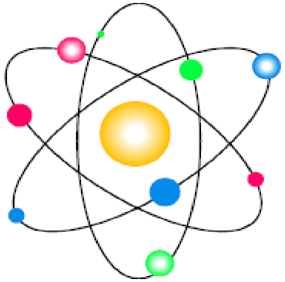


原子核alpha结团形成和衰变

—— Quartetting Wave Function Approach

许 昌

南京大学物理学院

Outline:

1. Brief review of alpha cluster motion

2. Quartetting wave function approach for alpha emitters

3. Recent progress on decay and fusion theory

4. Short summary

中国科技大学　　2021年12月30日

Alpha cluster motion and decay

原子核运动模式

单粒子运动:原子核壳模型

The Nobel Prize in Physics 1963

Eugene Paul Wigner
Prize share: 1/2

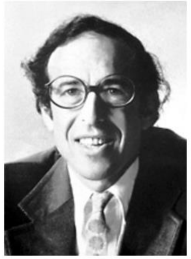
Maria Goeppert Mayer
Prize share: 1/4

J. Hans D. Jensen
Prize share: 1/4

集体运动:原子核集体模型

The Nobel Prize in Physics 1975

Aage Niels Bohr
Prize share: 1/3

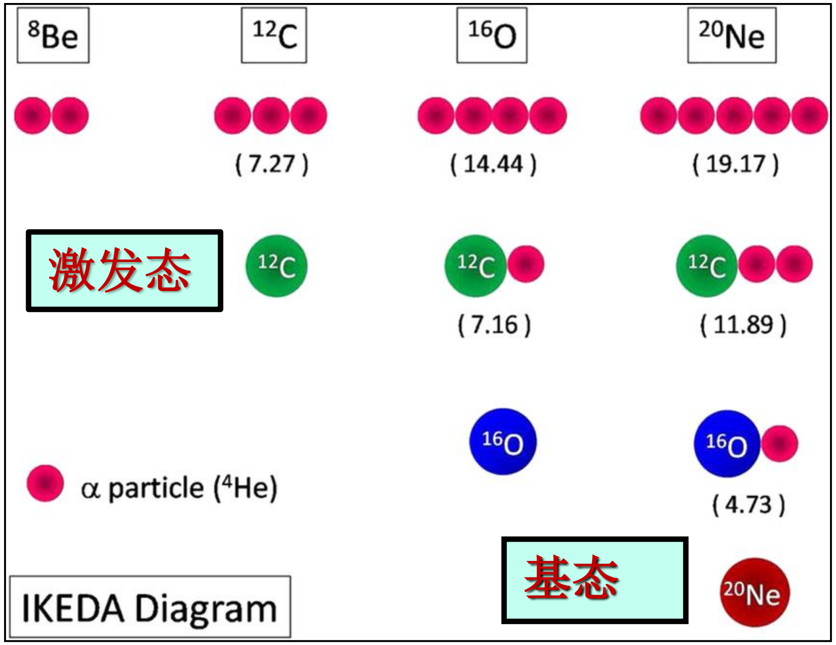


Ben Roy Mottelson
Prize share: 1/3

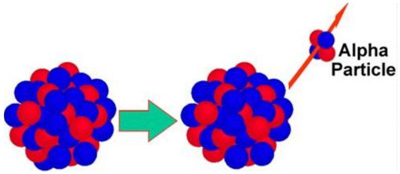
Leo James Rainwater
Prize share: 1/3

结团运动(α结团):研究较少

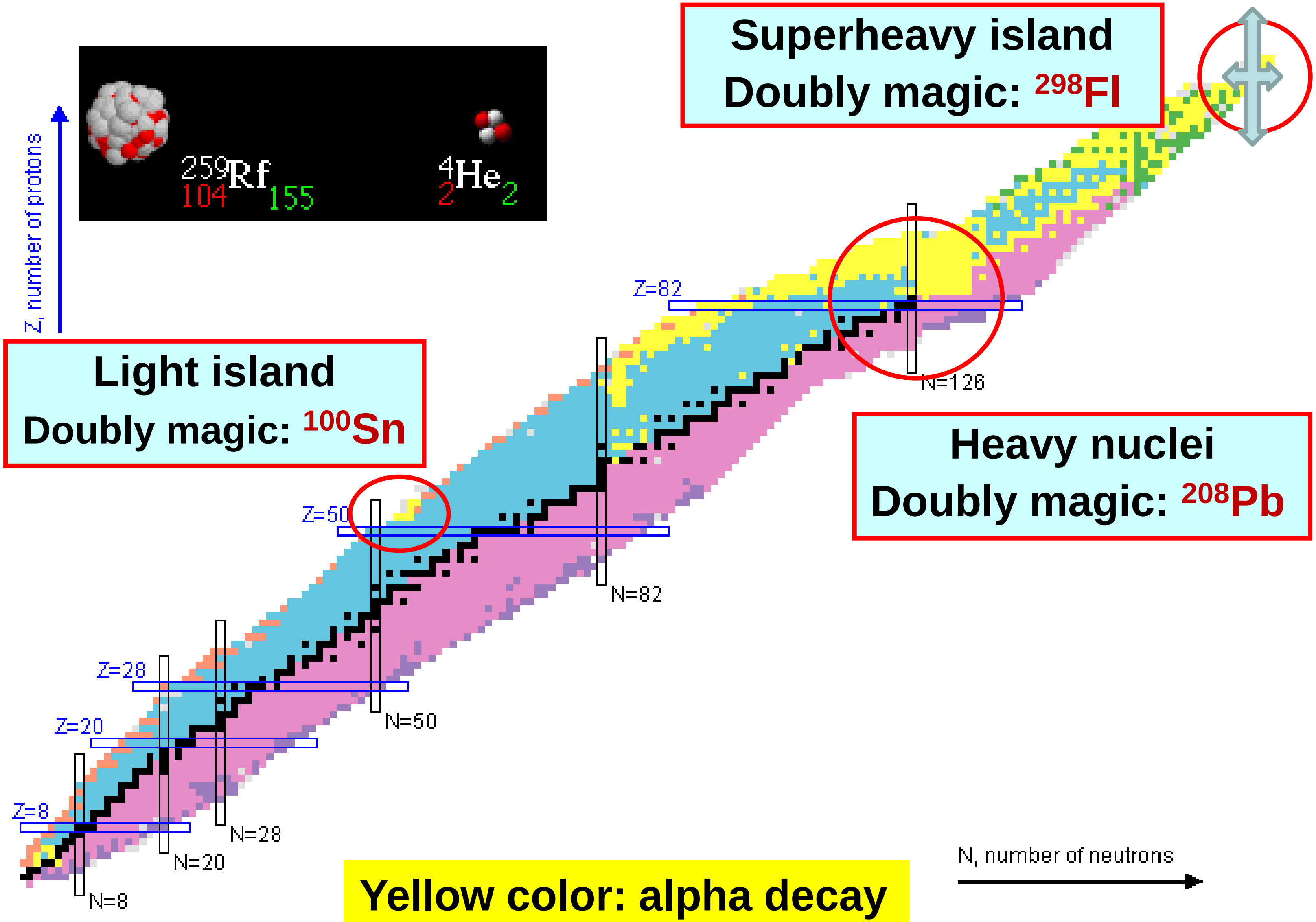
轻核alpha结团运动



重核alpha衰变



Alpha cluster decay in chart of nuclides



Superheavy island
Doubly magic: ^{298}Fl

Light island
Doubly magic: ^{100}Sn

Heavy nuclei
Doubly magic: ^{208}Pb

Yellow color: alpha decay

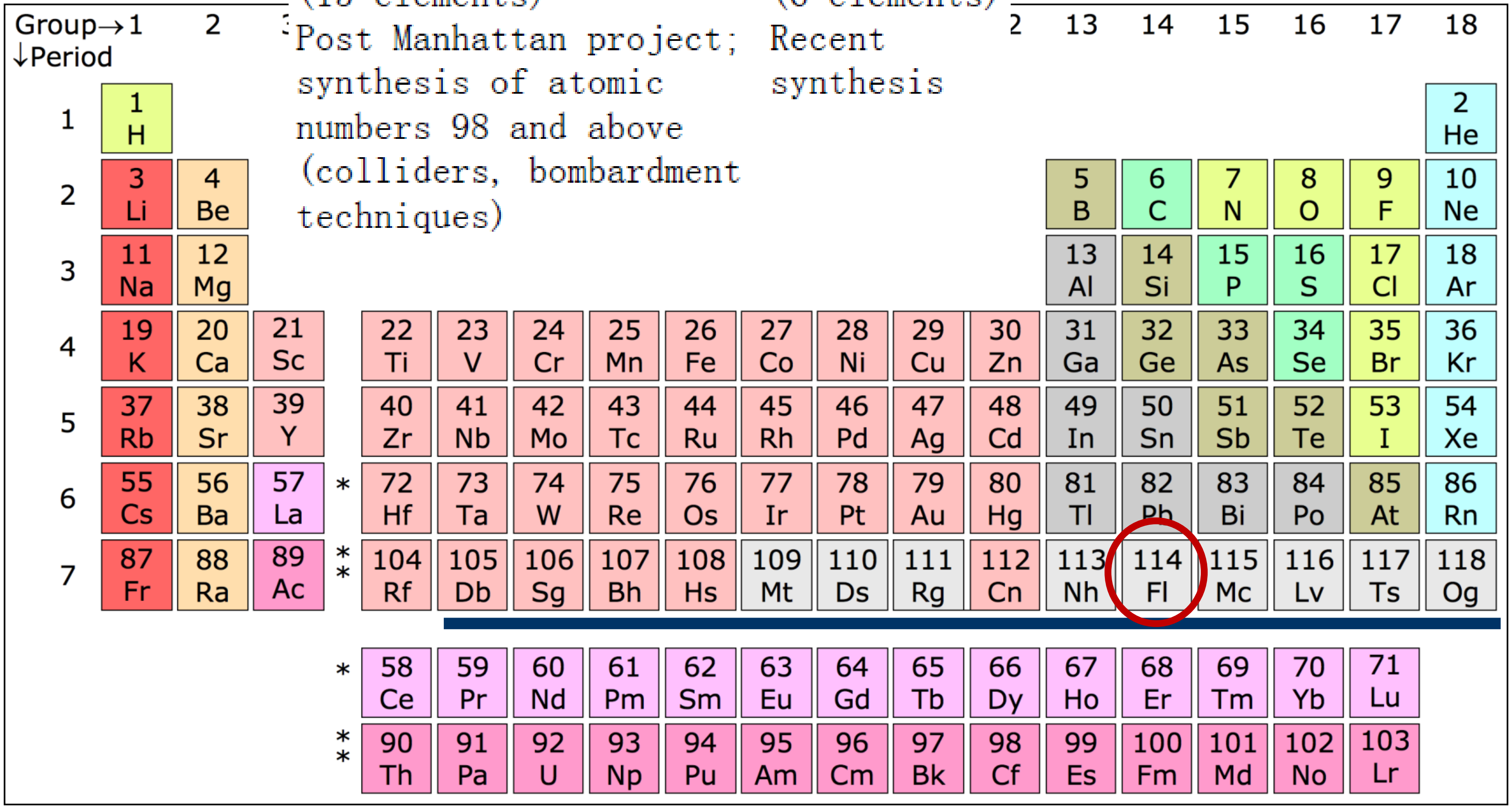
最新元素周期表

1950 - 1999

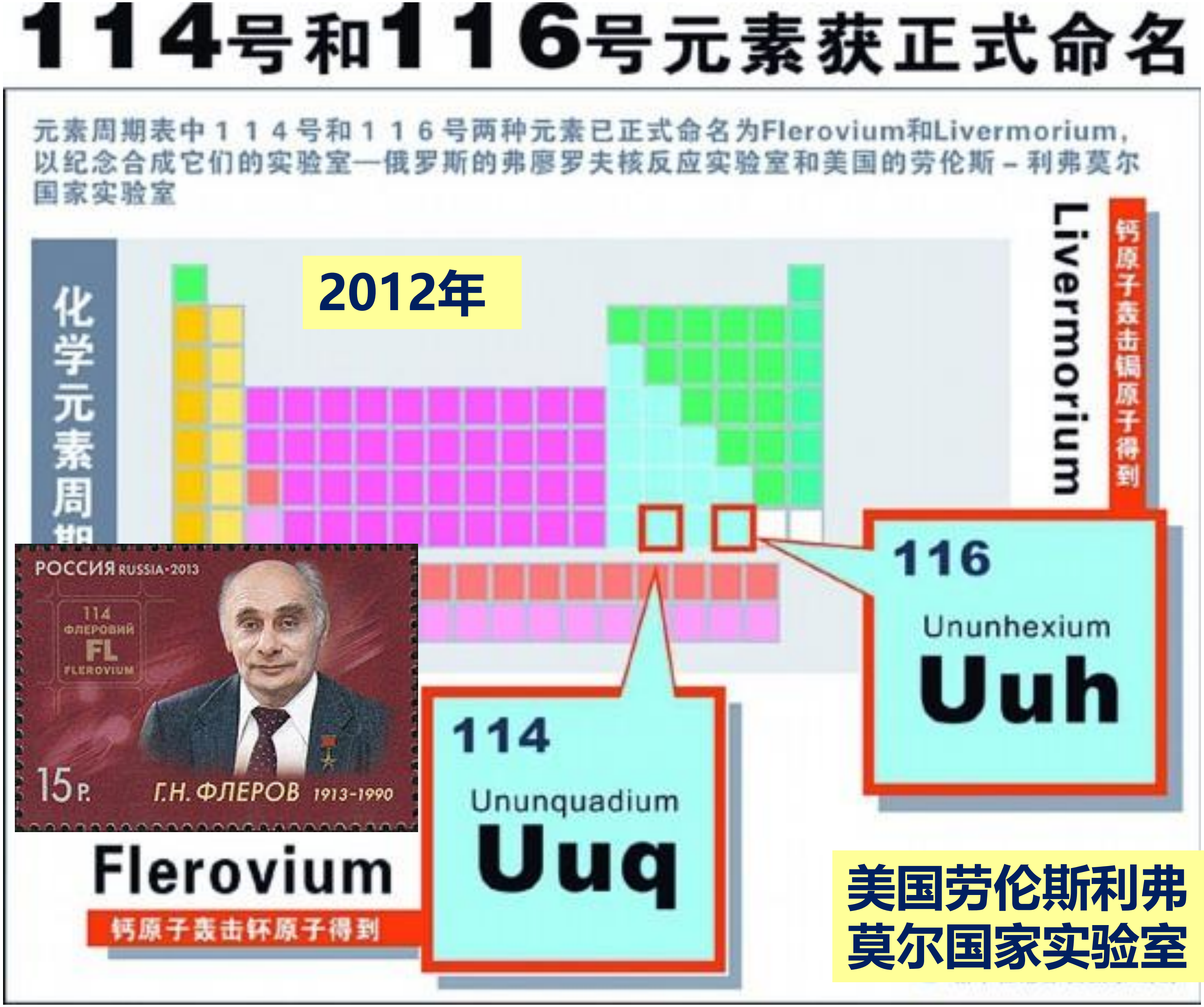
(15 elements)
Post Manhattan project; synthesis of atomic numbers 98 and above (colliders, bombardment techniques)

Since 2000

(6 elements)
Recent synthesis



Group→ ↓Period	1	2											2	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc		22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y		40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
				*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
				**	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	



114号和116号元素获正式命名

元素周期表中114号和116号两种元素已正式命名为Flerovium和Livermorium，以纪念合成它们的实验室—俄罗斯的弗廖罗夫核反应实验室和美国的劳伦斯－利弗莫尔国家实验室

2012年

美国劳伦斯利弗莫尔国家实验室

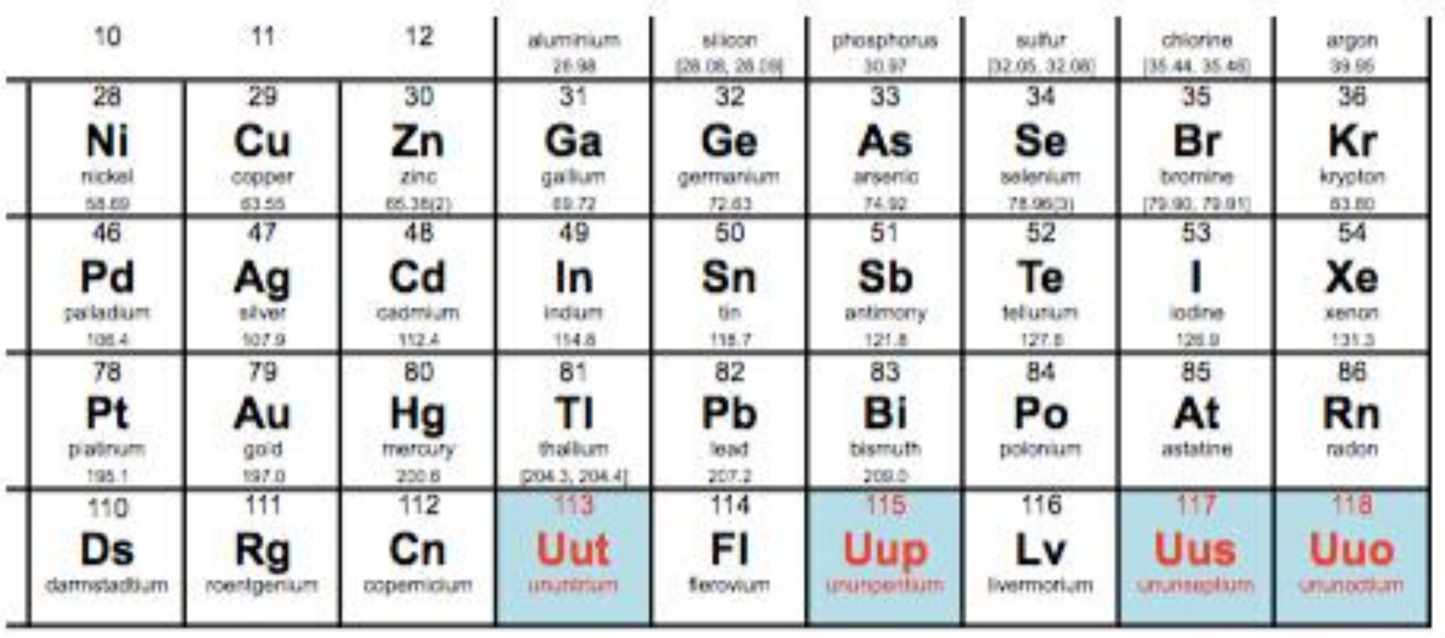
全国科学技术名词审定委员会公布114号、116号元素的中文名称

全国科学技术名词审定委员会根据国际纯粹与应用化学联合会(IUPAC)2012年5月对第114号、116号元素正式确定的英文名称,在广泛征求有关专家意见的基础上,提出了第114号、116号元素的中文定名草案。114号、116号元素使用的中文汉字“𫓧”“𫟷”已征得国家语言文字工作委员会的同意,并纳入国家规范用字。现经全国科学技术名词审定委员会批准予以公布使用。

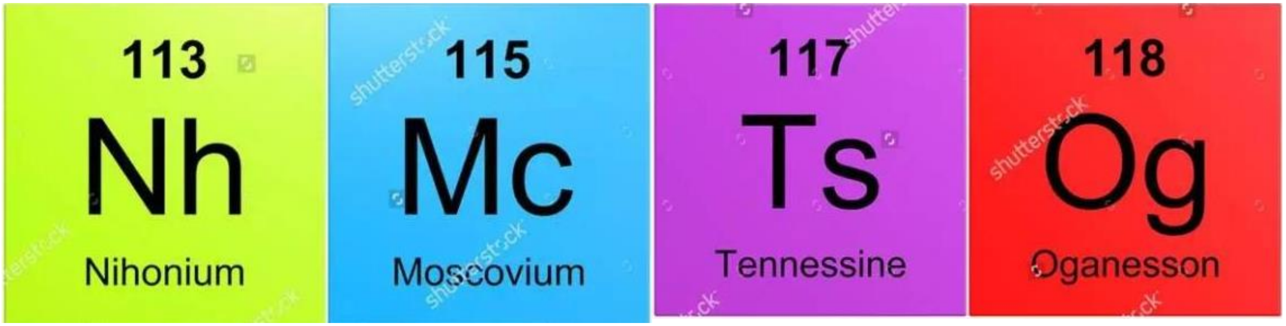
第114号、116号元素的中文名称

原子序数	英文名称	中文名称	符号	汉语拼音
114	flerovium	𫓧	Fl	fū
116	livermorium	𫟷	Lv	lì

2016年四个新元素正式命名



10	11	12	aluminium 26.98	silicon [28.08, 28.09]	phosphorus 30.97	sulfur [32.05, 32.08]	chlorine [35.44, 35.46]	argon 39.95
28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.38(2)	31 Ga gallium 69.72	32 Ge germanium 72.63	33 As arsenic 74.92	34 Se selenium 78.96(3)	35 Br bromine [79.90, 79.91]	36 Kr krypton 83.80
46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium [204.3, 204.4]	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium	85 At astatine	86 Rn radon
110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Uut ununtrium	114 Fl flerovium	115 Uup ununpentium	116 Lv livermorium	117 Uus ununseptium	118 Uuo ununoctium



113 Nh Nihonium	115 Mc Moscovium	117 Ts Tennessine	118 Og Oganesson

四个化学新元素中文命名发布

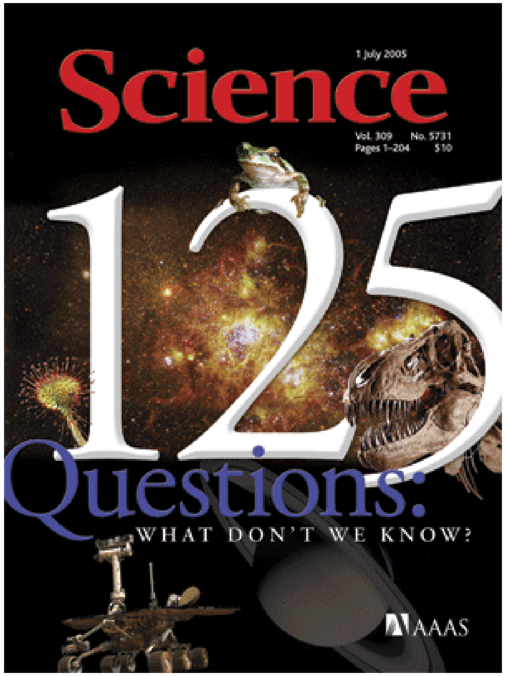
113、115、117、118号元素中文名称及由来

原子序数	英文名	符号	中文名	汉语拼音	名称由来
113	nihonium	Nh	鉨	nǐ	源于日本国（简称日本）的国名Nihon
115	moscovium	Mc	镆	mò	源于俄罗斯莫斯科市的市名Moscow
117	tennessine	Ts	石田	tián	源于美国田纳西州的州名Tennessee
118	oganesson	Og	气奥	ào	源于俄罗斯核物理学家尤里·奥加涅相（Yuri Oganessian 1933–）

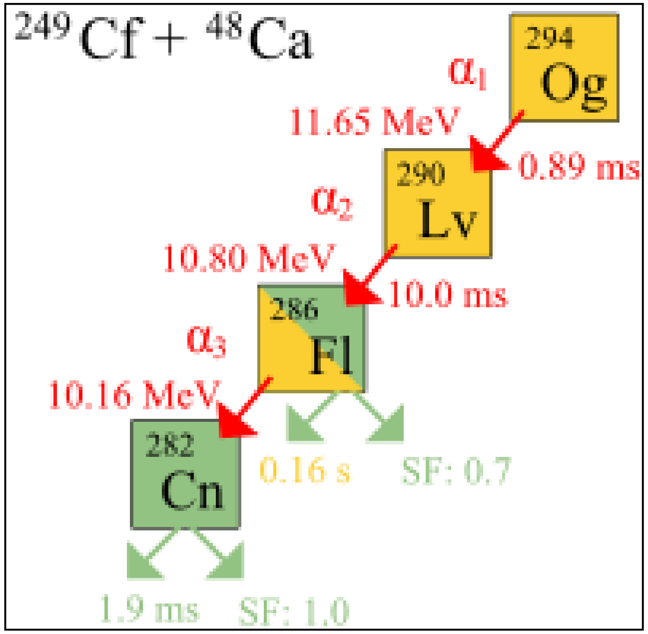
新华社发 金立旺 （大巢制图）

Superheavy elements and nuclides

《科学》杂志为纪念创刊125周年，提出了125个最重要的科学问题，中包含天文学，物理学、生命科学等领域。



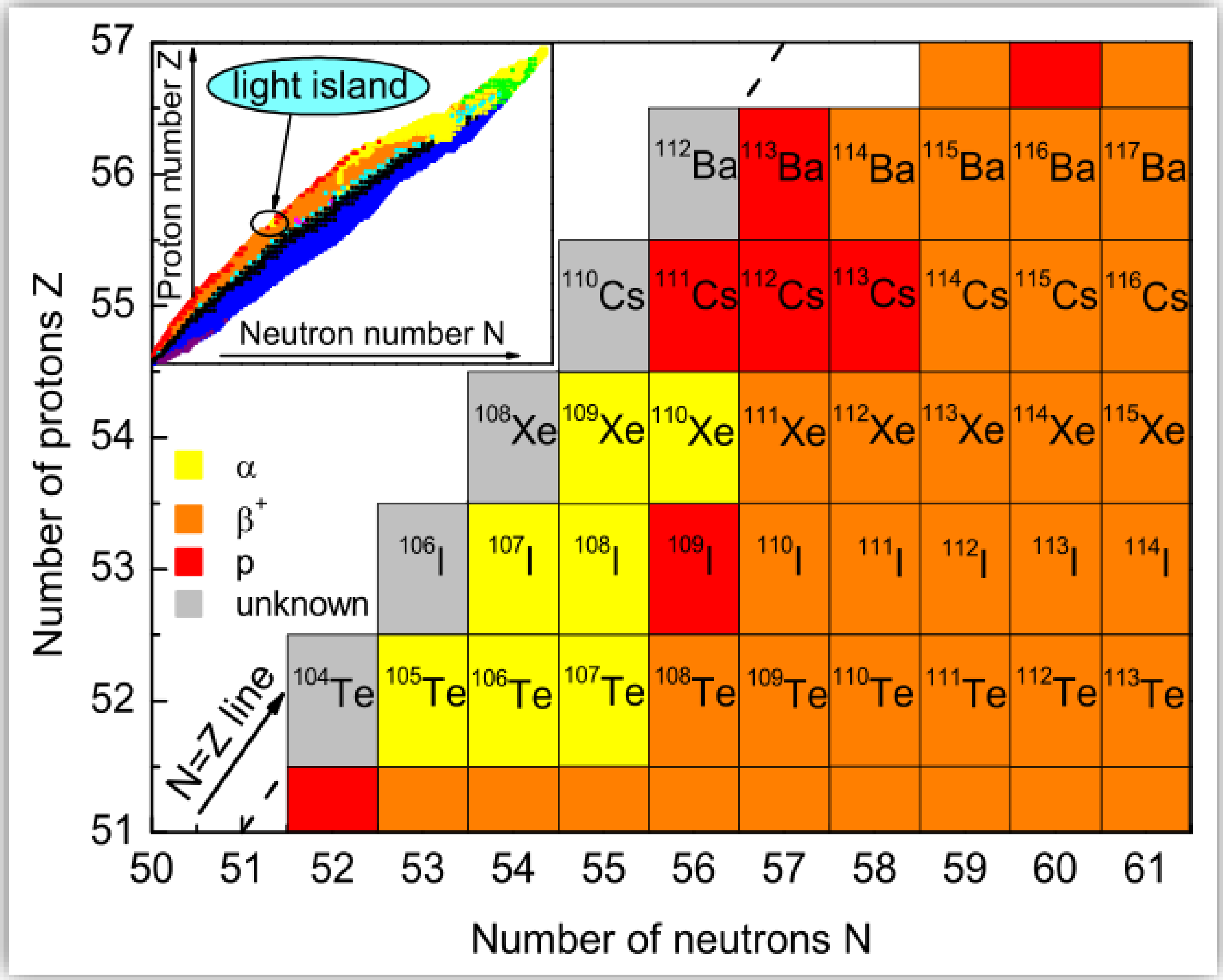
是否存在稳定的高原子序数元素？

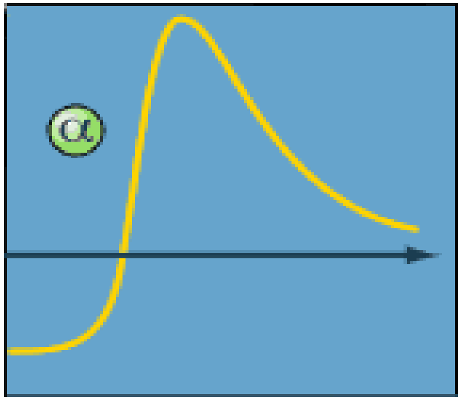


实验：中科院近代物理所—大装置

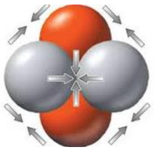
理论：原子核结团衰变—新理论

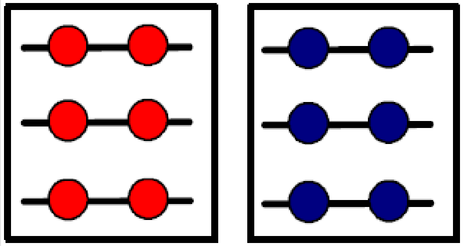
Alpha cluster formation in ^{104}Te





^{104}Te

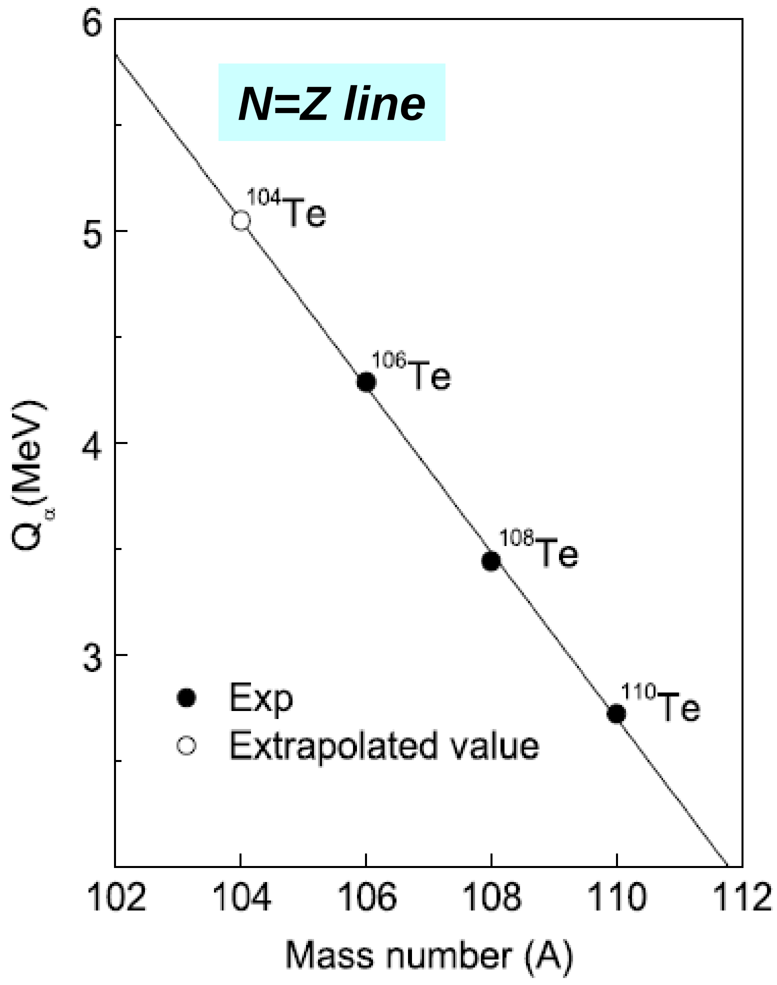


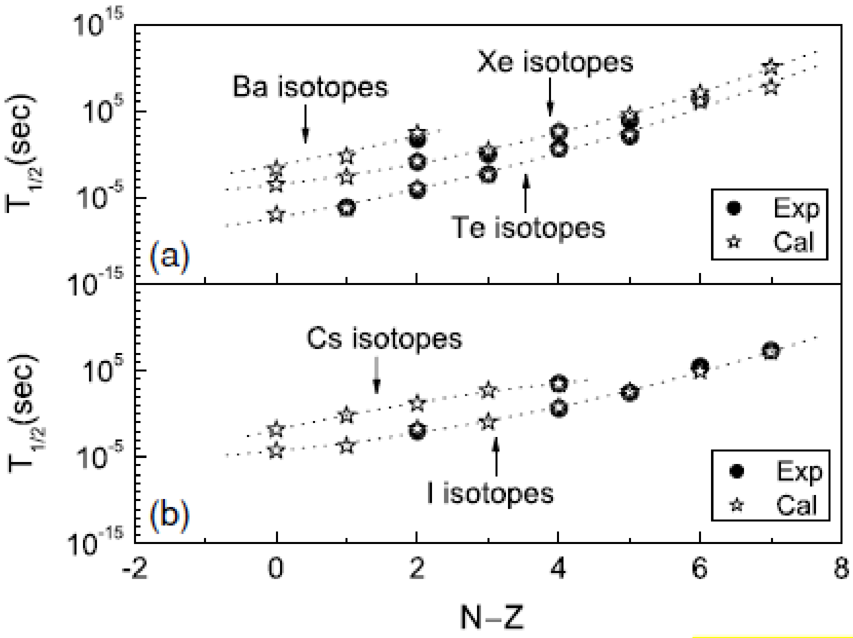


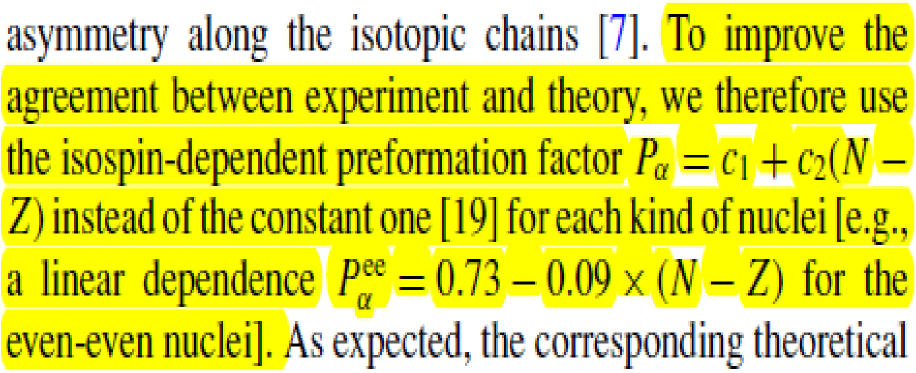
PHYSICAL REVIEW C **74**, 037302 (2006)

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*







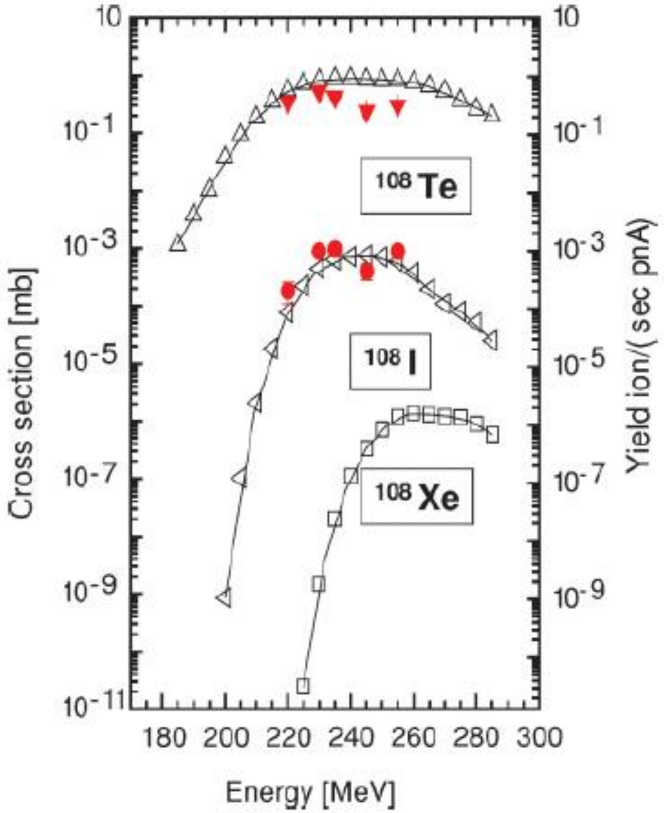
asymmetry along the isotopic chains [7]. To improve the agreement between experiment and theory, we therefore use the isospin-dependent preformation factor $P_\alpha = c_1 + c_2(N - Z)$ instead of the constant one [19] for each kind of nuclei [e.g., a linear dependence $P_\alpha^{ee} = 0.73 - 0.09 \times (N - Z)$ for the even-even nuclei]. As expected, the corresponding theoretical

PHYSICAL REVIEW C 77, 034301 (2008)

University of Tennessee

Toward ^{100}Sn: Studies of excitation functions for the reaction between ^{58}Ni and ^{54}Fe ions

A. Korgul,[1,2,3,4] K. P. Rykaczewski,[5] C. J. Gross,[5] R. K. Grzywacz,[3] S. N. Liddick,[3,6] C. Mazzocchi,[3,7] J. C. Batchelder,[8] C. R. Bingham,[3] I. G. Darby,[3] C. Goodin,[4] J. H. Hamilton,[4] J. K. Hwang,[4] S. V. Ilyushkin,[9] W. Królas,[10] and J. A. Winger[2,8,11]



beam energy around 240 MeV will maximize the production of the $A = 108$ isobar ^{108}Xe in the ^{58}Ni+^{54}Fe reaction. The cross section for the $4n$ evaporation channel can be expected at the (sub)nanobarn level, see Fig. 4. At $\sigma = 1$ nb, the implantation of about 20 ^{108}Xe ions can be achieved in 100 hr with 50 pnA beam intensity and a 300 μg/cm^2 ^{54}Fe target. The targets rotating with the speed corresponding to a linear velocity for the irradiated spot of about 0.3 m/s can withstand this high beam intensity, see, e.g., Ref. [32]. The predicted half-lives of ^{108}Xe and ^{104}Te are of the order of 50 μs and 10 ns, respectively [14,15]. Using digital pulse processing and recording decay signal waveforms, one should be able to identify the pileup of two α signals at the sum energy around 10 MeV [15].

[14] C. Xu and Z. Ren, Phys. Rev. C **74**, 037302 (2006).
[15] P. Mohr, Eur. Phys. J. A **31**, 23 (2007).

Proposal for Nuclear Physics Experiment at RI Beam Factory

(RIBF NP-PAC-19, 2018)

List of Collaborators (including spokesperson)

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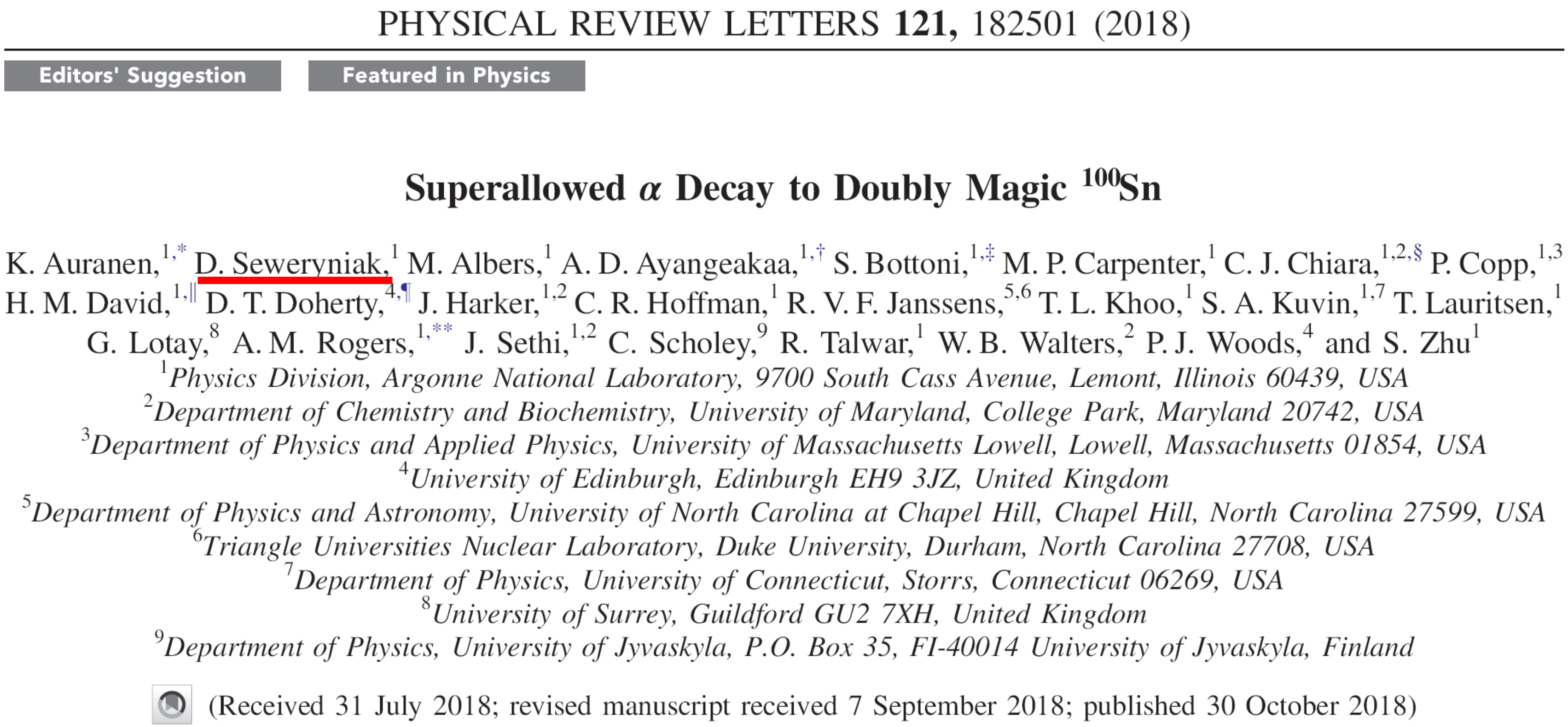
Katsuhisa Nishio	JAEA, Tokai	Manager	nishio.katsuhisa@jaea.go.jp



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]

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[4]*University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom*
[5]*Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599, USA*
[6]*Triangle Universities Nuclear Laboratory, Duke University, Durham, North Carolina 27708, USA*
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[8]*University of Surrey, Guildford GU2 7XH, United Kingdom*
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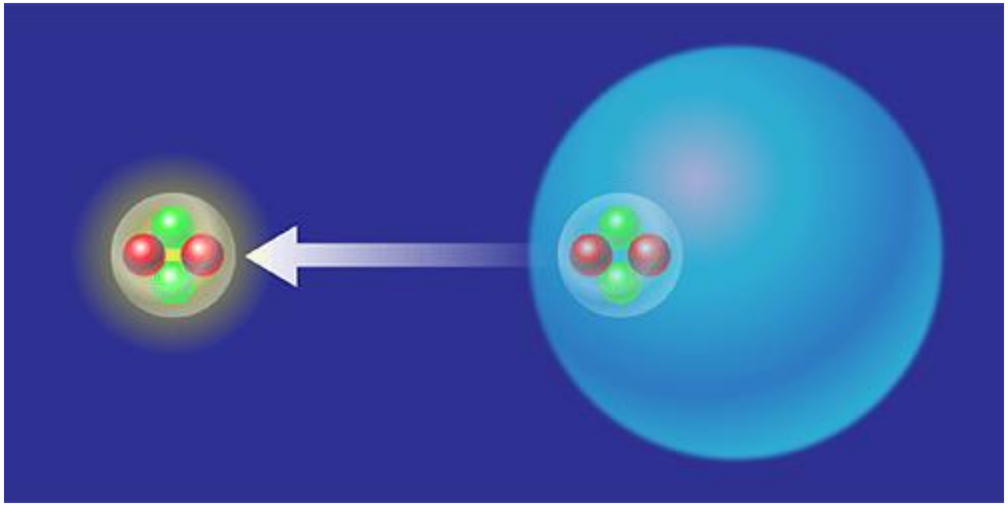
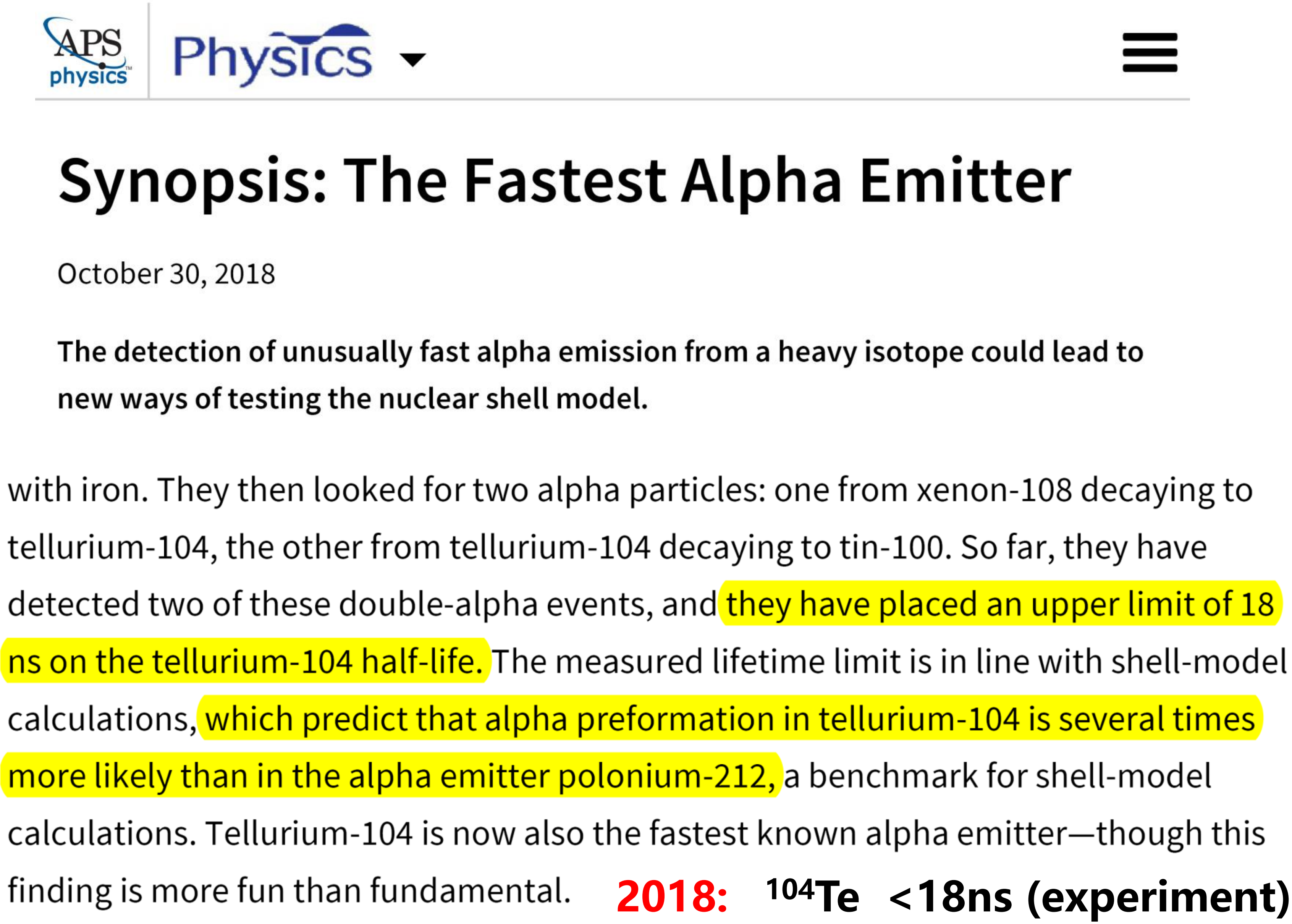
(Received 31 July 2018; revised manuscript received 7 September 2018; published 30 October 2018)



The Fastest Alpha Emitter

“Tellurium-104 is now also the fastest known alpha emitter—though this finding is more fun than fundamental. ”



APS physics | Physics

Synopsis: The Fastest Alpha Emitter

October 30, 2018

The detection of unusually fast alpha emission from a heavy isotope could lead to new ways of testing the nuclear shell model.

with iron. They then looked for two alpha particles: one from xenon-108 decaying to tellurium-104, the other from tellurium-104 decaying to tin-100. So far, they have detected two of these double-alpha events, and they have placed an upper limit of 18 ns on the tellurium-104 half-life. The measured lifetime limit is in line with shell-model calculations, which predict that alpha preformation in tellurium-104 is several times more likely than in the alpha emitter polonium-212, a benchmark for shell-model calculations. Tellurium-104 is now also the fastest known alpha emitter—though this finding is more fun than fundamental.

2018: ^{104}Te <18ns (experiment)

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

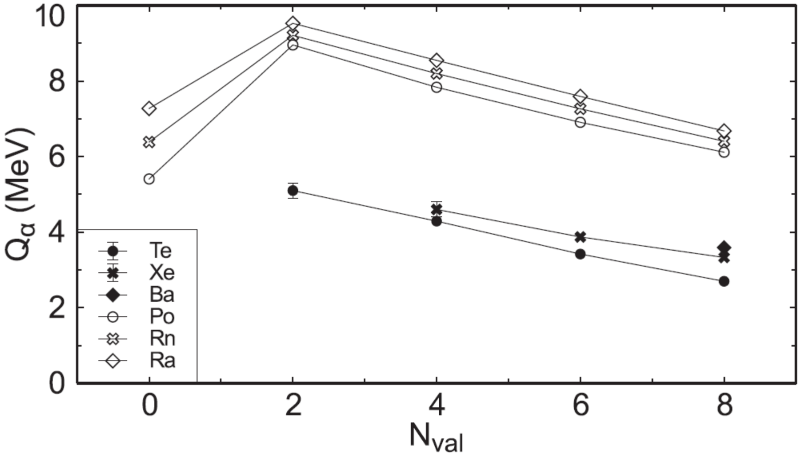
Editors' Suggestion **Featured in Physics**

Superallowed α Decay to Doubly Magic ^{100}Sn

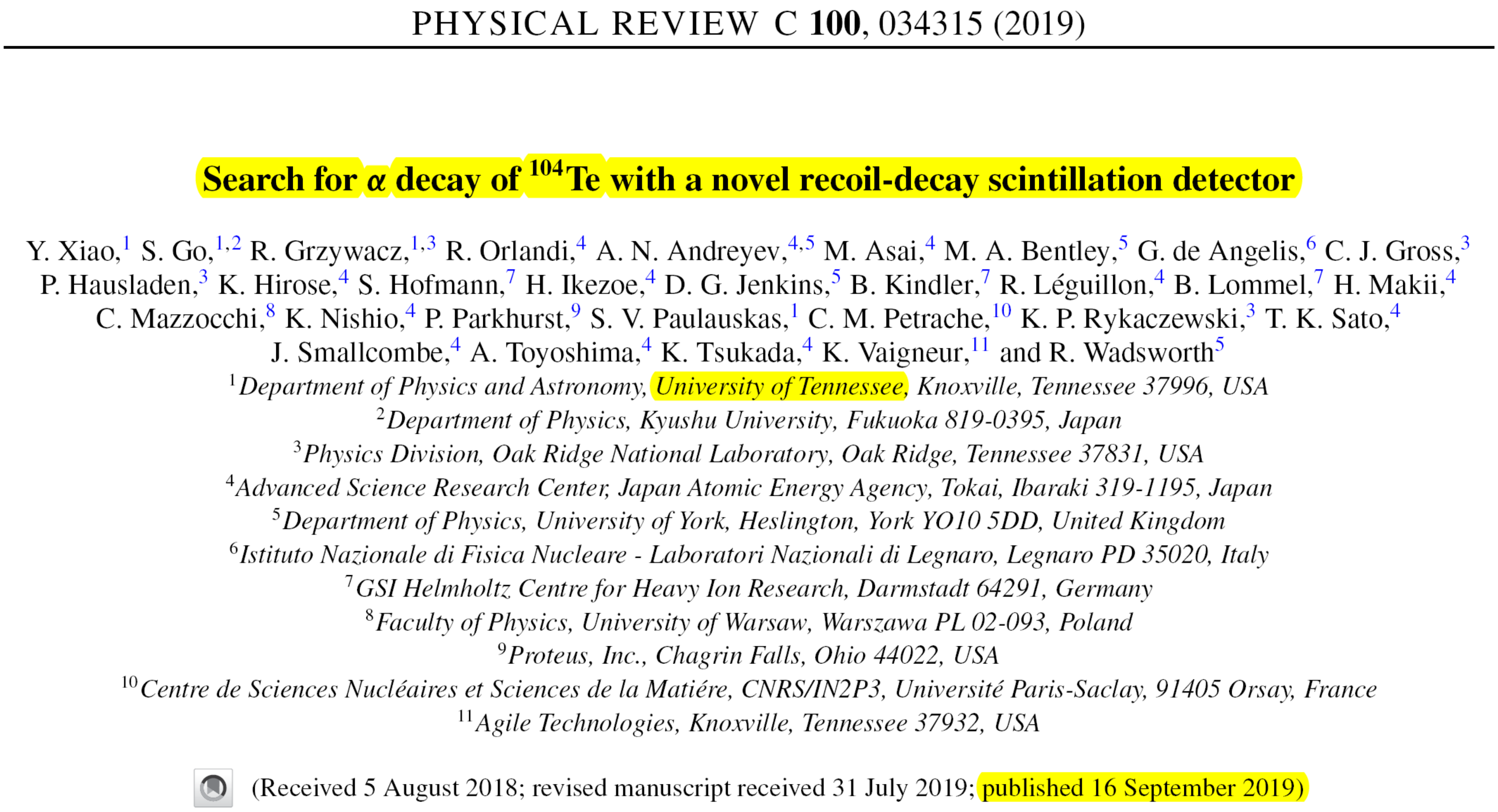
Chain	Nuclide	E_α (keV)	$T_{1/2}$	b_α (%)
$N = Z$	^{108}Xe	4400(200)	58^{+106}_{-23} μs	100[a]
$N = Z$	^{104}Te	4900(200)	<18 ns	100[a]
$N = Z + 2$	^{114}Ba	3480(20) [17]	380^{+190}_{-110} ms [17]	0.9(3) [35]
$N = Z + 2$	^{110}Xe	3720(20) [17]	95^{+25}_{-20} ms [17]	64(35) [35]
$N = Z + 2$	^{106}Te	4128(9) [36]	70^{+20}_{-15} μs [17]	100 [35]
$N = Z + 4$	^{112}Xe	3216(7) [36]	2.7(8) s [37]	$0.8^{+1.1}_{-0.5}$ [36]
$N = Z + 4$	^{108}Te	3314(4) [20]	2.1(1) s [37]	49(4) [36]

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).



New data on alpha decay of ^{104}Te



PHYSICAL REVIEW C **100**, 034315 (2019)

Search for α decay of ^{104}Te with a novel recoil-decay scintillation detector

Y. Xiao,[1] S. Go,[1,2] R. Grzywacz,[1,3] R. Orlandi,[4] A. N. Andreyev,[4,5] M. Asai,[4] M. A. Bentley,[5] G. de Angelis,[6] C. J. Gross,[3] P. Hausladen,[3] K. Hirose,[4] S. Hofmann,[7] H. Ikezoe,[4] D. G. Jenkins,[5] B. Kindler,[7] R. Léguillon,[4] B. Lommel,[7] H. Makii,[4] C. Mazzocchi,[8] K. Nishio,[4] P. Parkhurst,[9] S. V. Paulauskas,[1] C. M. Petrache,[10] K. P. Rykaczewski,[3] T. K. Sato,[4] J. Smallcombe,[4] A. Toyoshima,[4] K. Tsukada,[4] K. Vaigneur,[11] and R. Wadsworth[5]

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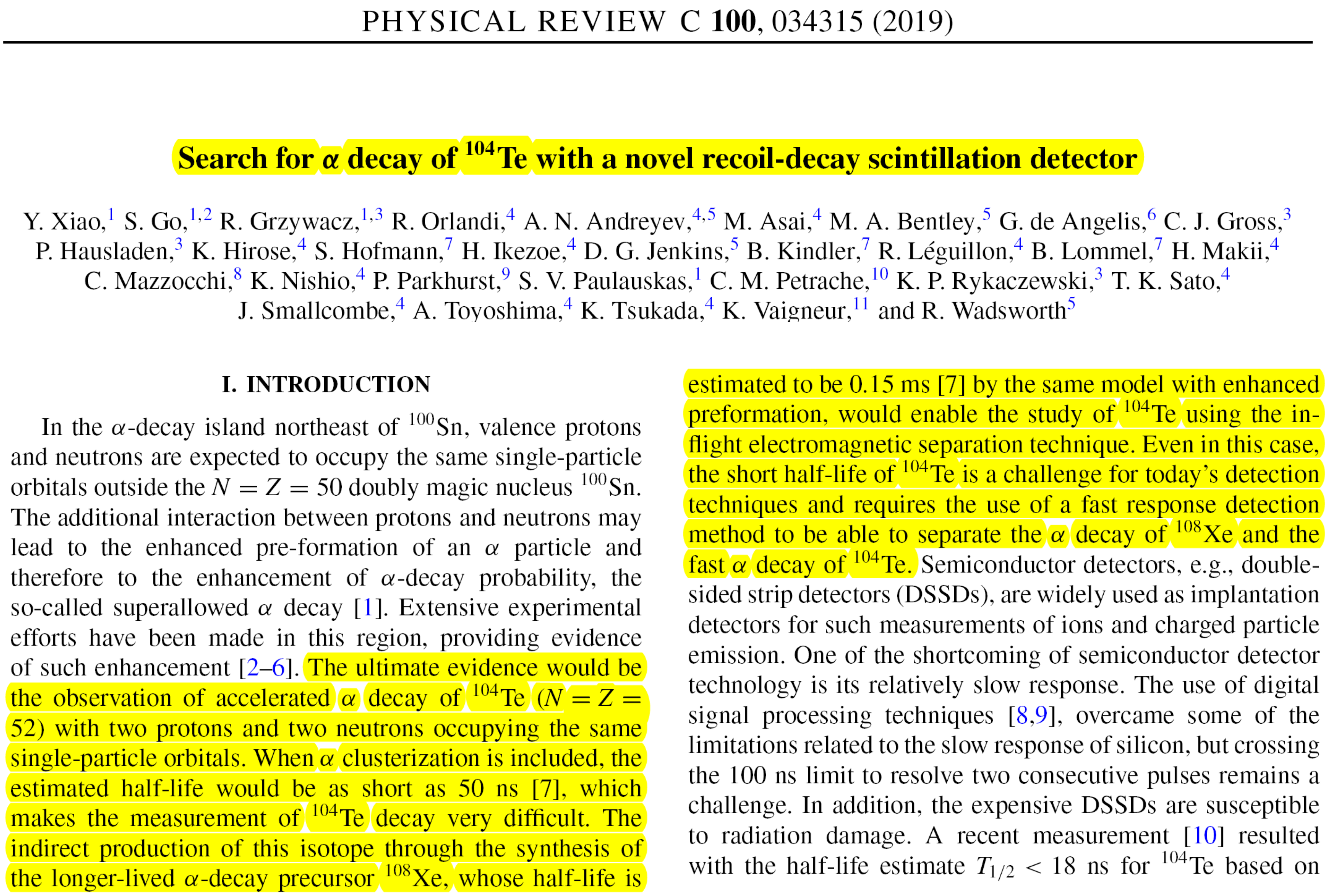
(Received 5 August 2018; revised manuscript received 31 July 2019; published 16 September 2019)



PHYSICAL REVIEW C **100**, 034315 (2019)

Search for α decay of ^{104}Te with a novel recoil-decay scintillation detector

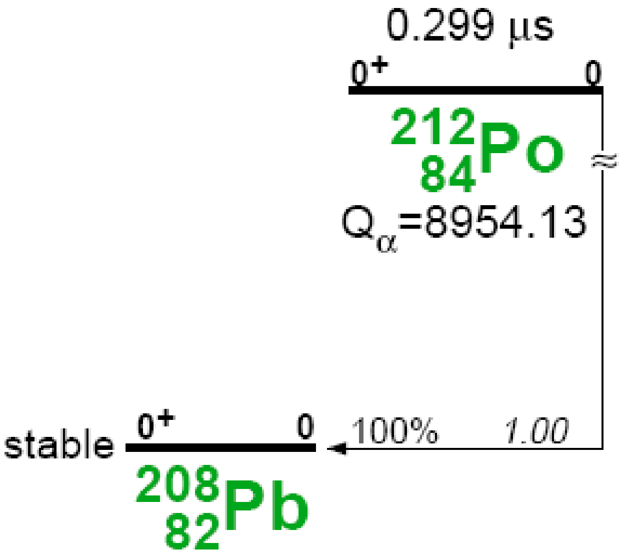
Y. Xiao,[1] S. Go,[1,2] R. Grzywacz,[1,3] R. Orlandi,[4] A. N. Andreyev,[4,5] M. Asai,[4] M. A. Bentley,[5] G. de Angelis,[6] C. J. Gross,[3]
P. Hausladen,[3] K. Hirose,[4] S. Hofmann,[7] H. Ikezoe,[4] D. G. Jenkins,[5] B. Kindler,[7] R. Léguillon,[4] B. Lommel,[7] H. Makii,[4]
C. Mazzocchi,[8] K. Nishio,[4] P. Parkhurst,[9] S. V. Paulauskas,[1] C. M. Petrache,[10] K. P. Rykaczewski,[3] T. K. Sato,[4]
J. Smallcombe,[4] A. Toyoshima,[4] K. Tsukada,[4] K. Vaigneur,[11] and R. Wadsworth[5]

I. INTRODUCTION

In the α-decay island northeast of ^{100}Sn, valence protons and neutrons are expected to occupy the same single-particle orbitals outside the $N = Z = 50$ doubly magic nucleus ^{100}Sn. The additional interaction between protons and neutrons may lead to the enhanced pre-formation of an α particle and therefore to the enhancement of α-decay probability, the so-called superallowed α decay [1]. Extensive experimental efforts have been made in this region, providing evidence of such enhancement [2–6]. The ultimate evidence would be the observation of accelerated α decay of ^{104}Te ($N = Z = 52$) with two protons and two neutrons occupying the same single-particle orbitals. When α clusterization is included, the estimated half-life would be as short as 50 ns [7], which makes the measurement of ^{104}Te decay very difficult. The indirect production of this isotope through the synthesis of the longer-lived α-decay precursor ^{108}Xe, whose half-life is estimated to be 0.15 ms [7] by the same model with enhanced preformation, would enable the study of ^{104}Te using the in-flight electromagnetic separation technique. Even in this case, the short half-life of ^{104}Te is a challenge for today's detection techniques and requires the use of a fast response detection method to be able to separate the α decay of ^{108}Xe and the fast α decay of ^{104}Te. Semiconductor detectors, e.g., double-sided strip detectors (DSSDs), are widely used as implantation detectors for such measurements of ions and charged particle emission. One of the shortcoming of semiconductor detector technology is its relatively slow response. The use of digital signal processing techniques [8,9], overcame some of the limitations related to the slow response of silicon, but crossing the 100 ns limit to resolve two consecutive pulses remains a challenge. In addition, the expensive DSSDs are susceptible to radiation damage. A recent measurement [10] resulted with the half-life estimate $T_{1/2} < 18$ ns for ^{104}Te based on

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

Alpha cluster formation and decay in ^{212}Po



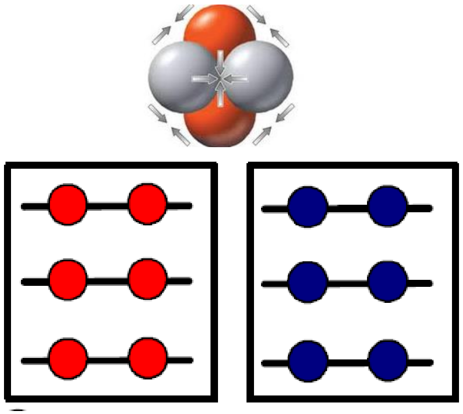
Spherical

Doubly magic

Only one decay channel

Accurate experimental data

……



Microscopic calculation of alpha cluster formation and decay in ^{212}Po

Alpha cluster formation and decay

——*Quartetting wave function approach*

1. **Quantum 5-body problem (2p+2n+core)**
2. **Subdivide the W.F into an intrinsic part and a c.o.m part**

$$\Psi(\mathbf{R},\mathbf{s}_j) = \varphi^{\mathrm{intr}}(\mathbf{s}_j,\mathbf{R})\,\Phi(\mathbf{R})$$

$$\begin{aligned}\mathbf{r}_{n,\uparrow} &= \mathbf{R}+\mathbf{S}/2+\mathbf{s}/2\\ \mathbf{r}_{n,\downarrow} &= \mathbf{R}+\mathbf{S}/2-\mathbf{s}/2\\ \mathbf{r}_{p,\uparrow} &= \mathbf{R}-\mathbf{S}/2+\mathbf{s}'/2\\ \mathbf{r}_{p,\downarrow} &= \mathbf{R}-\mathbf{S}/2-\mathbf{s}'/2\end{aligned}$$

equation for the c.m. motion

$$-\frac{\hbar^2}{2Am}\nabla_R^2\Phi(\mathbf{R}) - \frac{\hbar^2}{Am}\int ds_j\varphi^{\mathrm{intr},*}(\mathbf{s}_j,\mathbf{R})[\nabla_R\varphi^{\mathrm{intr}}(\mathbf{s}_j,\mathbf{R})][\nabla_R\Phi(\mathbf{R})]$$

$$-\frac{\hbar^2}{2Am}\int ds_j\varphi^{\mathrm{intr},*}(\mathbf{s}_j,\mathbf{R})\left[\nabla_R^2\varphi^{\mathrm{intr}}(\mathbf{s}_j,\mathbf{R})\right]\Phi(\mathbf{R}) + \int dR'\,W(\mathbf{R},\mathbf{R}')\Phi(\mathbf{R}') = E\,\Phi(\mathbf{R})$$

equation for the intrinsic motion

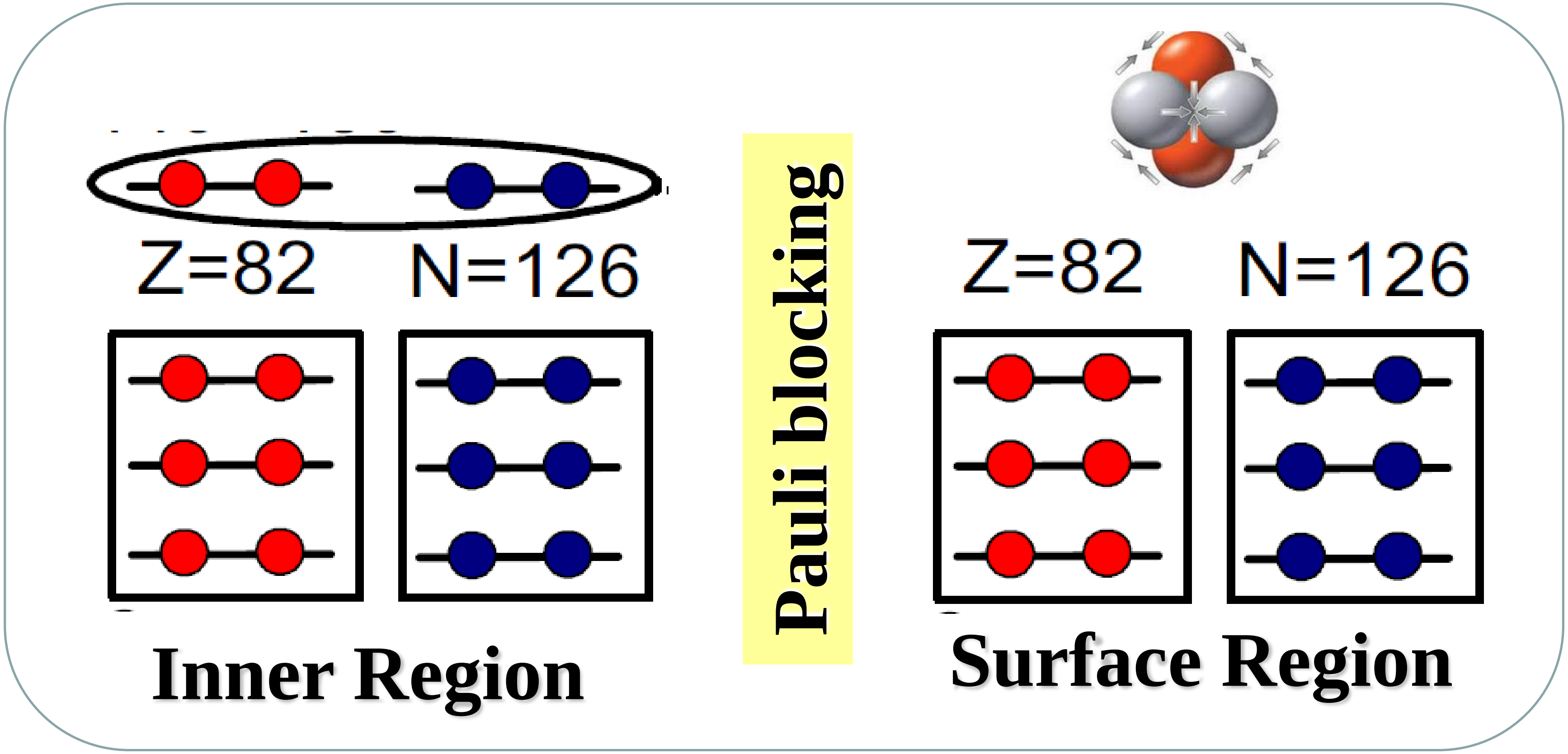
$$-\frac{\hbar^2}{Am}\Phi^*(\mathbf{R})[\nabla_R\Phi(\mathbf{R})][\nabla_R\varphi^{\mathrm{intr}}(\mathbf{s}_j,\mathbf{R})] - \frac{\hbar^2}{2Am}|\Phi(\mathbf{R})|^2\nabla_R^2\varphi^{\mathrm{intr}}(\mathbf{s}_j,\mathbf{R})$$

$$+\int dR'\,ds'_j\,\Phi^*(\mathbf{R})\left\{T\left[\nabla_{s_j}\right]\delta(\mathbf{R}-\mathbf{R}')\delta(\mathbf{s}_j-\mathbf{s}'_j) + V(\mathbf{R},\mathbf{s}_j;\mathbf{R}',\mathbf{s}'_j)\right\}\Phi(\mathbf{R}')\varphi^{\mathrm{intr}}(\mathbf{s}'_j,\mathbf{R}') = F(\mathbf{R})\varphi^{\mathrm{intr}}(\mathbf{s}_j,\mathbf{R})$$

Alpha cluster formation and decay

——*Quartetting wave function approach*

3. Intrinsic bound-state W. F. transforms at critical density into an unbound 4 nucleon shell-model state



Pauli blocking

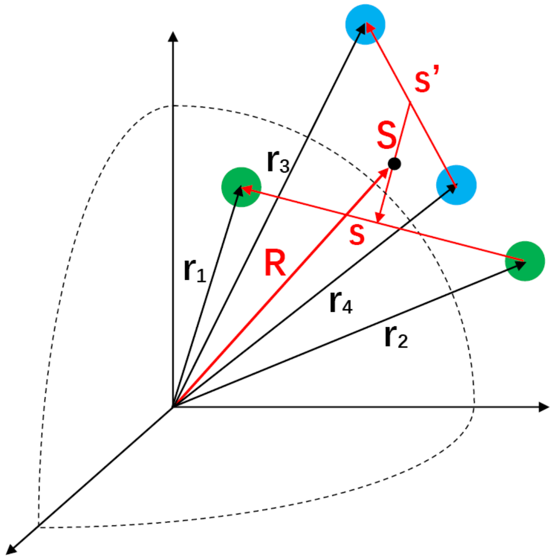
Inner Region

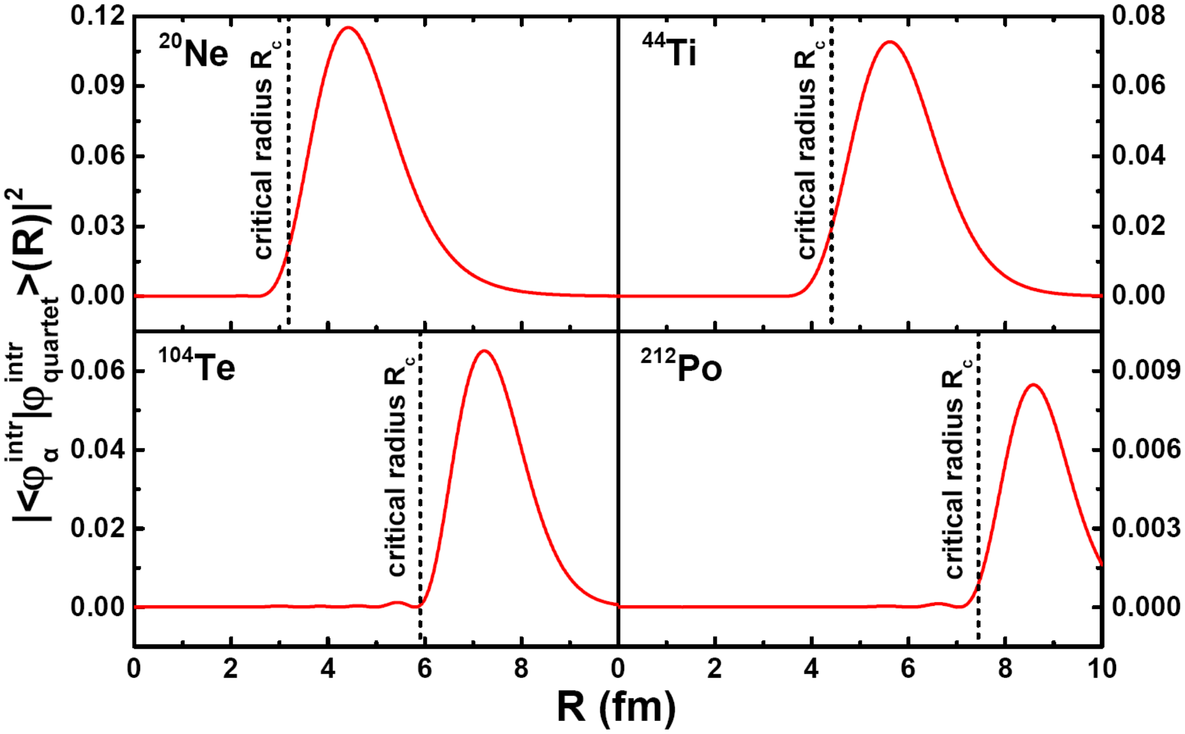
Surface Region

Alpha cluster formation and decay

——*Quartetting wave function approach*

$$\begin{aligned}\left\langle \varphi_\alpha^{\rm intr} | \varphi_{\rm quartet}^{\rm intr} \right\rangle (R) = & \int d^3S\, d^3s\, d^3s'\, \varphi_\alpha^{{\rm intr},*}(\mathbf{S},\mathbf{s},\mathbf{s}')\varphi_{\rm quartet}^{\rm intr}(\mathbf{R},\mathbf{S},\mathbf{s},\mathbf{s}') \\ = & \int d^3S\, d^3s\, d^3s'\, \frac{\mathscr{Y}_\alpha^*(\mathbf{r_1})\mathscr{Y}_\alpha^*(\mathbf{r_2})\mathscr{Y}_\alpha^*(\mathbf{r_3})\mathscr{Y}_\alpha^*(\mathbf{r_4})\Phi_{\rm quartet}(\mathbf{R},\mathbf{S},\mathbf{s},\mathbf{s}')}{\mathscr{Z}_\alpha^*(\mathbf{R})\Psi_{\rm quartet}^{\rm com}(\mathbf{R})} \\ = & \frac{64(2\pi)^9}{\mathscr{Z}_\alpha(\mathbf{R})\Psi_{\rm quartet}^{\rm com}(\mathbf{R})} \int d^3p\, \phi_{12}(\mathbf{p})\phi_{34}(\mathbf{p})e^{i\mathbf{p}\cdot\mathbf{R}}. \qquad (\end{aligned}$$





Alpha cluster formation and decay

——*Quartetting wave function approach*

4. First-principle approach to nuclear many-body system: several approximations performed to make the approach practicable

$$\left[-\frac{\hbar^2}{8m}\frac{\partial^2}{\partial \mathbf{R}^2}+W(\mathbf{R})\right]\Phi(\mathbf{R})=E_4\Phi(\mathbf{R}),$$

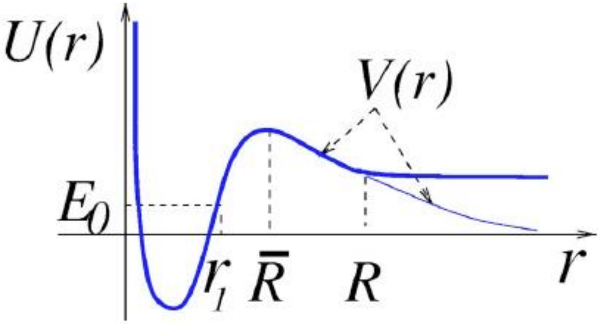
with

$$\begin{aligned}W(\mathbf{R})=E_4^{\mathrm{intr}}(\mathbf{R})&=W^{\mathrm{ext}}(\mathbf{R})+W^{\mathrm{intr}}(\mathbf{R})\\&=W^{\mathrm{ext}}(\mathbf{R})+E_\alpha^{(0)}+W^{\mathrm{Pauli}}(\mathbf{R})\end{aligned}$$

5. Alpha cluster preformation, pre-factor and penetration probability simultaneously calculated

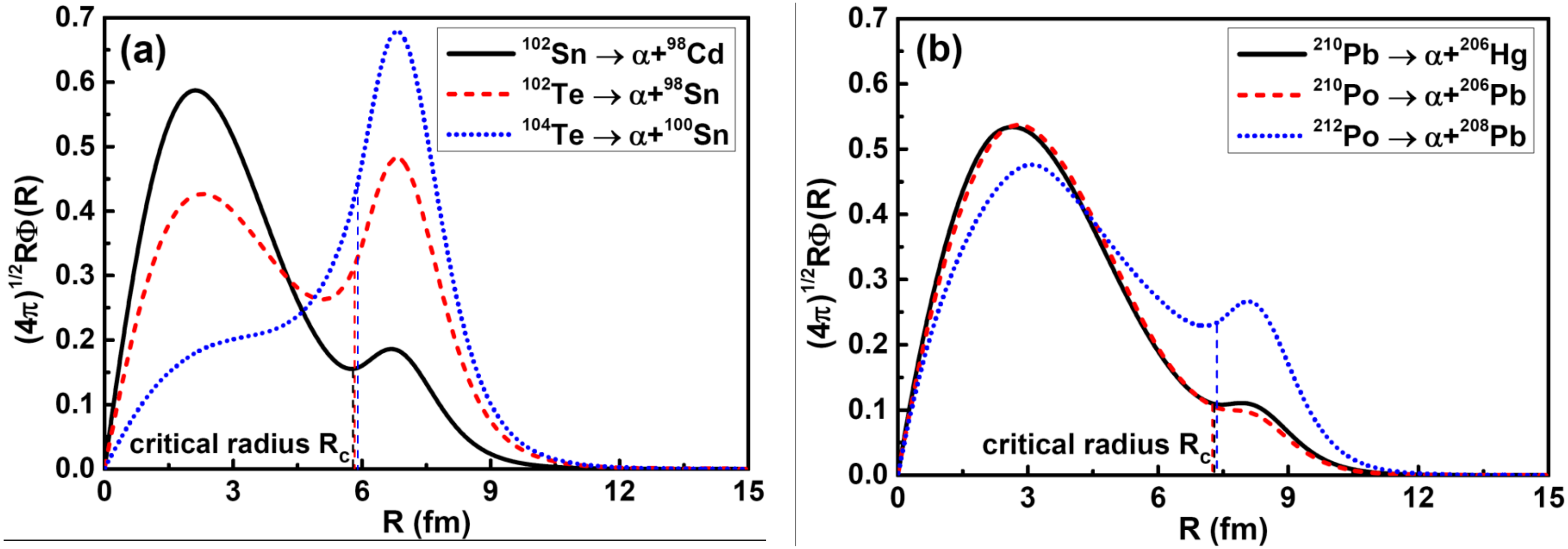
$$P_\alpha=\int_0^\infty d^3r\,|\Phi(r)|^2\,\Theta\left[n_B^{\mathrm{Mott}}-n_B(r)\right]$$

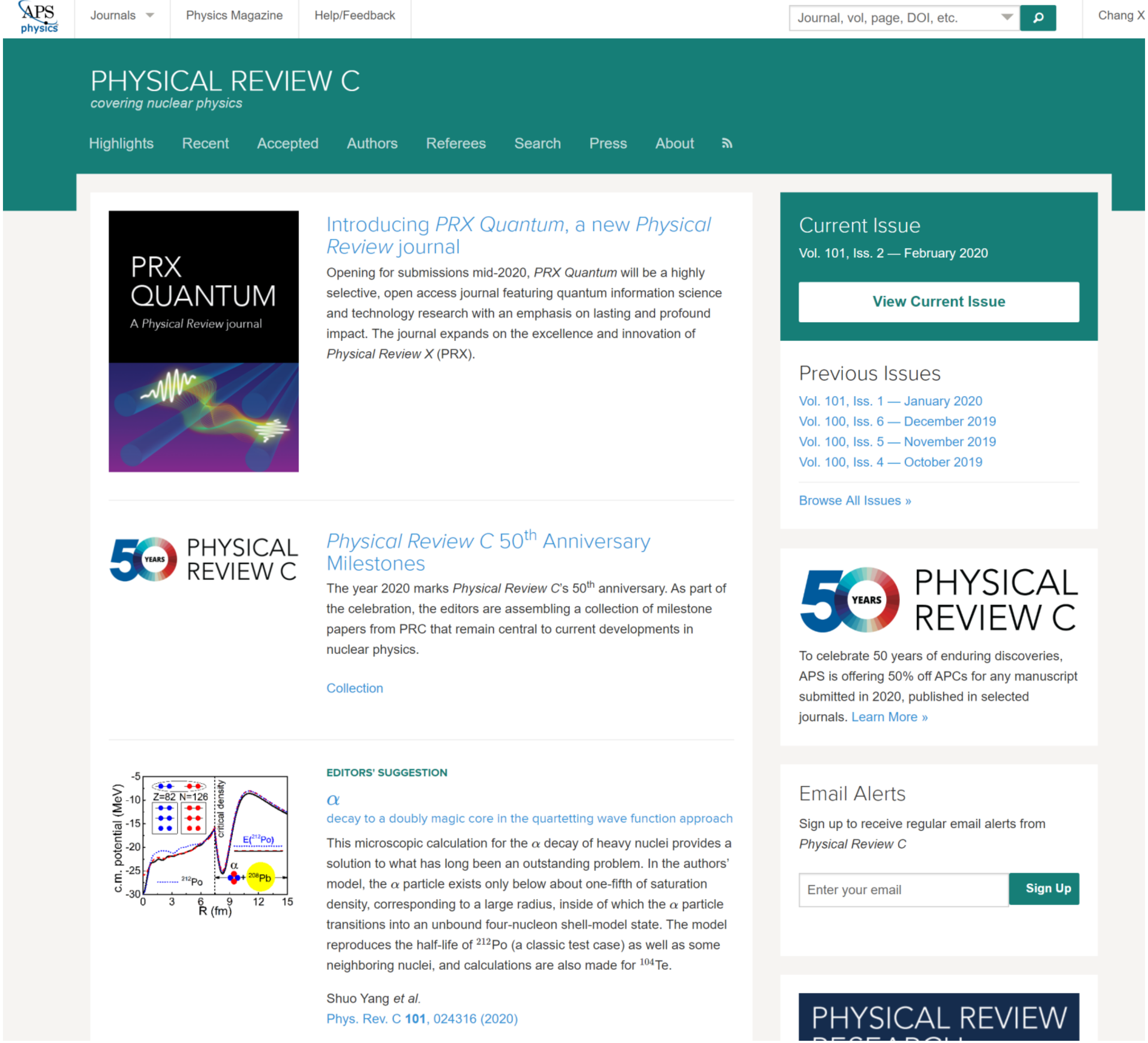
$$\Gamma=\nu\times\mathcal{T}=\frac{4\hbar^2\alpha^2}{\mu k}|\Phi(r_{\mathrm{sep}})\chi_k(r_{\mathrm{sep}})|^2$$



Alpha decay in ^{104}Te, ^{210}Pb, ^{210}Po, and ^{212}Po

Parent	Z	N	Q_α [MeV]	P_α	$T_{1/2}^{\text{calc.}}$ [s]	$T_{1/2}^{\text{expt.}}$ [s]
^{102}Sn	50	52		0.0551		
^{102}Te	52	50		0.3718		
^{104}Te	52	52	4.900	0.7235	1.479×10^{-8}	$<1.8\times10^{-8}$
^{210}Pb	82	128	3.792	0.0176	1.777×10^{16}	3.701×10^{16}
^{210}Po	84	126	5.408	0.0137	1.060×10^{7}	1.196×10^{7}
^{212}Po	84	128	8.954	0.1045	3.395×10^{-7}	2.997×10^{-7}





PHYSICAL REVIEW C

covering nuclear physics

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Collection

EDITORS' SUGGESTION

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

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.

Shuo Yang *et al.*

Phys. Rev. C **101**, 024316 (2020)

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Vol. 101, Iss. 2 — February 2020

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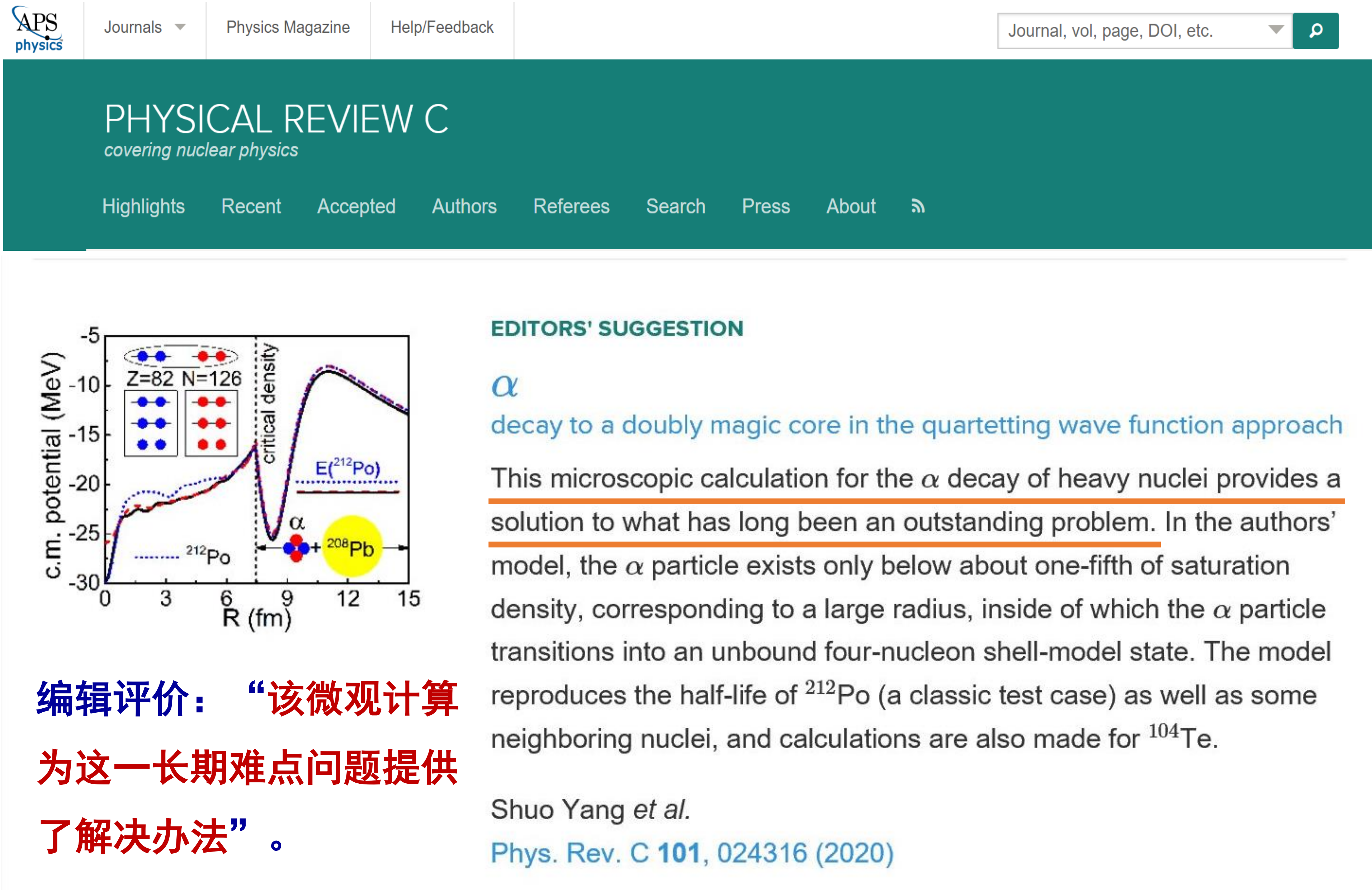

PHYSICAL REVIEW C

covering nuclear physics

EDITORS' SUGGESTION

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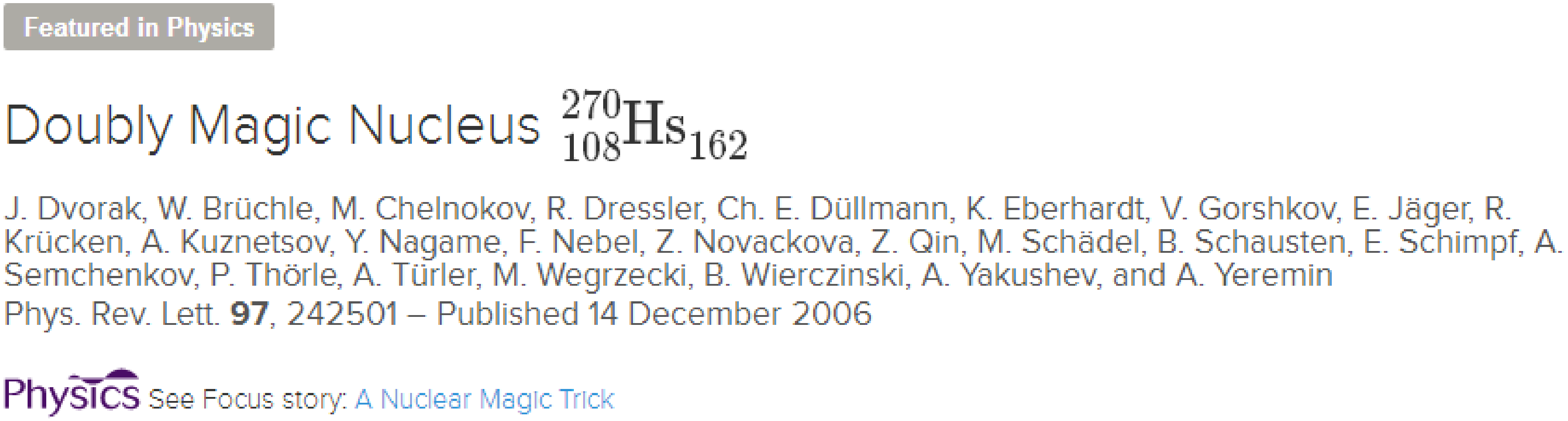
Shuo Yang *et al.*

Phys. Rev. C **101**, 024316 (2020)

编辑评价：“该微观计算为这一长期难点问题提供了解决办法”。

Alpha cluster formation and decay in superheavy nuclei



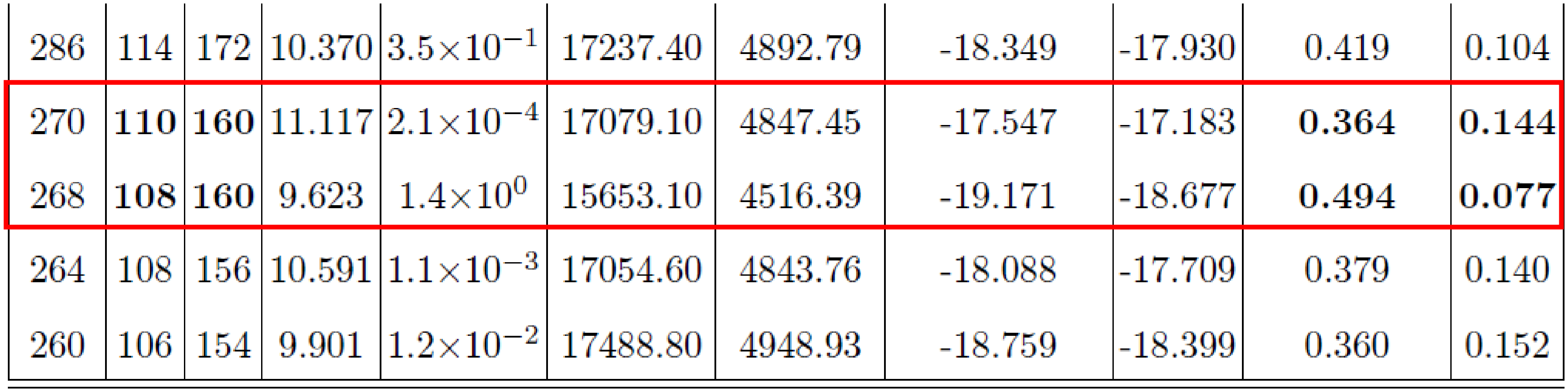
Featured in Physics

Doubly Magic Nucleus $^{270}_{108}\mathrm{Hs}_{162}$

J. Dvorak, W. Brüchle, M. Chelnokov, R. Dressler, Ch. E. Düllmann, K. Eberhardt, V. Gorshkov, E. Jäger, R. Krücken, A. Kuznetsov, Y. Nagame, F. Nebel, Z. Novackova, Z. Qin, M. Schädel, B. Schausten, E. Schimpf, A. Semchenkov, P. Thörle, A. Türler, M. Wegrzecki, B. Wierczinski, A. Yakushev, and A. Yeremin

Phys. Rev. Lett. **97**, 242501 – Published 14 December 2006

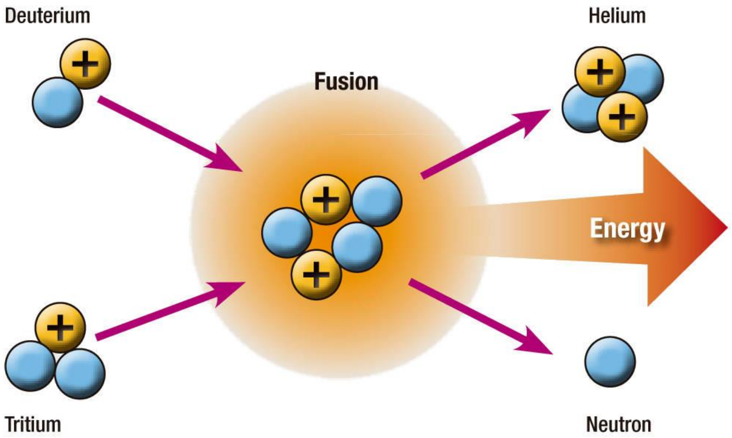
Physics See Focus story: A Nuclear Magic Trick

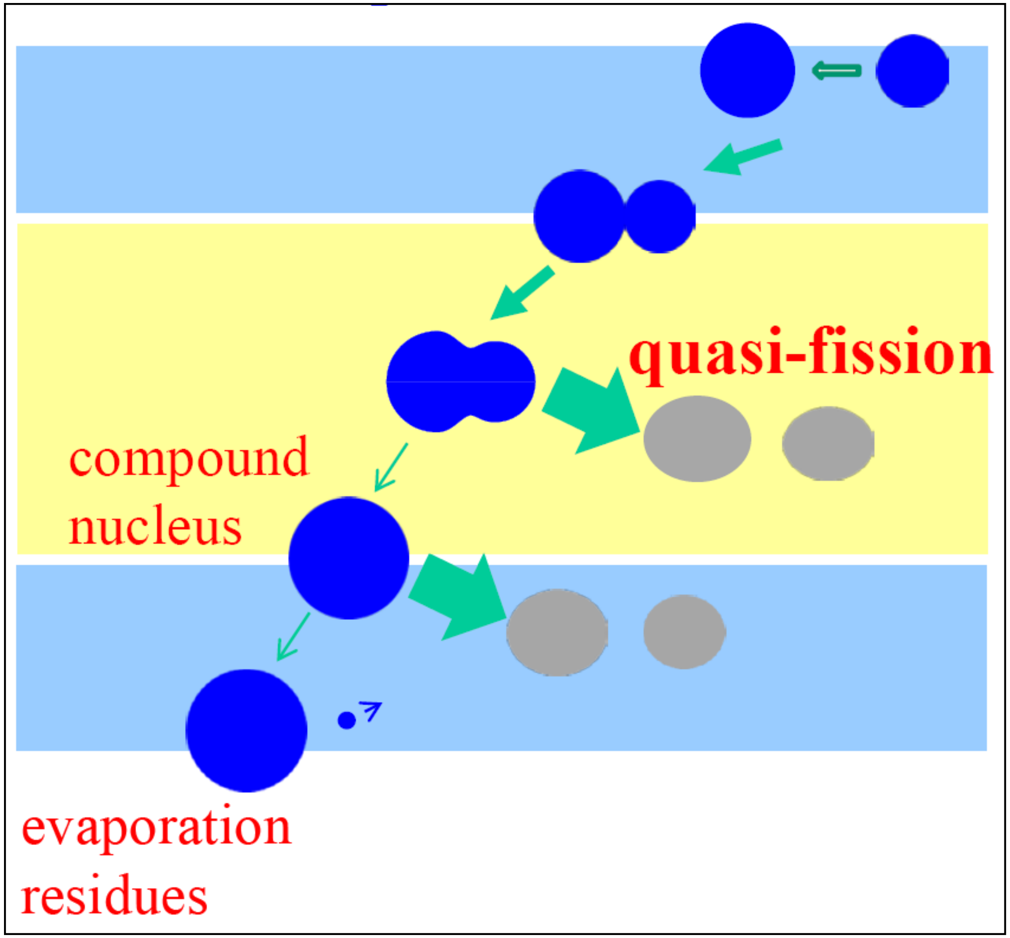


286	114	172	10.370	3.5×10^{-1}	17237.40	4892.79	-18.349	-17.930	0.419	0.104
270	**110**	**160**	11.117	2.1×10^{-4}	17079.10	4847.45	-17.547	-17.183	**0.364**	**0.144**
268	**108**	**160**	9.623	1.4×10^{0}	15653.10	4516.39	-19.171	-18.677	**0.494**	**0.077**
264	108	156	10.591	1.1×10^{-3}	17054.60	4843.76	-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

Decay and Fusion: two sides of the same coin

Fusion reaction: nucleosynthesis in the early universe , energy production in stars, superheavy elements…





VOLUME 89, NUMBER 5 PHYSICAL REVIEW LETTERS 29 JULY 2002

Unexpected Behavior of Heavy-Ion Fusion Cross Sections at Extreme Sub-Barrier Energies

C. L. Jiang, H. Esbensen, K. E. Rehm, B. B. Back, R. V. F. Janssens, J. A. Caggiano, P. Collon, J. Greene, A. M. Heinz,
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Physics Division, Argonne National Laboratory, Argonne, Illinois 60439

(Received 9 January 2002; published 11 July 2002)

The excitation function for fusion evaporation in the ^{60}Ni + ^{89}Y system was measured over a range in cross section covering 6 orders of magnitude. The cross section exhibits an abrupt decrease at extreme sub-barrier energies. This behavior, which is also present in a few other systems found in the literature, cannot be reproduced with present models, including those based on a coupled-channels approach. Possible causes are discussed, including a dependence on the intrinsic structure of the participants.

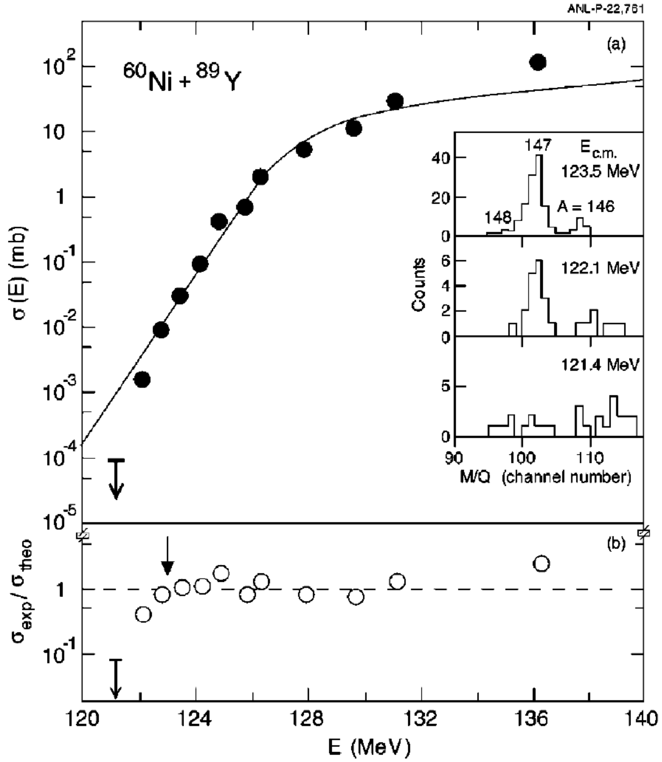

FIG. 2. Experimental evaporation residue cross sections

<u>Fusion deep sub-barrier hindrance phenomenon:</u>

Unexpected falloff feature in experimental fusion cross sections

Hard to explain by the standard coupled channels model

PRL **96,** 112701 (2006) PHYSICAL REVIEW LETTERS week ending 24 MARCH 2006

Hindrance of Heavy-Ion Fusion due to Nuclear Incompressibility

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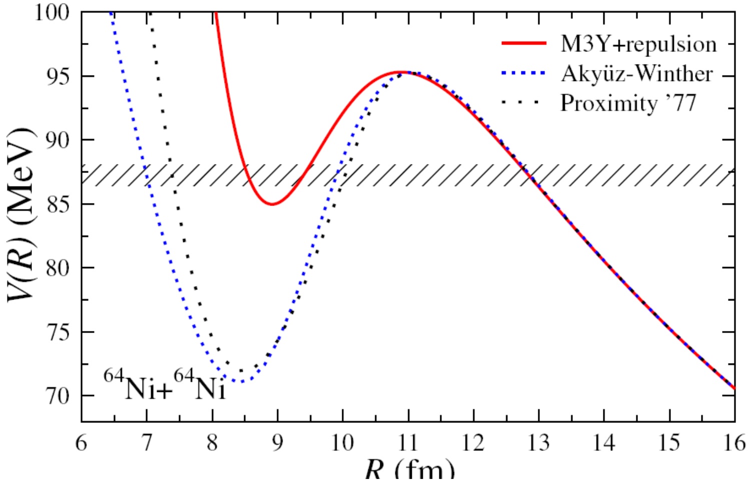
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

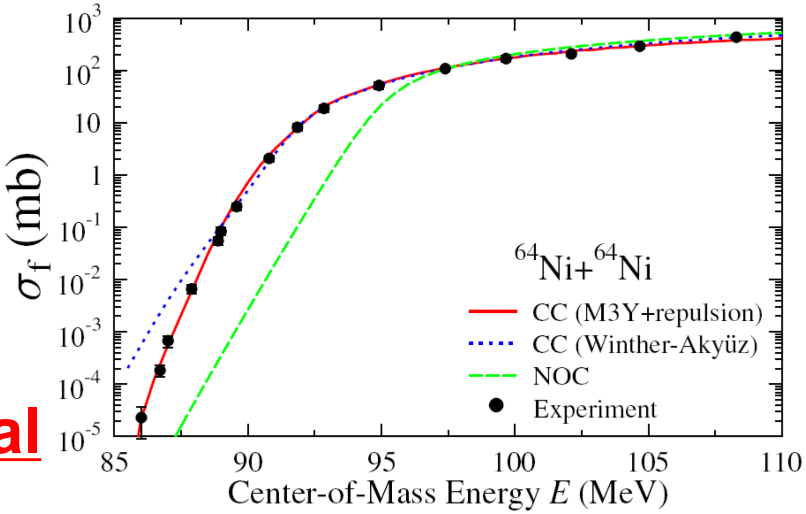
(Received 26 January 2006; published 21 March 2006)

$$\varepsilon(\rho,\delta) = \varepsilon_F\left[A(\delta)\left(\frac{\rho}{\rho_0}\right)^{2/3} + B(\delta)\left(\frac{\rho}{\rho_0}\right) + C(\delta)\left(\frac{\rho}{\rho_0}\right)^{5/3}\right],$$

$$\Delta V \approx 2A_p[\varepsilon(2\rho_0,\delta) - \varepsilon(\rho_0,\delta)].$$

$$K = 9\left(\rho^2\frac{\partial^2\varepsilon}{\partial\rho^2}\right)_{\rho=\rho_0} \qquad V_N(0) = \Delta V \approx \frac{A_p}{9}K$$





Signature of a "pocket" potential

PHYSICAL REVIEW C **67**, 054603 (2003)

Fusion cross sections at deep sub-barrier energies

K. Hagino,[1,2] N. Rowley,[3] and M. Dasgupta[4]
[1] *Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*
[2] *Institut de Physique Nucléaire, IN2P3-CNRS, Université Paris-Sud, F-91406 Orsay Cedex, France*
[3] *Institut de Recherches Subatomiques, UMR7500, IN2P3-CNRS/Universtité Louis Pasteur, BP28, F-67037 Strasbourg Cedex 2, France*
[4] *Department of Nuclear Physics, Research School of Physical Sciences and Engineering, Australian National University, Canberra ACT0200, Australia*

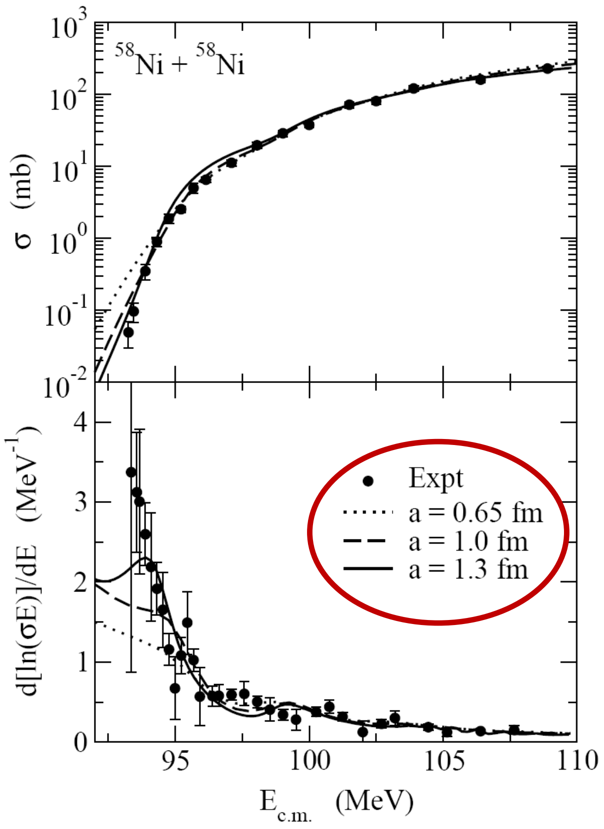


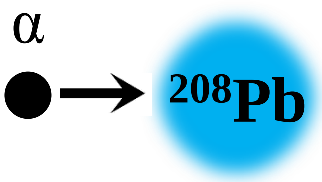
FIG. 3. Dependence of the fusion cross section (upper panel) and the logarithmic slope (lower panel) on the surface diffuseness

Large difference in diffuseness parameter of the WS potential extracted from scattering and from fusion analyses

A large surface diffuseness: reflects the true nature of the potential or simply mocks up other effects?

Neither the deep or shallow double-folding potential nor the geometrical corrections to the coupling potential seem to resolve this problem

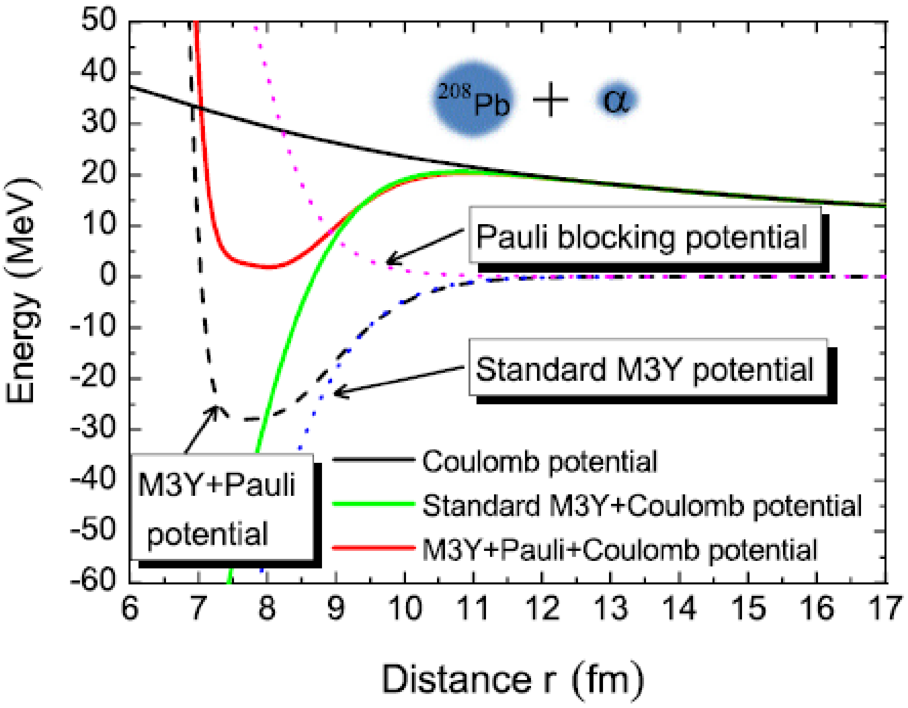
Fusion cross section of alpha-particle-induced reactions

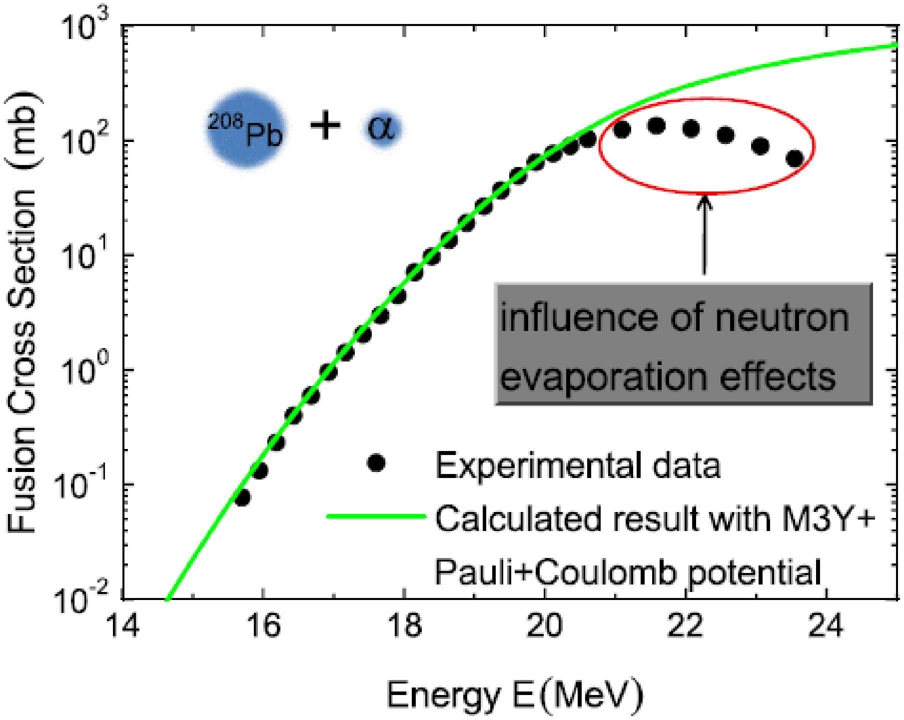


PHYSICAL REVIEW C **99**, 014607 (2019)

Pauli blocking effects in α-induced fusion reactions

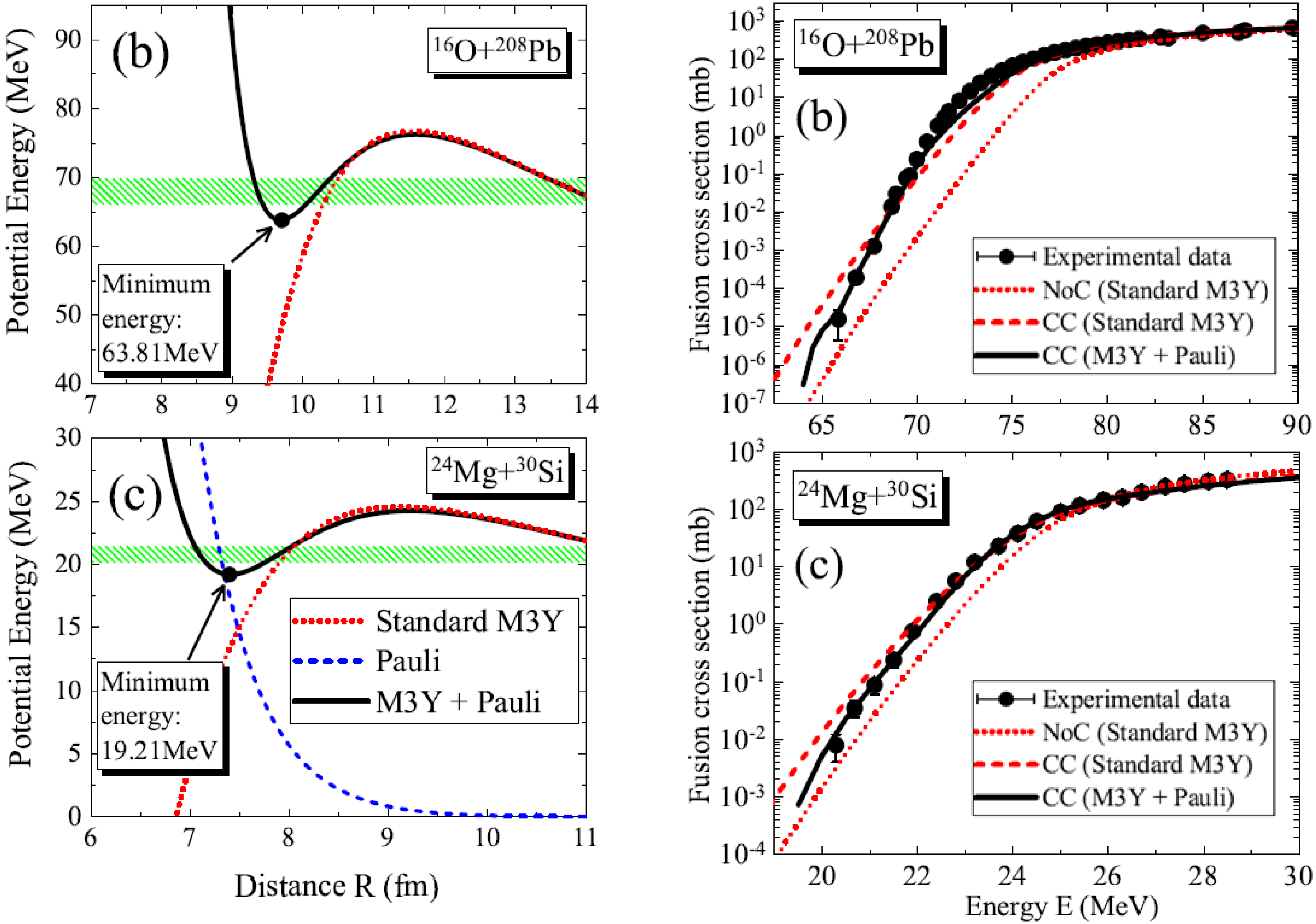
Kaixuan Cheng and Chang Xu*
School of Physics, Nanjing University, Nanjing 210093, China





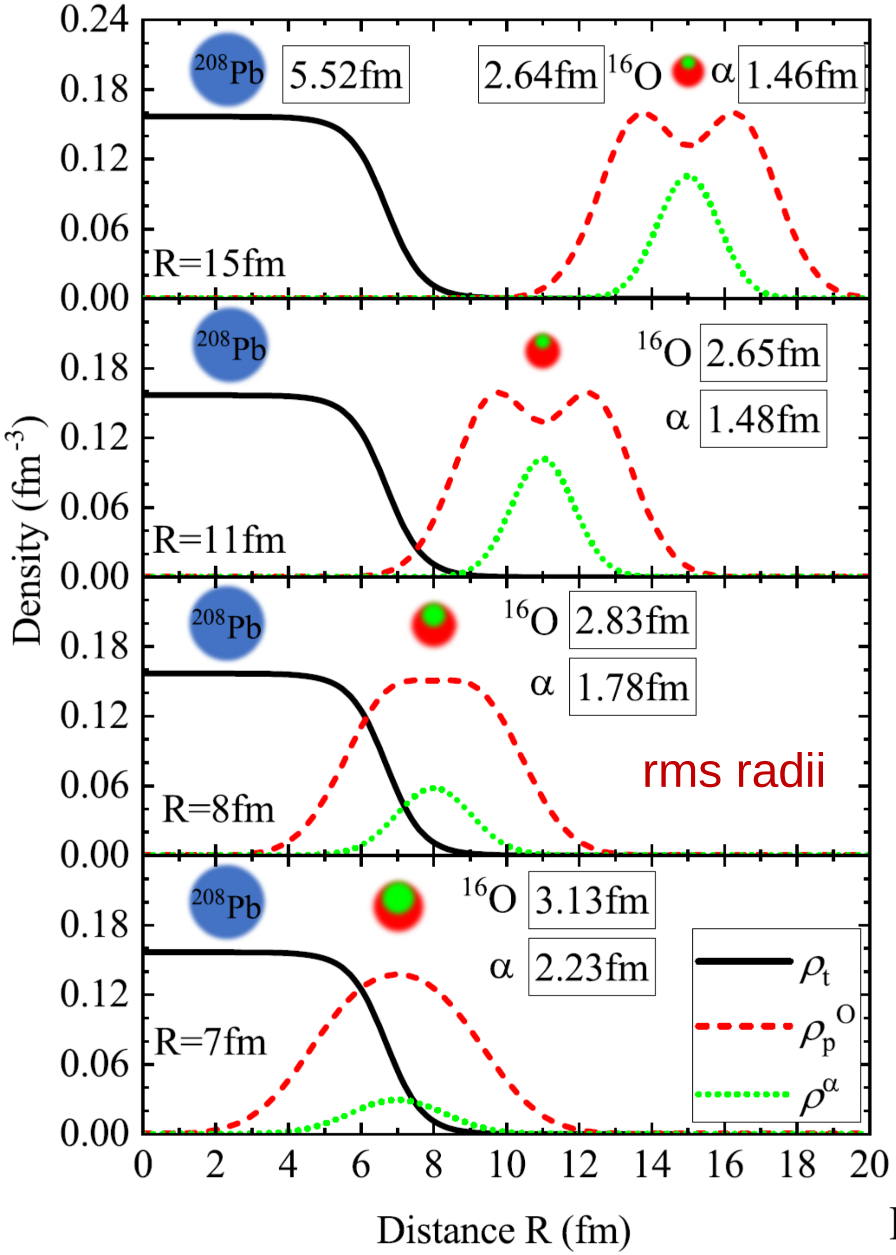
influence of neutron evaporation effects

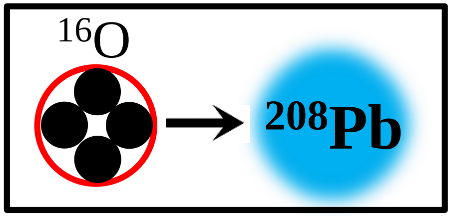
N-alpha-particle-induced fusion reactions

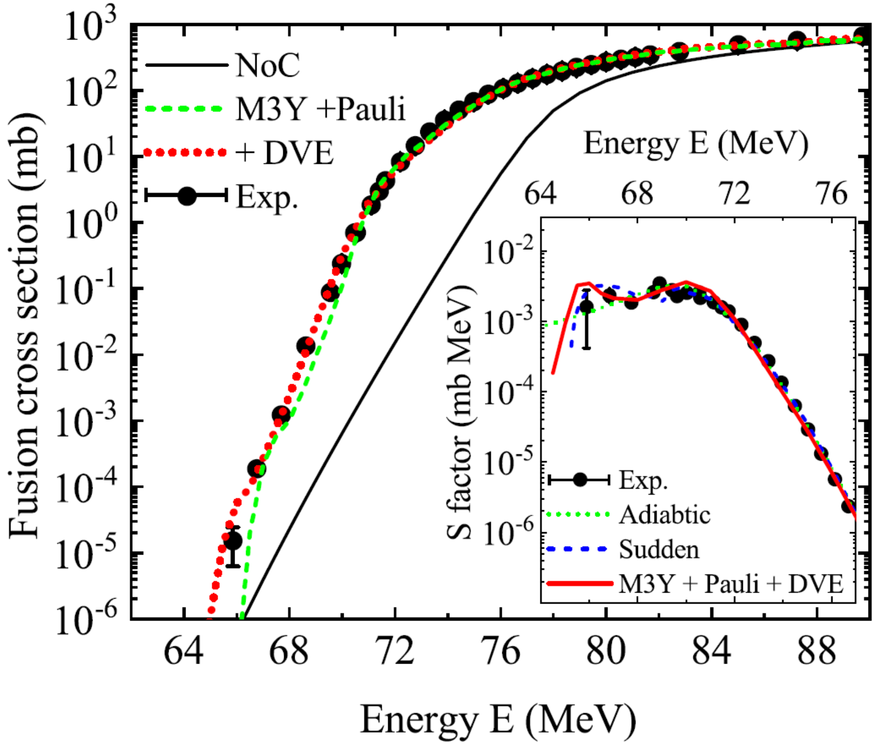


Kaixuan Cheng and Chang Xu* PHYSICAL REVIEW C **102**, 014619 (2020)

A hybrid approach between sudden model and adiabatic one







PHYSICAL REVIEW C **103**, 014613 (2021)

Eur. Phys. J. A (2021) 57:235
https://doi.org/10.1140/epja/s10050-021-00536-2

THE EUROPEAN
PHYSICAL JOURNAL

Review

Heavy-ion fusion reactions at extreme sub-barrier energies

C. L. Jiang[1,a], **B. B. Back**[1], **K. E. Rehm**[1], **K. Hagino**[2], **G. Montagnoli**[3], **A. M. Stefanini**[4]

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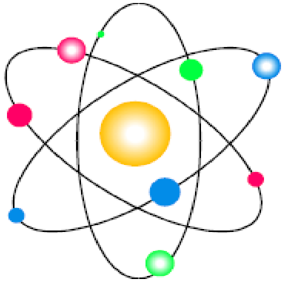
[2] Department of Physics, Kyoto University, Kyoto 606-8502, Japan
[3] Dipartimento di Fisica e Astronomia, Università di Padova, and INFN, Sez. di Padova, 35131 Padua, Italy
[4] INFN, Laboratori Nazionali di Legnaro, 35020 Legnaro, Padova, Italy

Notice that the microscopic origin of the repulsion in the overlapping region is due to the Pauli principle, as pointed out in Ref. [125] (see also Refs. [131, 132]). In this model, the authors introduced a new microscopic approach to heavy-ion fusion and demonstrated, on the basis of density-constrained frozen Hartree–Fock calculations, that the main effect of Pauli repulsion is to reduce the tunneling probability inside the Coulomb barrier, thus producing the hindrance.

This trend at far sub-barrier energies (no hindrance observed for ^{58}Ni + ^{64}Ni) suggests that, as was observed for ^{40}Ca + ^{96}Zr, the availability of several states following transfer with $Q > 0$ effectively counterbalances the Pauli repulsion that, in general, is predicted to reduce the tunneling probability through the Coulomb barrier [125, 153].

131. K. Cheng, C. Xu, Phys. Rev. C **102**, 014619 (2020)
132. K. Cheng, C. Xu, Phys. Rev. C **99**, 014607 (2019)
153. Kaixuan Cheng, Xu Chang, Phys. Rev. C **102**, 014619 (2020)



Short summary

Microscopic understanding of large amplitude motions of quantum many-body systems with strong interaction

Alpha decay: an important problem with renewed interest

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

Fusion reactions and hindrance phenomenon: strong interplay between reaction and structure

谢 谢！

Collaborators :, G. Roepke, Z. Ren，P. Schuck, A. Tohsaki, Y. Funaki, T. Yamada, H. Horiuchi, B. Zhou, M. J. Lyu, Bao-An Li, L. W. Chen, T. Myo, H. Toki，J. Liu，N. Wan