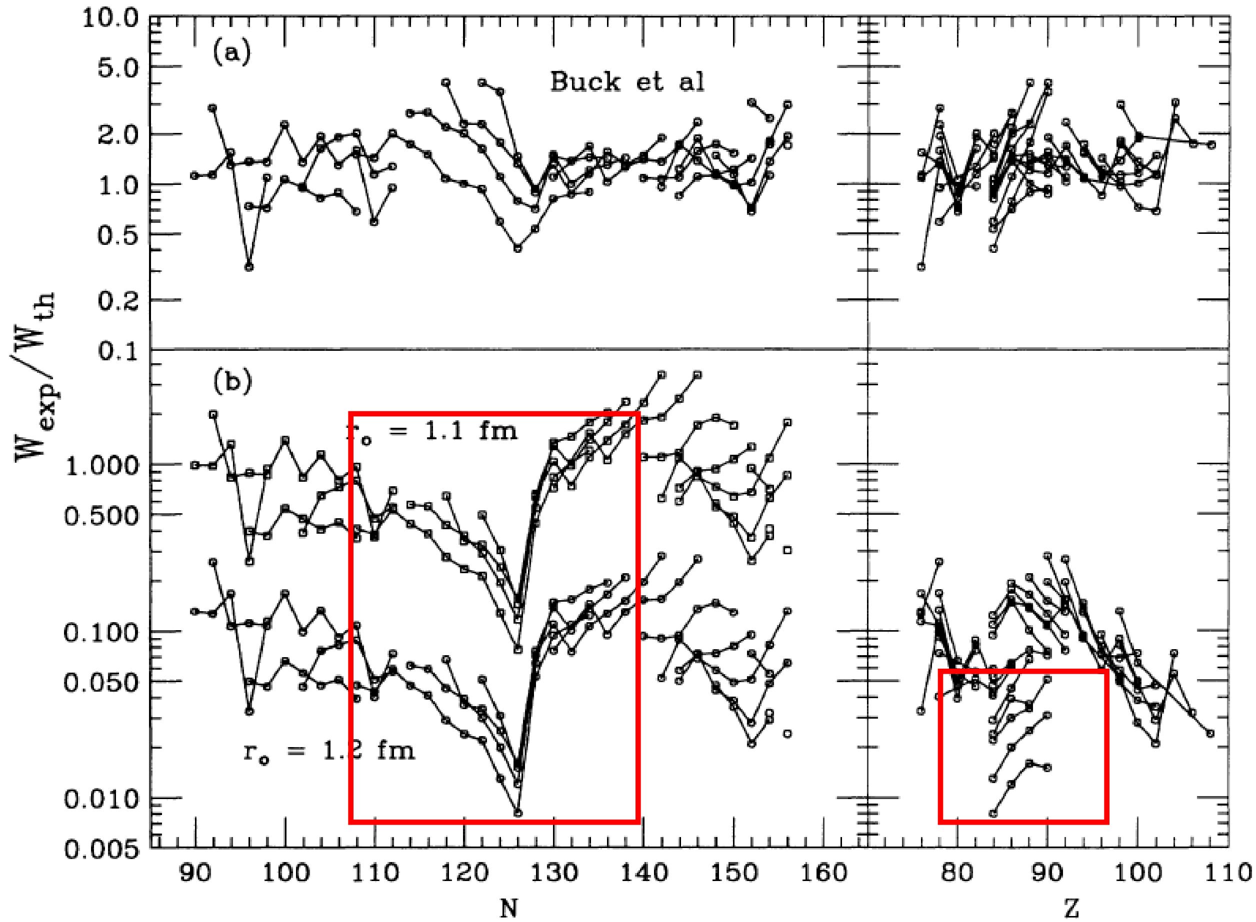
Darleane C. Hoffman
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720



PHYSICAL REVIEW C VOLUME 46, NUMBER 2 AUGUST 1992

Simple relation for alpha decay half-lives

B. Alex Brown
National Superconducting Cyclotron Laboratory
and Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824



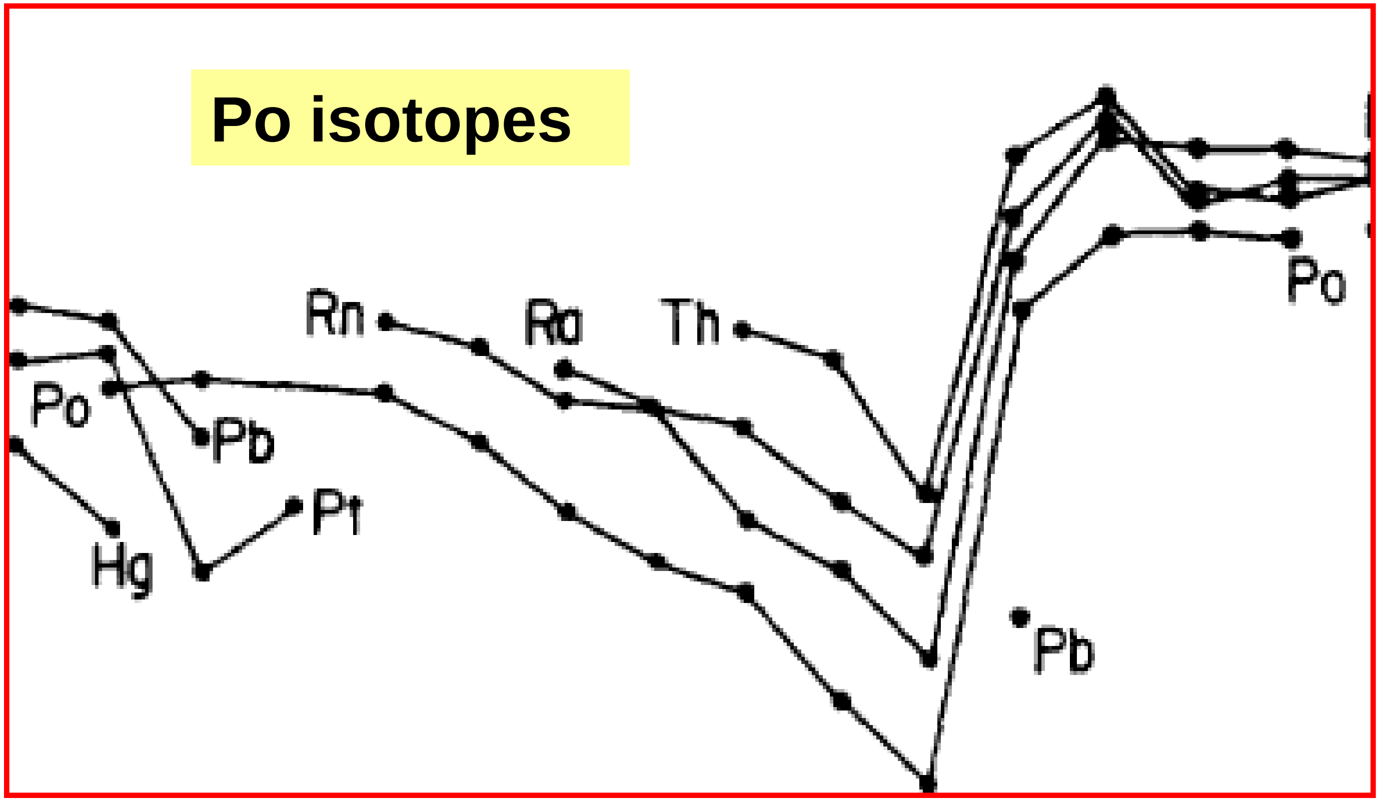
PHYSICAL REVIEW C VOLUME 42, NUMBER 2 AUGUST 1990

Systematics of alpha decay half-lives

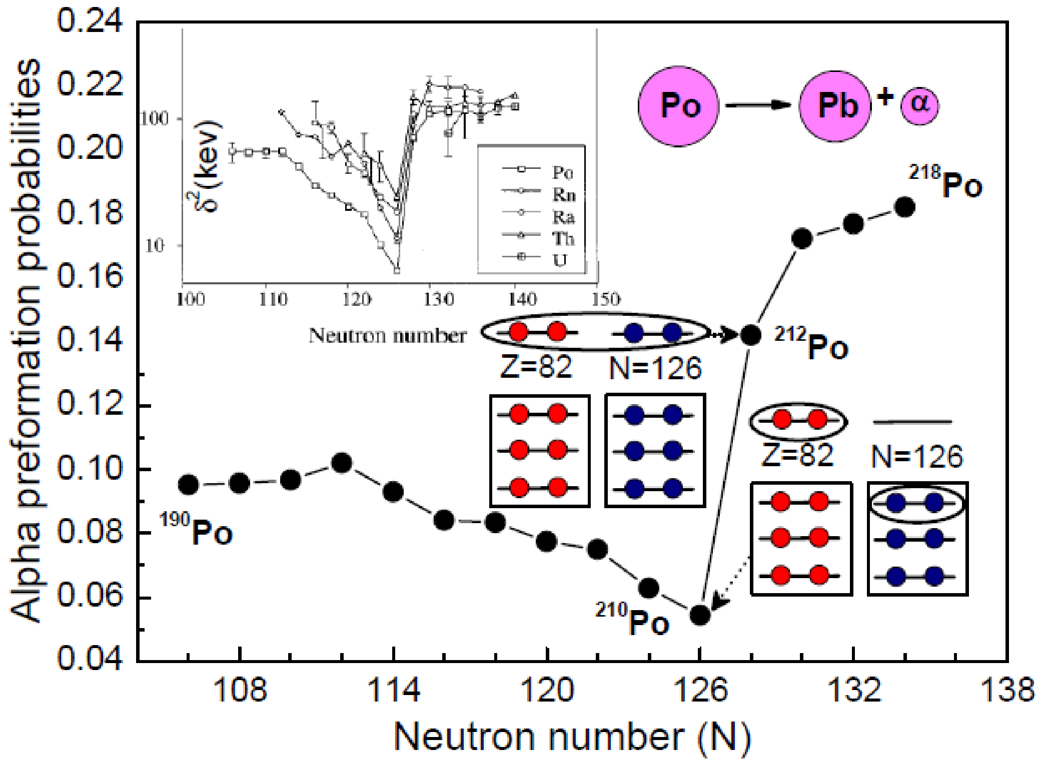
Yuichi Hatsukawa
Department of Radioisotopes, Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-11, Japan

Hiromichi Nakahara
Department of Chemistry, Tokyo Metropolitan University, Setagaya, Tokyo 158, Japan

Darleane C. Hoffman
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720



Microscopic results of alpha cluster preformation probabilities
Daughter nuclei: Z=82 isotopes



Experimental data:
Qa and Ta (well measured)

c and *d* fitted to Qa and Ta

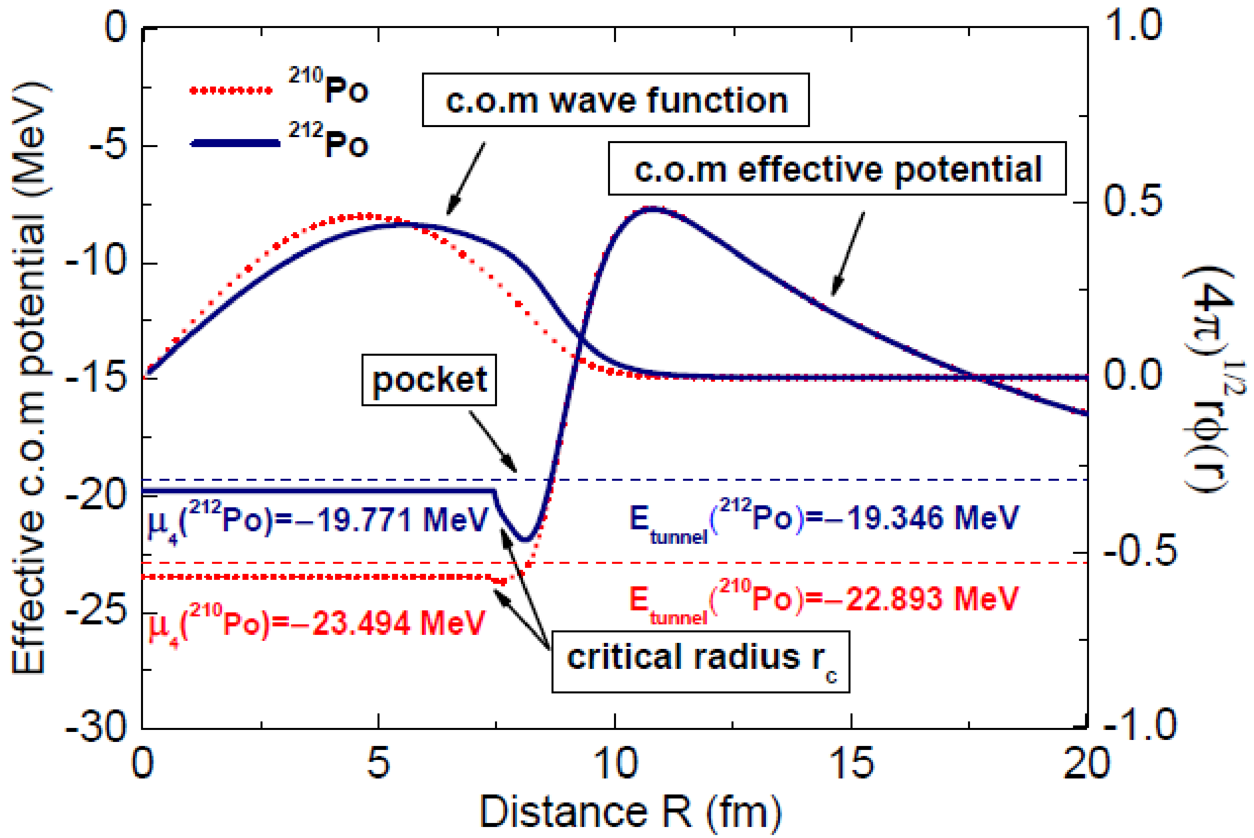
Preformation probabilities are obtained for each nucleus

shell effect: important

$$v(s) = c\exp(-4s)/(4s) - d\exp(-2.5s)/(2.5s)$$

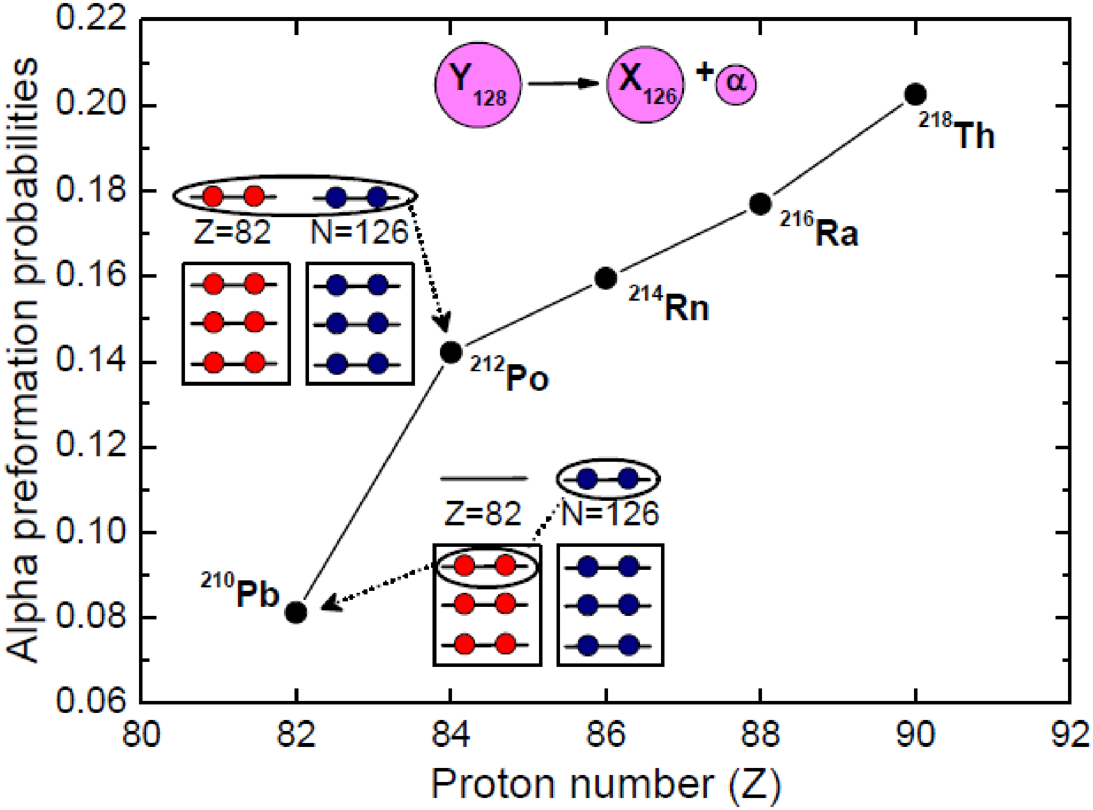
describing a short-range repulsion (*c*) and a long-range attraction (*d*);
S denotes the nucleon-nucleon distance.

Microscopic results of alpha cluster preformation probabilities
Daughter nuclei: Z=82 isotopes



Comparison of the c.o.m. effective potentials, the c.o.m. wave functions, and the Fermi energies for two neighbouring alpha-emitters

Microscopic results of alpha cluster preformation probabilities
Daughter nuclei: N=126 isotones



Experimental data:
Qa and Ta (well measured)

c and *d* fitted to Qa and Ta

Preformation probabilities are obtained for each nucleus

shell effect: important

$$v(s) = c\exp(-4s)/(4s) - d\exp(-2.5s)/(2.5s)$$

describing a short-range repulsion (*c*) and a long-range attraction (*d*);
S denotes the nucleon-nucleon distance.

Microscopic results of alpha preformation probabilities Superheavy nuclei

Mass	Z	N	Q_α MeV	Half-life $T_{1/2}$[s]	c [MeV fm]	d [MeV fm]	Fermi energy μ_4[MeV]	E_{tunnel} [MeV]	$E_{\text{tunnel}} - \mu_4$ [MeV]	P_α
294	118	176	11.810	1.4×10^{-3}	17066.70	4847.61	-16.889	-16.490	0.399	0.110
292	116	176	10.774	2.4×10^{-2}	19237.20	5365.62	-17.772	-17.526	0.246	0.197
290	116	174	10.990	8.0×10^{-3}	19027.50	5315.41	-17.568	-17.310	0.258	0.191
288	114	174	10.072	7.5×10^{-1}	18743.70	5251.07	-18.549	-18.228	0.320	0.156
286	114	172	10.370	3.5×10^{-1}	17237.40	4892.79	-18.349	-17.930	0.419	0.104
270	**110**	**160**	11.117	2.1×10^{-4}	17079.10	4847.45	-17.547	-17.183	**0.364**	**0.144**
268	**108**	**160**	9.623	1.4×10^{0}	15653.10	4516.39	-19.171	-18.677	**0.494**	**0.077**
264	108	156	10.591	1.1×10^{-3}	17054.60	4843.76	-18.088	-17.709	0.379	0.140
260	106	154	9.901	1.2×10^{-2}	17488.80	4948.93	-18.759	-18.399	0.360	0.152

A brief summary of my talk

1. Alpha decay: old problem but still not fully solved

challenge: alpha cluster preformation

- **Light island (doubly magic ^{100}Sn)**
- **doubly magic ^{208}Pb**
- **Superheavy island (next doubly magic nucleus)**

2. Preformation probability of ^{212}Po: a quartetting wave function approach

3. Microscopic calculations on more alpha emitters around Z=82 and N=126 region, superheavy nuclei

谢谢!

Collaborators: C. Xu, G. Roepke, P. Schuck, T. Yamada, Y. Funaki, H. Horiuchi, A. Tohsaki，B. Zhou, Mengjiao Lyu

Towards a fully microscopic calculation of the alpha decay problem!!!

Microscopic calculation of preformation factor in a two level model

Ren and Xu, PRC 36, 456,1987…

PHYSICAL REVIEW C VOLUME 36, NUMBER 1 JULY 1987

Reduced alpha transfer rates in a schematic model

Ren Zhong-zhou and Xu Gong-ou
Department of Physics, Nanjing University, Nanjing, China
(Received 27 January 1987)

The reduced alpha transfer rates are studied microscopically with a schematic model. Results for ground state to ground state alpha transfer reactions are given.