30 years of
Bucharest-Stockholm collaboration in the field of emission processes

IFIN-HH, Bucharest

Doru S. Delion

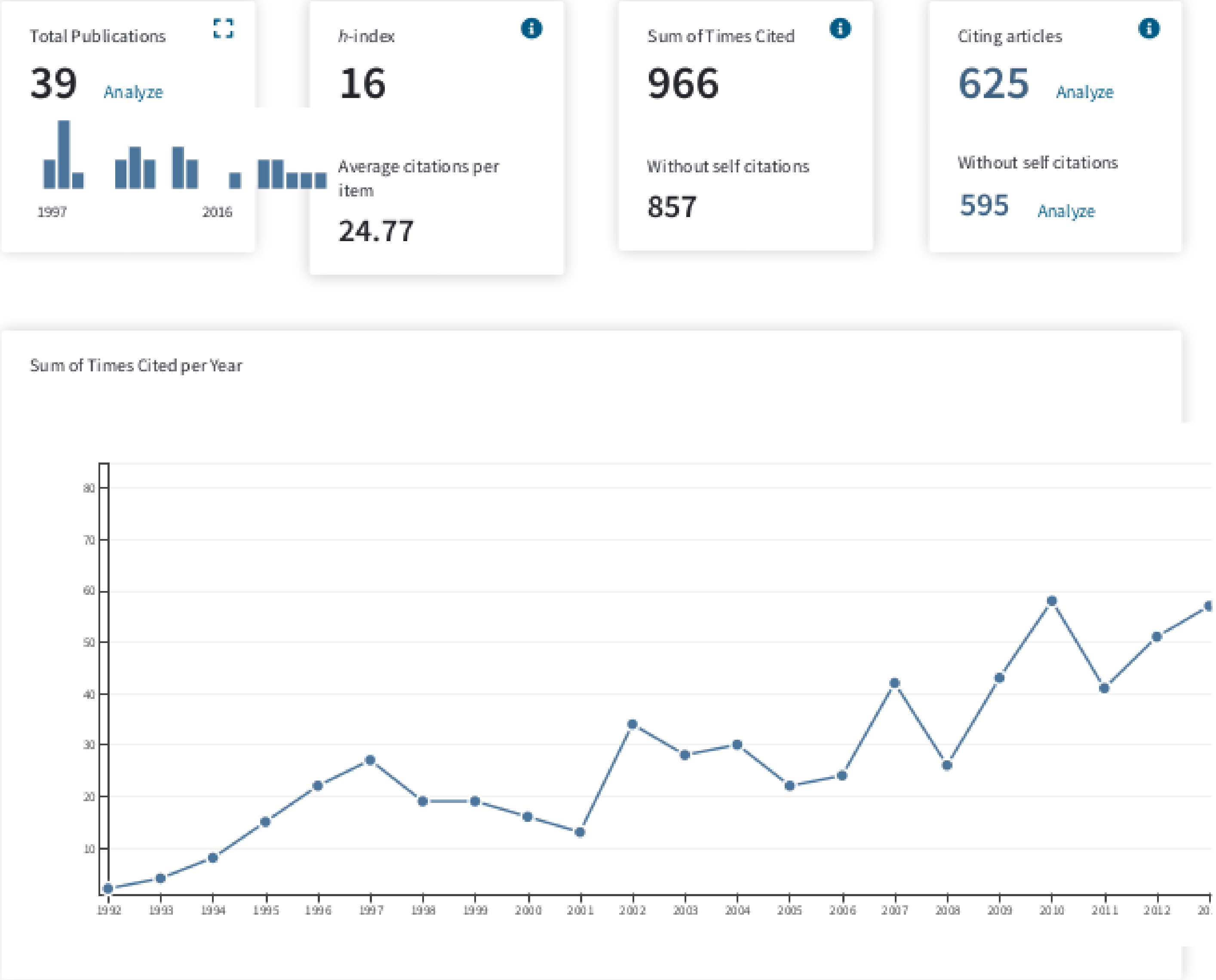
KTH, Stockholm

Roberto J. Liotta (since 1990)

Ramon Wyss (since 2003)

Chong Qi (since 2012)

Our publications (11.08.2019)



Total Publications

39 Analyze

h-index

16

Average citations per item

24.77

Sum of Times Cited

966

Without self citations

857

Citing articles

625 Analyze

Without self citations

595 Analyze

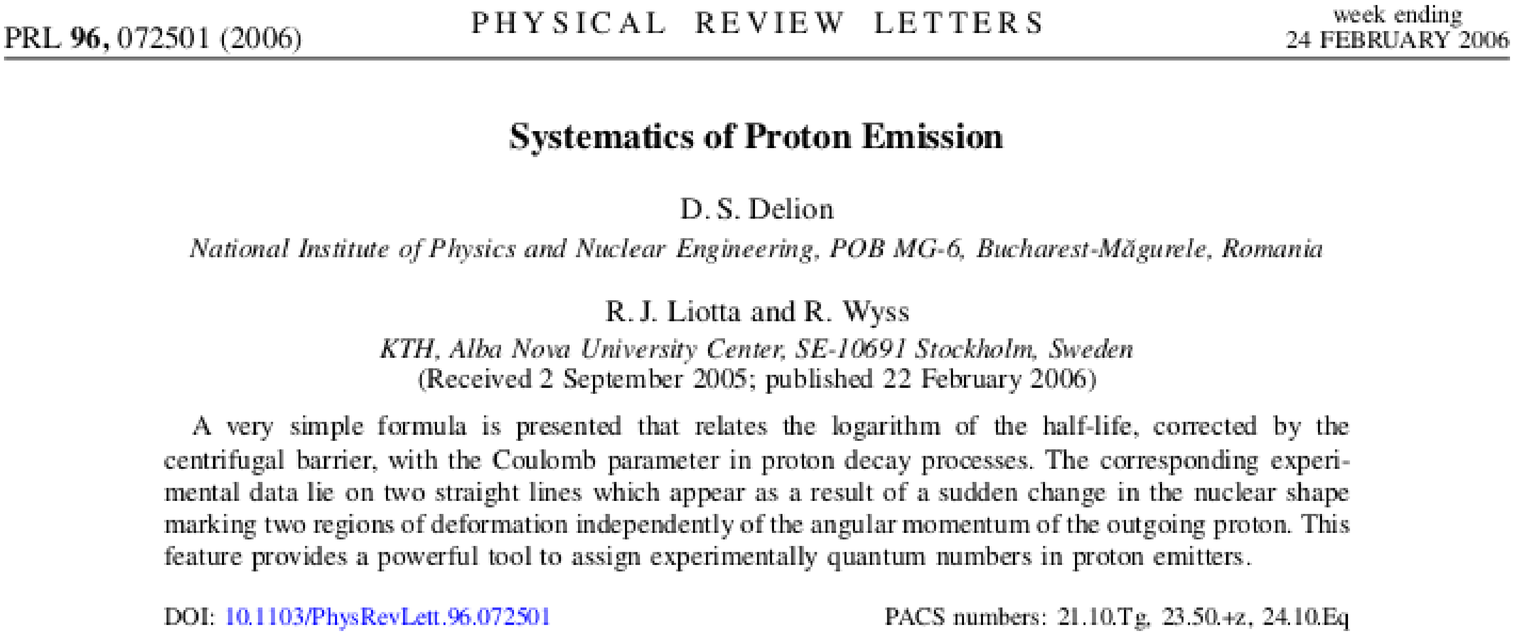
Sum of Times Cited per Year

We investigated cold emission processes

defined by the splitting of a nucleus
into two or more fragments
in their ground or low-lying states
which energetically are more bound

1. Proton and two-proton emission
(predicted in 1960 by V.I. Goldansky)
2. Alpha decay
(discovered in 1899 by E. Rutherford)
3. Heavy-cluster emission
(predicted in 1977 by A. Sandulescu)

1. Proton emission



PRL **96,** 072501 (2006) PHYSICAL REVIEW LETTERS week ending 24 FEBRUARY 2006

Systematics of Proton Emission

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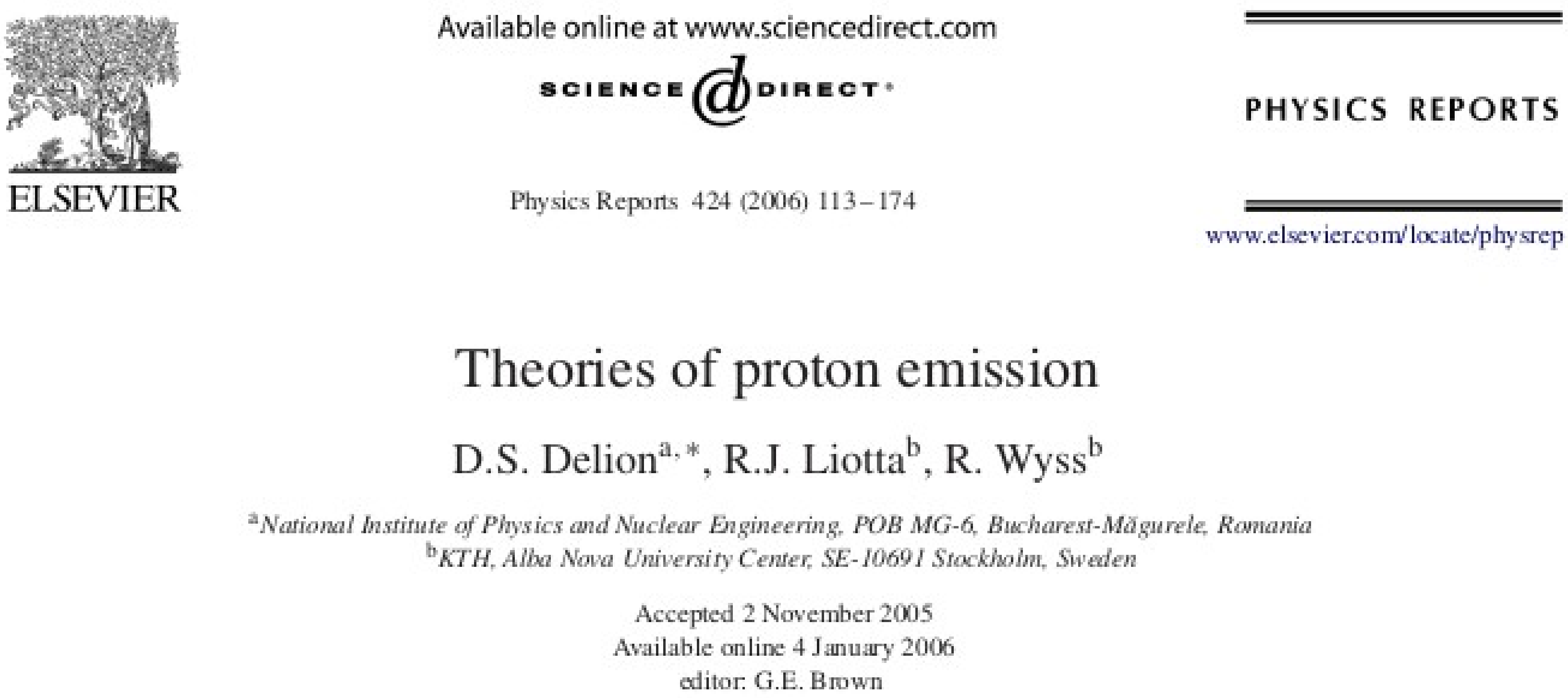
(Received 2 September 2005; published 22 February 2006)

A very simple formula is presented that relates the logarithm of the half-life, corrected by the centrifugal barrier, with the Coulomb parameter in proton decay processes. The corresponding experimental data lie on two straight lines which appear as a result of a sudden change in the nuclear shape marking two regions of deformation independently of the angular momentum of the outgoing proton. This feature provides a powerful tool to assign experimentally quantum numbers in proton emitters.

DOI: 10.1103/PhysRevLett.96.072501 PACS numbers: 21.10.Tg, 23.50.+z, 24.10.Eq

Review paper on proton emission



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Theories of proton emission

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Available online 4 January 2006
editor: G.E. Brown

Proton emission systematics for reduced (on angular momentum) half life

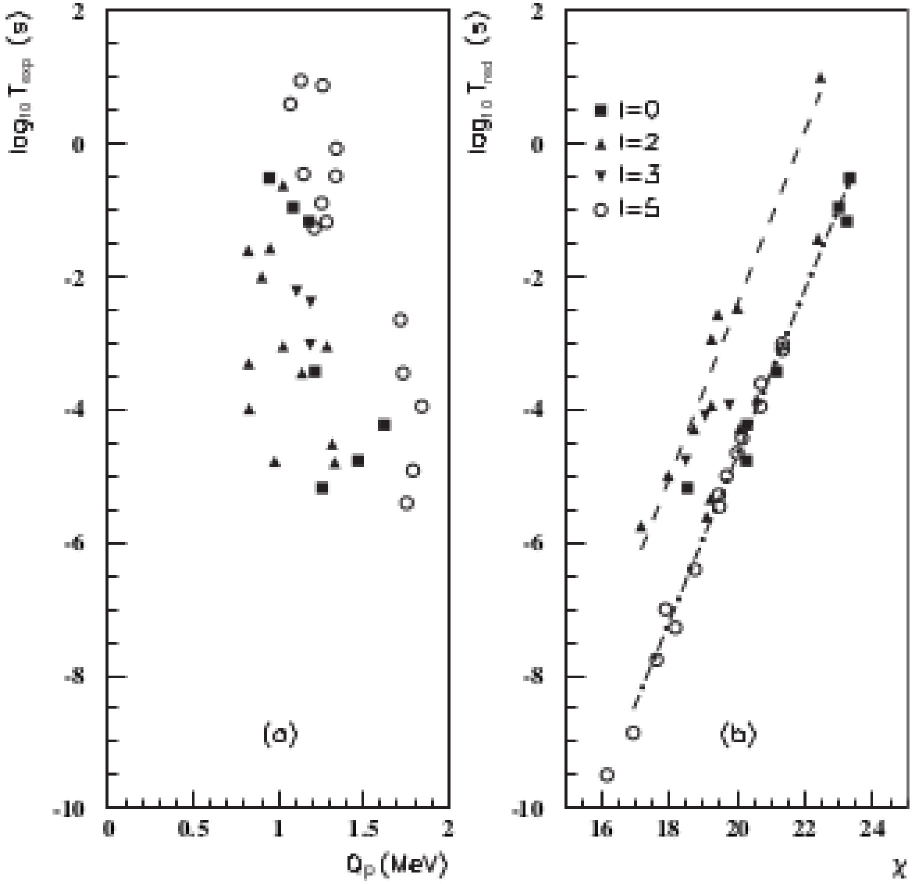


FIG. 1. (a) Logarithm of the experimental half-lives corresponding to proton decay as a function of the Q value. The data are taken from Ref. [4]. (b) Values of $\log_{10} T_{\rm red}$, Eq. (6), as a function of the Coulomb parameter χ. The numbers labeling the different symbols correspond to the l values of the outgoing proton. The two lines are computed according to Eq. (8).

$$T_{\rm red} = \frac{T_{1/2}}{C_l^2}:$$

$$C_l(\chi,\rho) = \exp\left[\frac{l(l+1)}{\chi}\tan\alpha\right],$$

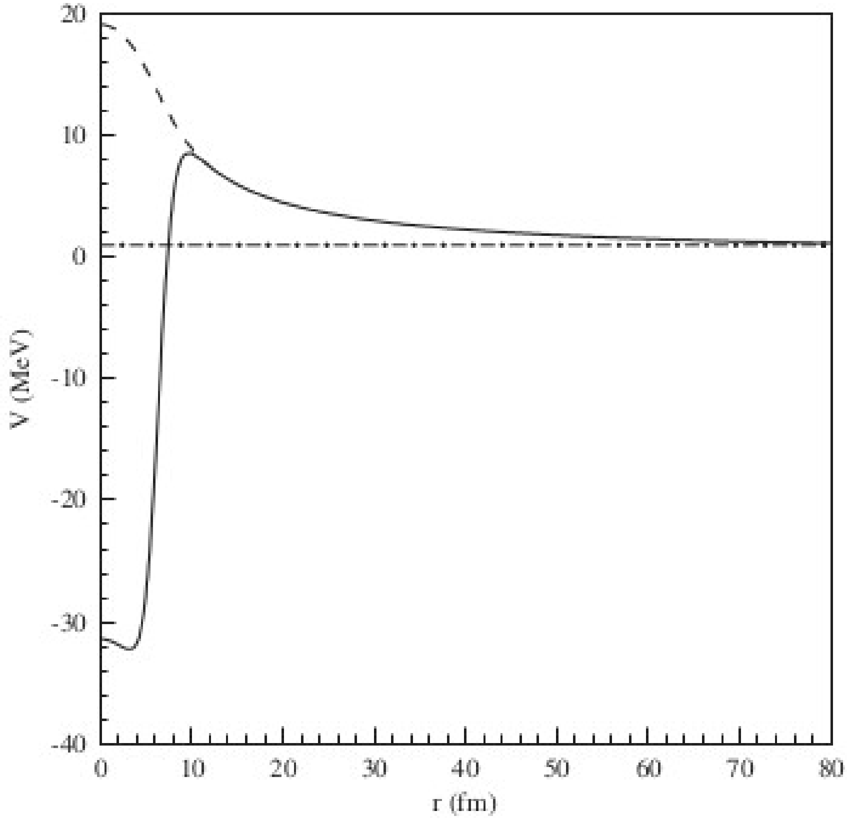
$$\cos^2\alpha = \frac{Q_p}{V_c(R)} = \frac{\rho}{\chi},$$

$$\log_{10} T_{\rm red}^{(k)} = a_k(\chi - 20) + b_k,$$

$$a_1 = 1.31, \qquad b_1 = -2.44 \quad \text{for } Z < 68$$

$$\text{and} \quad a_2 = 1.25, \qquad b_2 = -4.71 \quad \text{for } Z > 68, \qquad (8)$$

Particle dynamics in the external barrier explains the dependence on Coulomb parameter and proton angular momentum



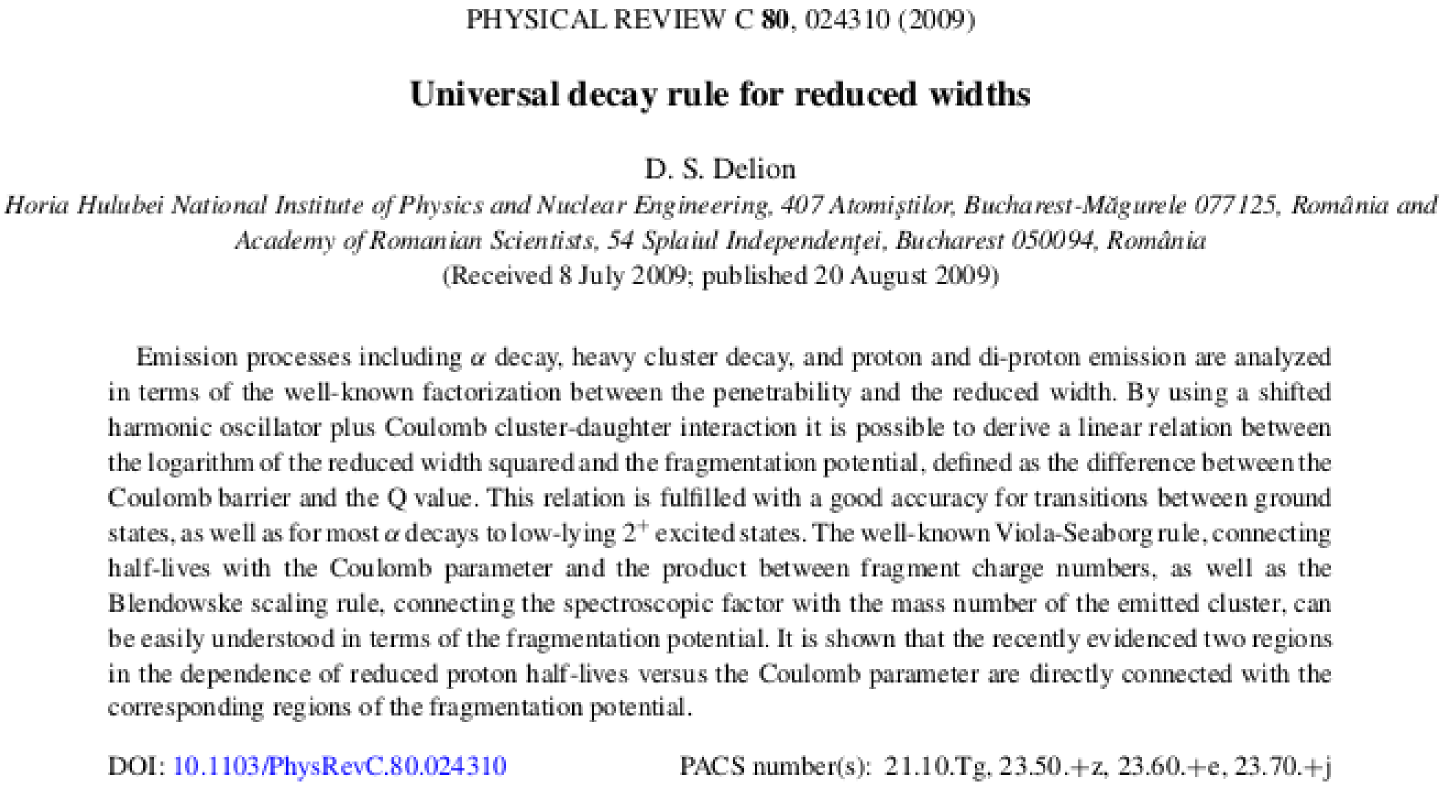
$$\left[-\frac{d^2}{d\rho^2}+\frac{l(l+1)}{\rho^2}+\frac{\chi}{\rho}-1\right] f_{lj}(\chi,\rho)=0,$$

$$\chi=\frac{2Z_D e^2}{\hbar v};$$

$$\rho=kr$$

$$f_{lj}(\chi,\rho)=N_l H_l^{(+)}(\chi,\rho)]\equiv N_l C_l\, H_0^{(+)}(\chi,\rho)$$

The two lines are explained by



PHYSICAL REVIEW C **80**, 024310 (2009)

Universal decay rule for reduced widths

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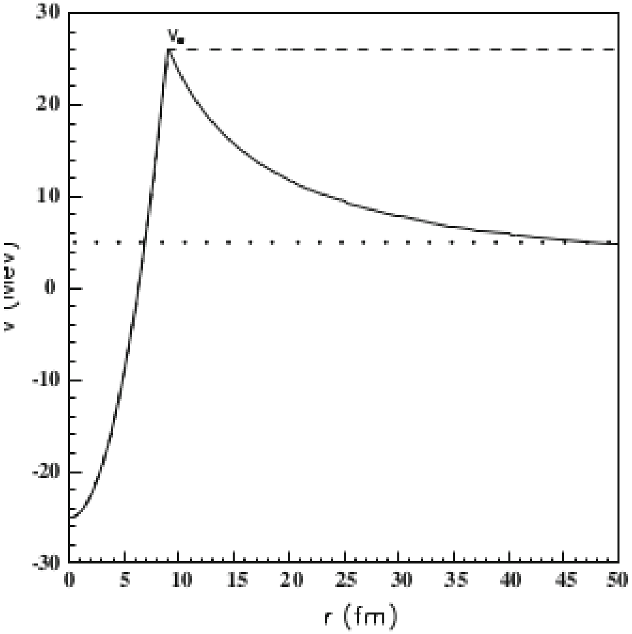
(Received 8 July 2009; published 20 August 2009)

Emission processes including α decay, heavy cluster decay, and proton and di-proton emission are analyzed in terms of the well-known factorization between the penetrability and the reduced width. By using a shifted harmonic oscillator plus Coulomb cluster-daughter interaction it is possible to derive a linear relation between the logarithm of the reduced width squared and the fragmentation potential, defined as the difference between the Coulomb barrier and the Q value. This relation is fulfilled with a good accuracy for transitions between ground states, as well as for most α decays to low-lying 2^+ excited states. The well-known Viola-Seaborg rule, connecting half-lives with the Coulomb parameter and the product between fragment charge numbers, as well as the Blendowske scaling rule, connecting the spectroscopic factor with the mass number of the emitted cluster, can be easily understood in terms of the fragmentation potential. It is shown that the recently evidenced two regions in the dependence of reduced proton half-lives versus the Coulomb parameter are directly connected with the corresponding regions of the fragmentation potential.

DOI: 10.1103/PhysRevC.80.024310 PACS number(s): 21.10.Tg, 23.50.+z, 23.60.+e, 23.70.+j

By using a schematic ho + Coulomb interaction one obtains for the reduced width γ²



$$\Gamma_l = 2P_l(E_l, r)\gamma_l^2(\beta, r),$$

$$P_l(E_l, r) = \frac{\kappa_l r}{\left|H_l^{(+)}(\chi_l, \kappa_l r)\right|^2},$$

the following universal law

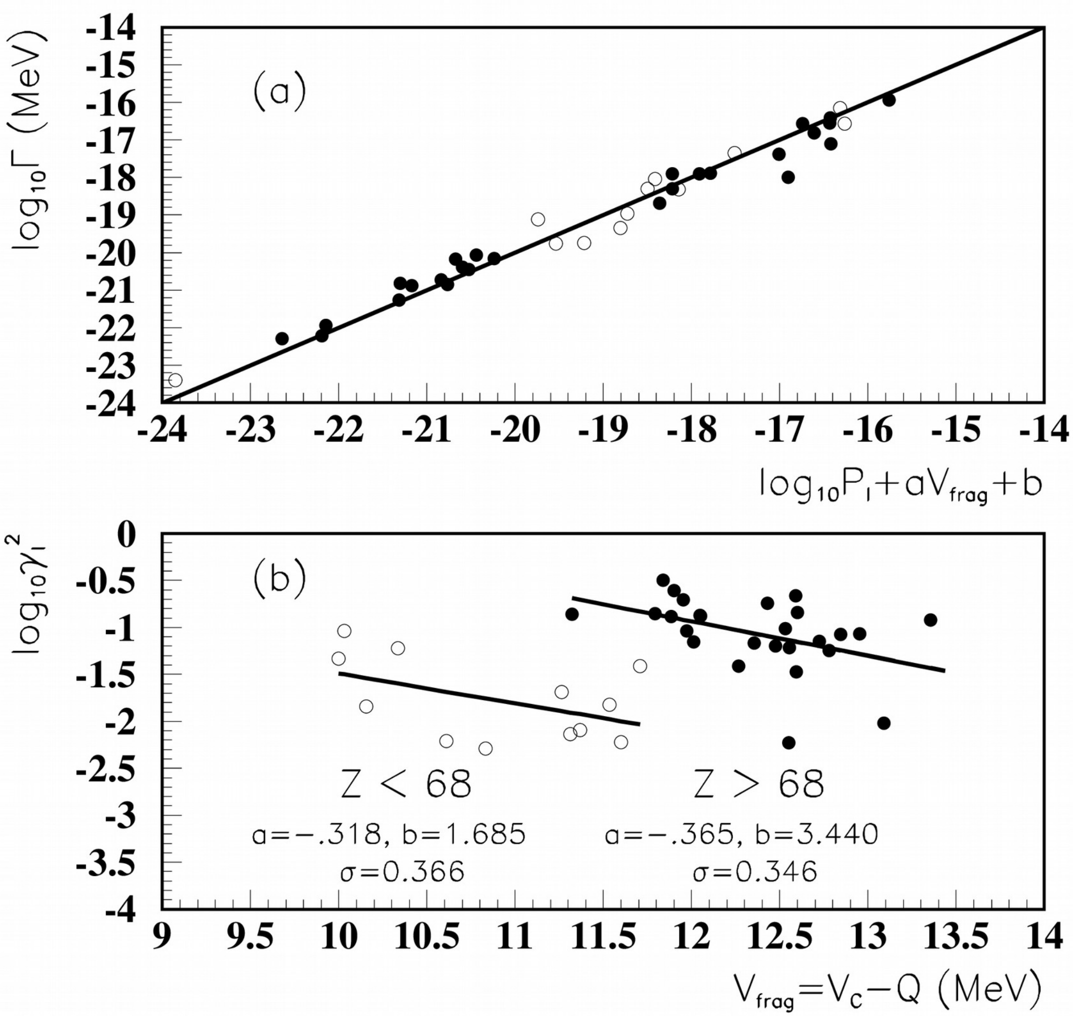
$$\log_{10}\gamma^2(r_B) = -\frac{\log_{10} e^2}{\hbar\omega} V_{\mathrm{frag}}(r_B) + \log_{10}\frac{\hbar^2 A_0^2}{2e\mu r_B}.$$

in terms of fragmentation potential $V_{\mathrm{frag}}(r_B) = V_C(r_B) - Q.$

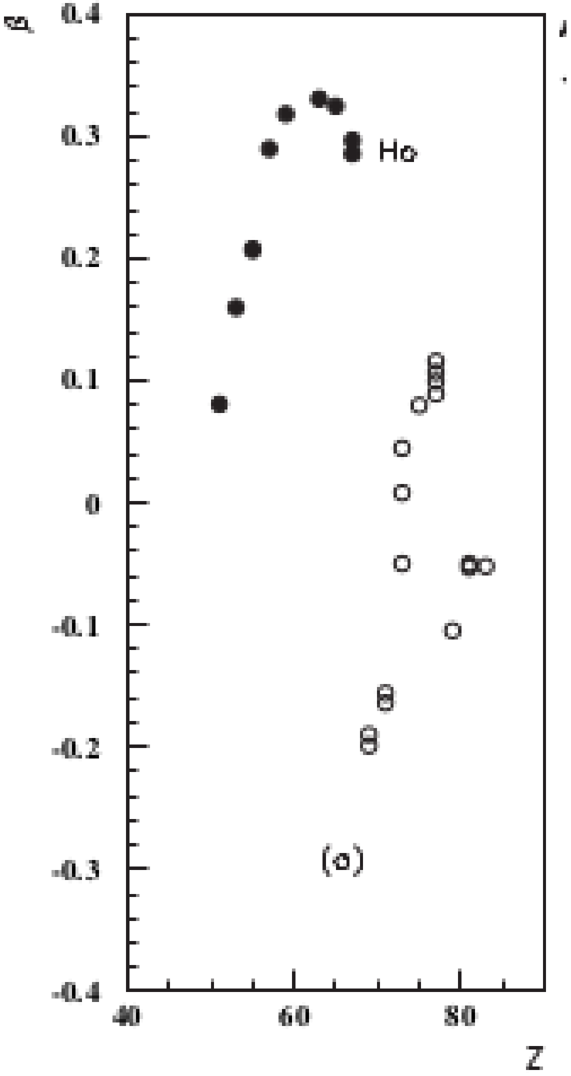
and cluster amplitude A_0

The two lines in systematics correspond to two different regions of the fragmentation potential V_c-Q (b)

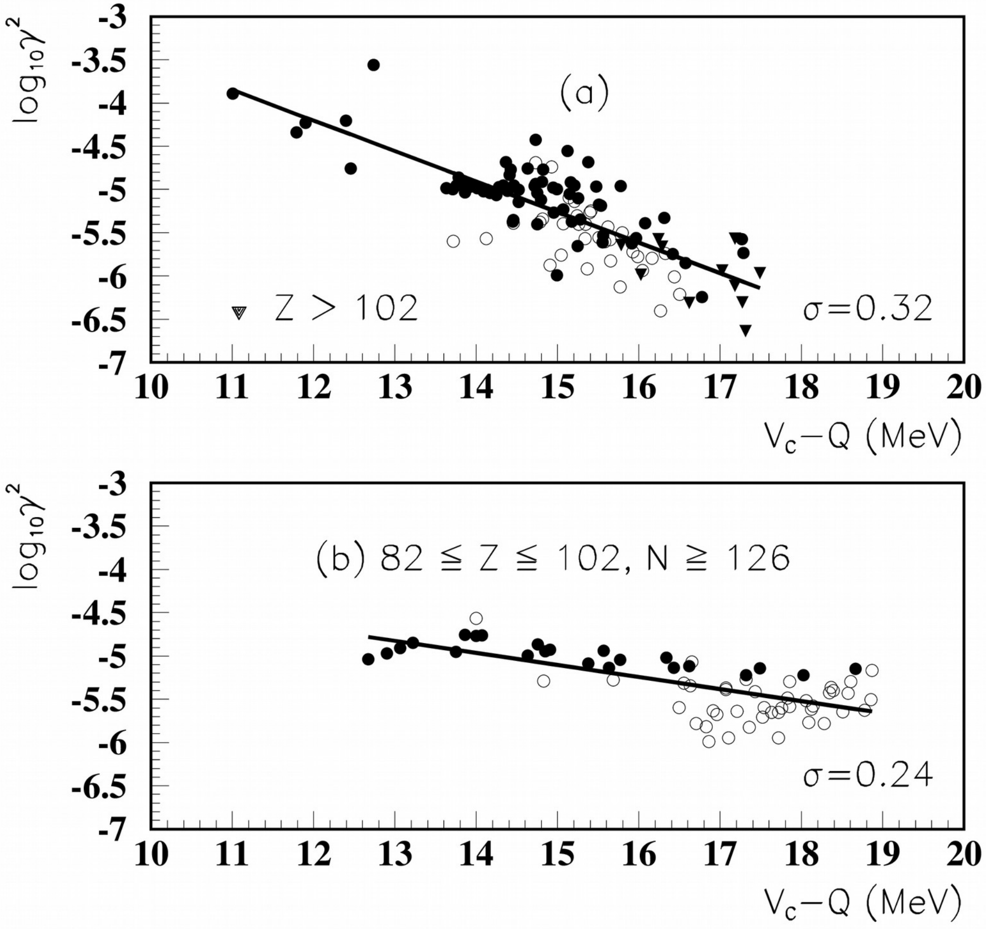
log-log dependence by using the parameters in (b)



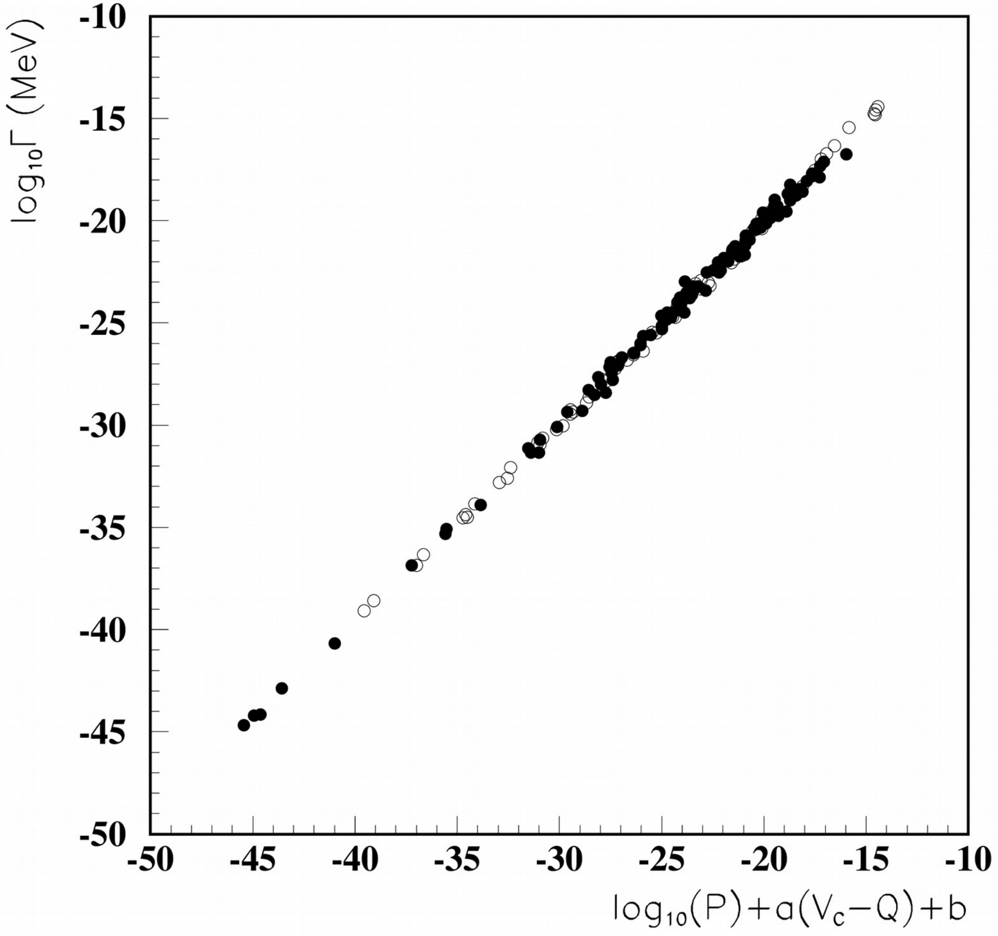
By crossing Z=68 one has a large shape transition from β ~ 0.3 up tp β ~ -0.2



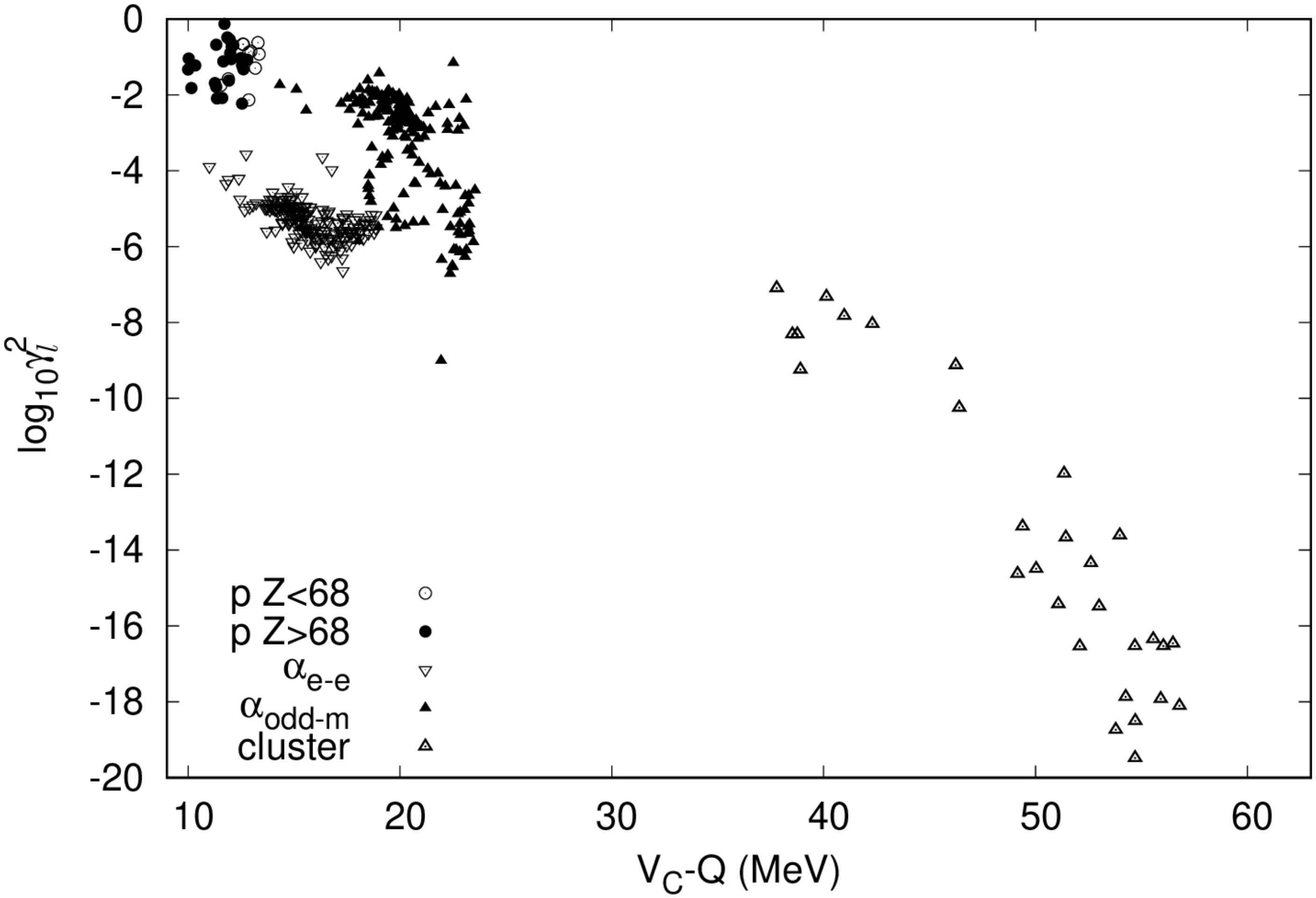
Universal law for reduced widths is also fulfilled by alpha emitters below and above ^{208}Pb
D.S. Delion, A. Dumitrescu (At.Data Nucl.Data Tab, in prep.)



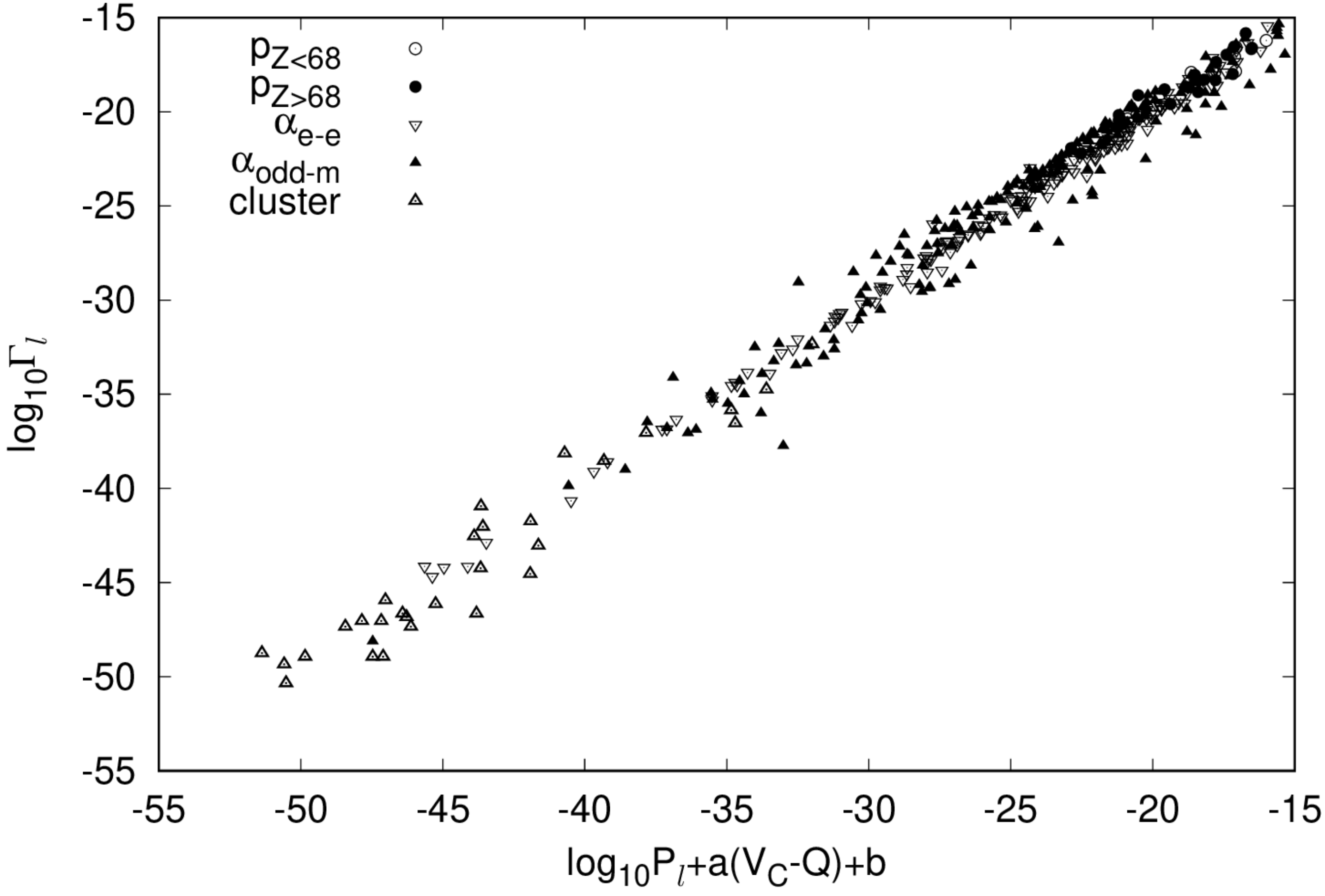
Alpha-decay log(width)-log(penetrability) dependence by using the fit parameters is equivalent to the Viola-Seaborg rule



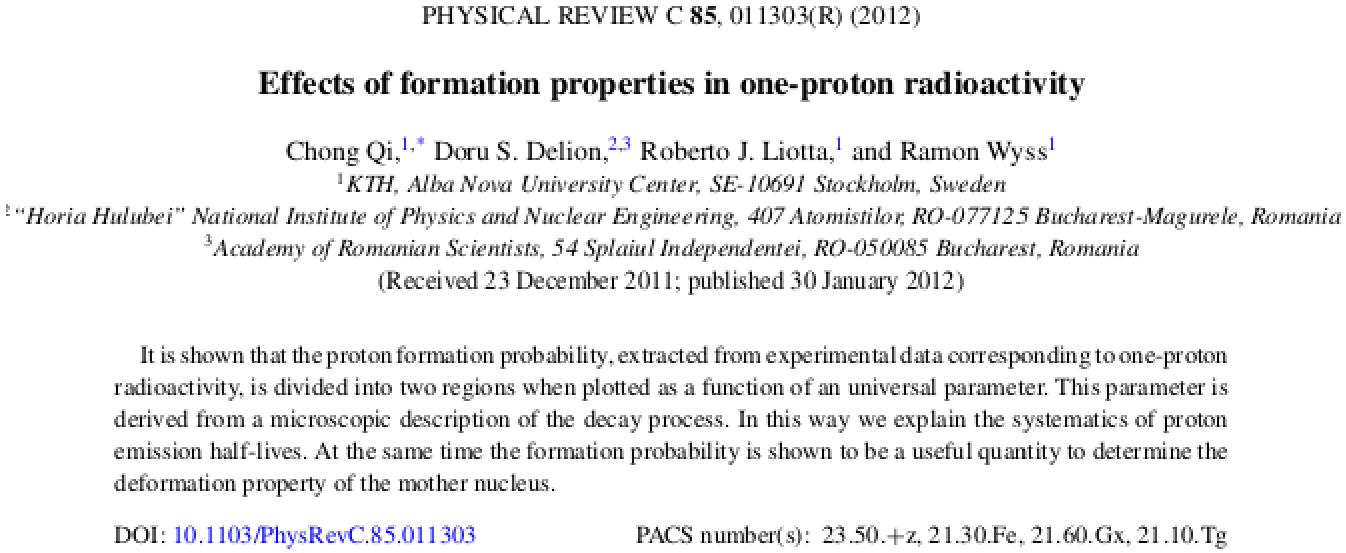
Universal law for reduced widths is valid for all emission processes: proton, alpha & cluster decays



One obtains a general log(width)-log(penetrability) dependence for all emission processes by using the corresponding fit parameters



An equivalent explanation is given by



PHYSICAL REVIEW C **85**, 011303(R) (2012)

Effects of formation properties in one-proton radioactivity

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(Received 23 December 2011; published 30 January 2012)

It is shown that the proton formation probability, extracted from experimental data corresponding to one-proton radioactivity, is divided into two regions when plotted as a function of an universal parameter. This parameter is derived from a microscopic description of the decay process. In this way we explain the systematics of proton emission half-lives. At the same time the formation probability is shown to be a useful quantity to determine the deformation property of the mother nucleus.

DOI: 10.1103/PhysRevC.85.011303 PACS number(s): 23.50.+z, 21.30.Fe, 21.60.Gx, 21.10.Tg

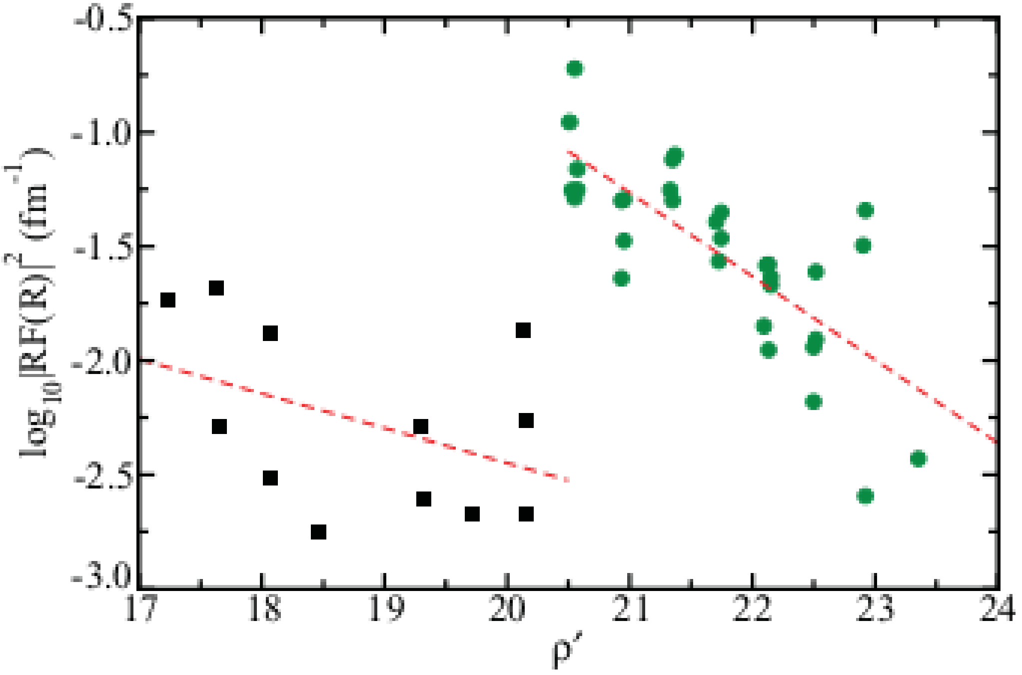
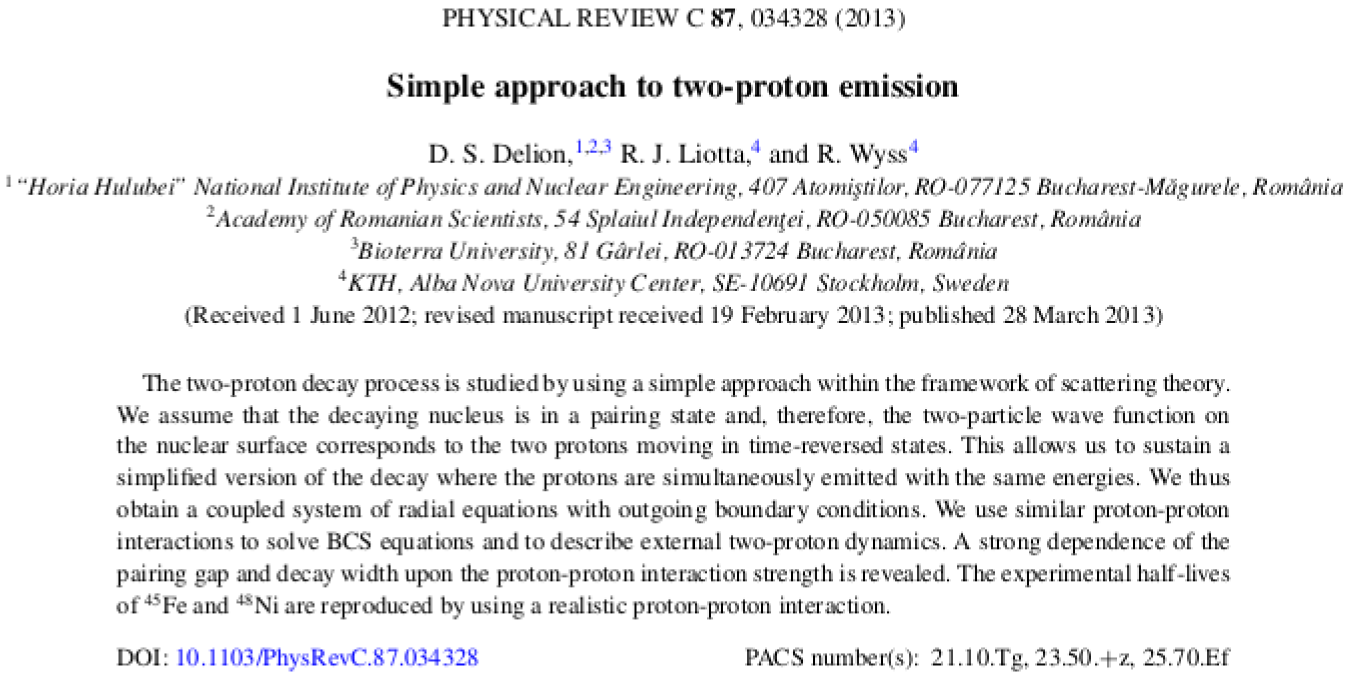


FIG. 2. (Color online) Proton-decay formation amplitudes $\log_{10}|RF(R)|^2$ extracted from experimental data as a function of ρ'. Squares correspond to nuclei with $N < 75$ ($Z \leqslant 67$) while circles are for $N \geqslant 75$ ($Z > 67$).

$$T_{1/2} = \frac{\hbar \ln 2}{\Gamma_l} = \frac{\ln 2}{\nu}\left|\frac{H_l^+(\chi,\rho)}{R\mathcal{F}_l(R)}\right|^2,$$

$$\rho' = \sqrt{AZ_pZ_d(A_d^{1/3}+A_p^{1/3})},\ A = A_dA_p/(A_d+A_p),$$

Two proton emission
from superfluid emitters



PHYSICAL REVIEW C **87**, 034328 (2013)

Simple approach to two-proton emission

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The two-proton decay process is studied by using a simple approach within the framework of scattering theory. We assume that the decaying nucleus is in a pairing state and, therefore, the two-particle wave function on the nuclear surface corresponds to the two protons moving in time-reversed states. This allows us to sustain a simplified version of the decay where the protons are simultaneously emitted with the same energies. We thus obtain a coupled system of radial equations with outgoing boundary conditions. We use similar proton-proton interactions to solve BCS equations and to describe external two-proton dynamics. A strong dependence of the pairing gap and decay width upon the proton-proton interaction strength is revealed. The experimental half-lives of ^{45}Fe and ^{48}Ni are reproduced by using a realistic proton-proton interaction.

DOI: 10.1103/PhysRevC.87.034328 PACS number(s): 21.10.Tg, 23.50.+z, 25.70.Ef

Pairing wave function is peaked on nuclear surface and around the angle φ ~ 45° ($r_1 \sim r_2$)

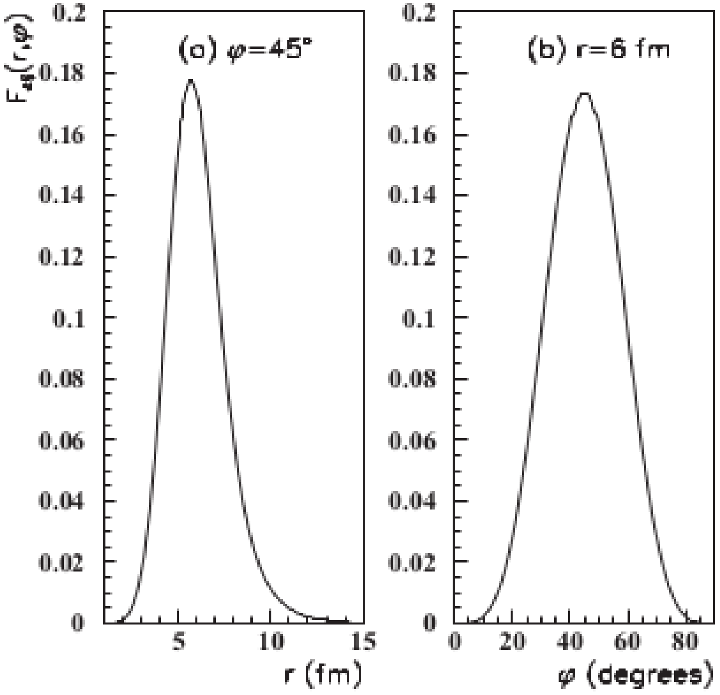


FIG. 3. (a) Two-proton radial wave function in ^{45}Fe, given by Eq. (2.7), as a function of the coordinate r for $\varphi = 45^\circ$. The parameters of the proton-proton interaction in Eq. (2.14) are $v_0 = 35$ MeV and $r_0 = 2$ fm. (b) Same as in panel (a) but as a function of the angle φ corresponding to the maximal value of the wave function at $r = 6$ fm.

$$r_1 = r\cos\varphi, \quad r_2 = r\sin\varphi,$$

$$r \in [0, \infty), \quad \varphi \in \left[0, \frac{\pi}{2}\right].$$

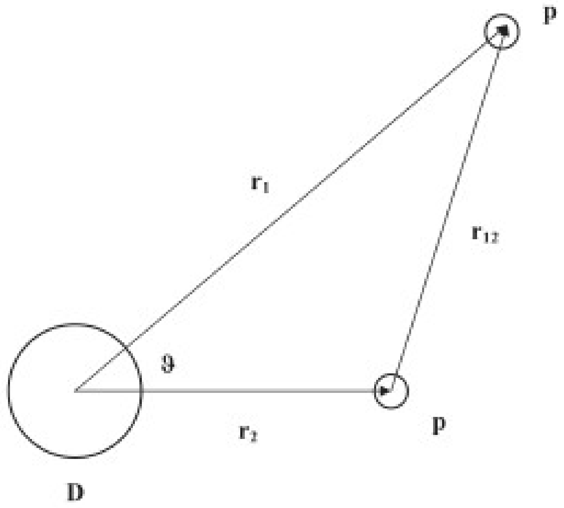


FIG. 1. The geometry of the two-proton emission.

pp interaction

$$v(r_{12}) = -v_0 e^{-(r_{12}/r_0)^2} + V_C(e^2, r_0, r_{12}).$$

We considered radial motion for a fixed angle φ The main effect on the decay width is given for $\varphi \sim 45^o$ ($r_1 \sim r_2$)

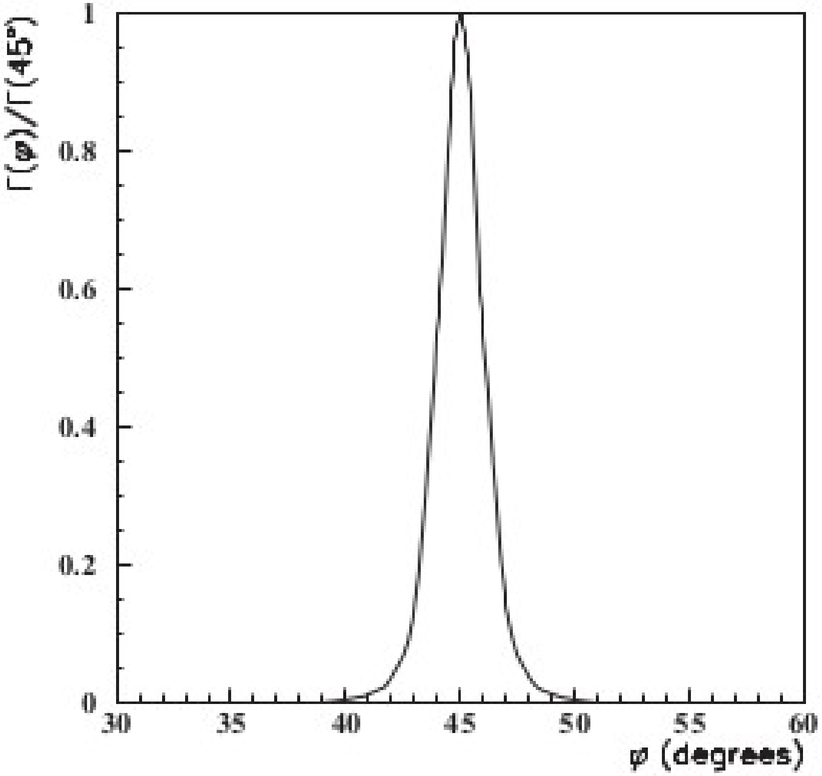


FIG. 6. The ratio of the angular-dependent width given by Eq. (2.31) and its value at $\varphi = 45^\circ$ versus the angle φ for $v_0 = 35$ MeV and $r_0 = 2$ fm.

Half life strongly depends on the pairing strength (and the pairing gap)

$$v(r_{12}) = -v_0 e^{-(r_{12}/r_0)^2} + V_C(e^2, r_0, r_{12}).$$

realistic value
is v_0=35 MeV

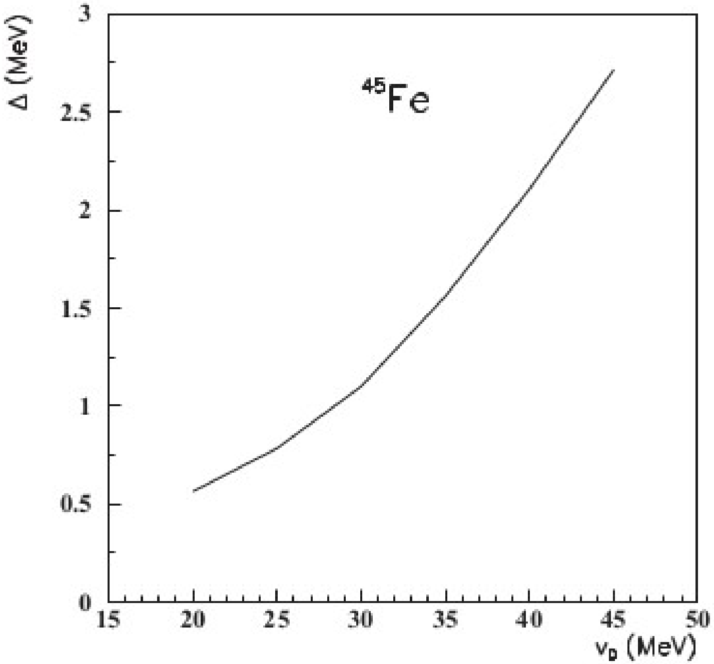


FIG. 4. Proton pairing gap versus proton-proton strength v_0 in ^{45}Fe.

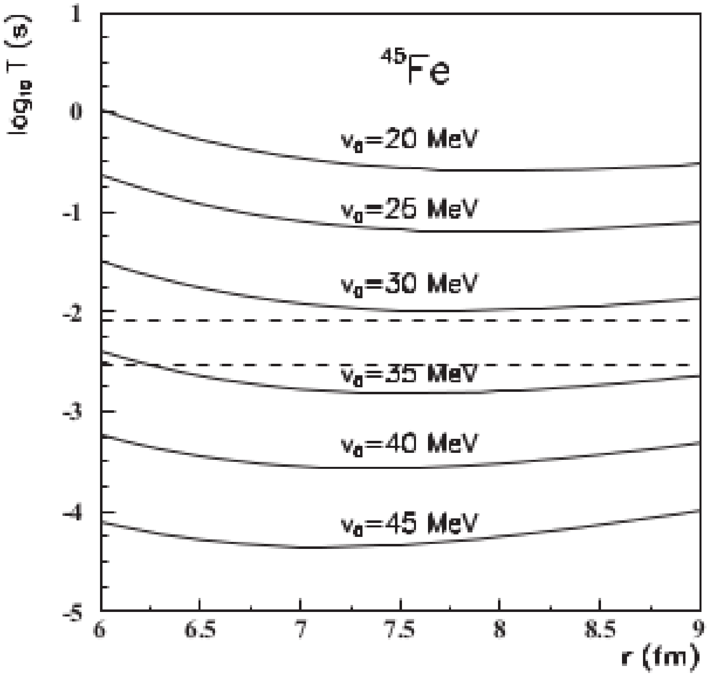
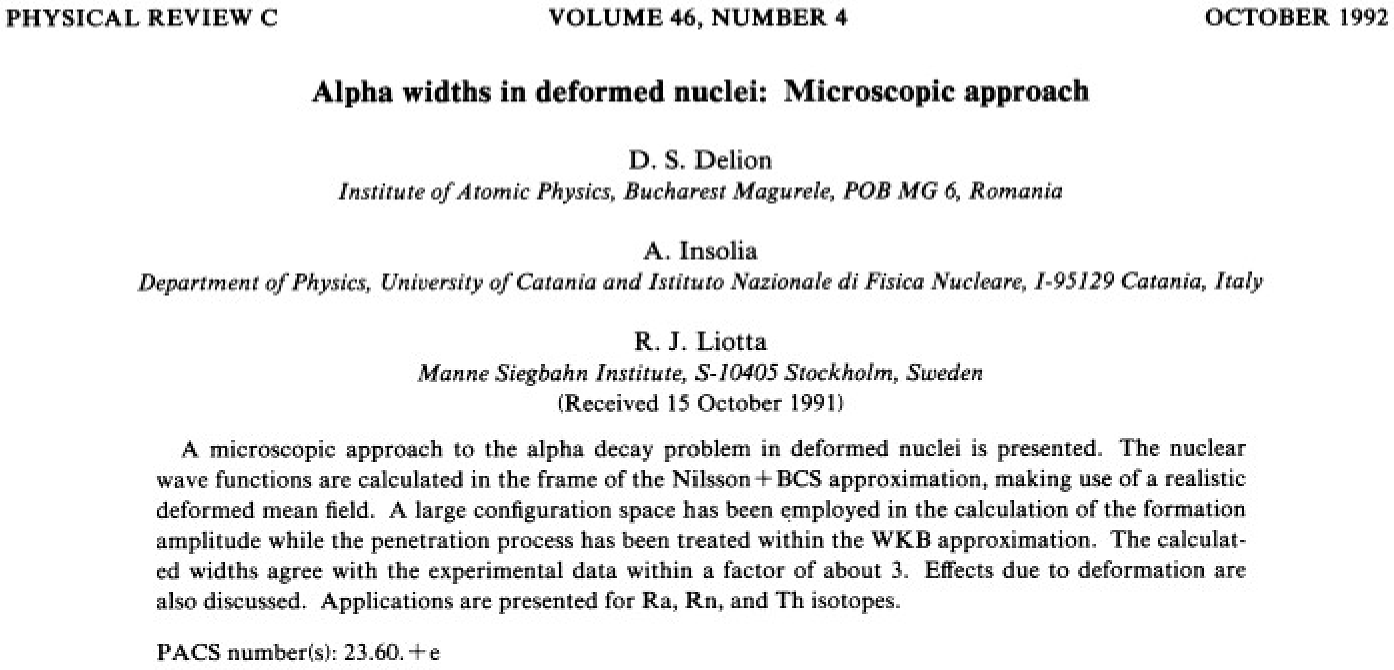


FIG. 7. Theoretical two-proton half-life for ^{45}Fe, versus the matching proton radius for various proton-proton interaction strengths v_0 in Eq. (2.14) (solid lines). The dashed lines indicate the upper and lower experimental limits.

2. Alpha decay
Microscopic description in deformed nuclei in terms of the mean field + pairing approach



PHYSICAL REVIEW C VOLUME 46, NUMBER 4 OCTOBER 1992

Alpha widths in deformed nuclei: Microscopic approach

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(Received 15 October 1991)

A microscopic approach to the alpha decay problem in deformed nuclei is presented. The nuclear wave functions are calculated in the frame of the Nilsson + BCS approximation, making use of a realistic deformed mean field. A large configuration space has been employed in the calculation of the formation amplitude while the penetration process has been treated within the WKB approximation. The calculated widths agree with the experimental data within a factor of about 3. Effects due to deformation are also discussed. Applications are presented for Ra, Rn, and Th isotopes.

PACS number(s): 23.60.+e

Formation amplitude is the overlap between parent and daughter * alpha wave functions

$$\mathscr{F}(\mathbf{R}_\alpha) = \langle \alpha D | P \rangle = \int d\mathbf{x}_\alpha d\mathbf{x}_D \left[\psi_\alpha^{(\beta_\alpha)}(\mathbf{x}_\alpha) \Psi^{(D)}(\mathbf{x}_D) \right]^* \Psi^{(P)}(\mathbf{x}_P)$$

By using the cm and relative coordinates
it becomes a superposition of ho orbitals
depending on alpha-core radius
with four times sp ho parameter 4β

$$\mathscr{F}_\alpha(\mathbf{R}) = \sum_{L_\alpha} \mathscr{F}_{L_\alpha}^{(\alpha)}(\mathbf{R}) = \sum_{L_\alpha} \sum_{N_\alpha} W(N_\alpha L_\alpha) \phi_{N_\alpha L_\alpha M_\alpha}^{(4\beta)}(\mathbf{R}).$$

where W-coefficients depend on
Nilsson expansion coefficients
and BCS amplitudes

Formation probability is peaked on the nuclear surface but the total decay width is underestimated

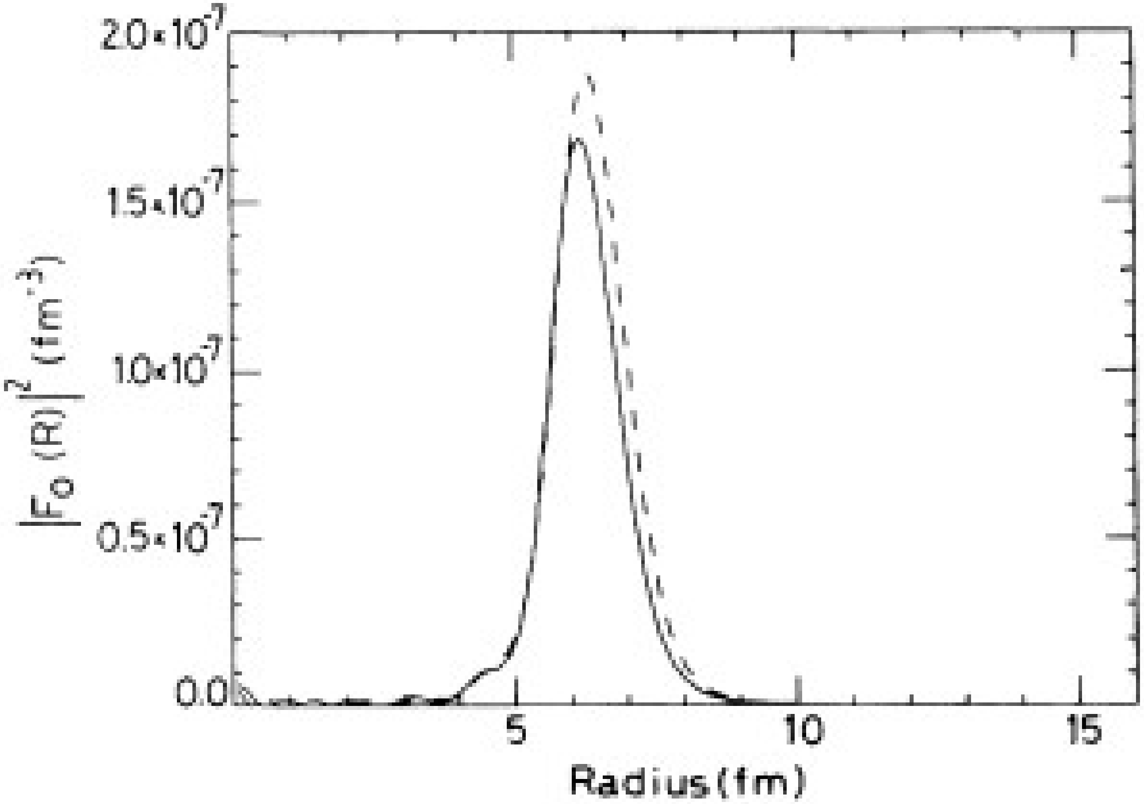
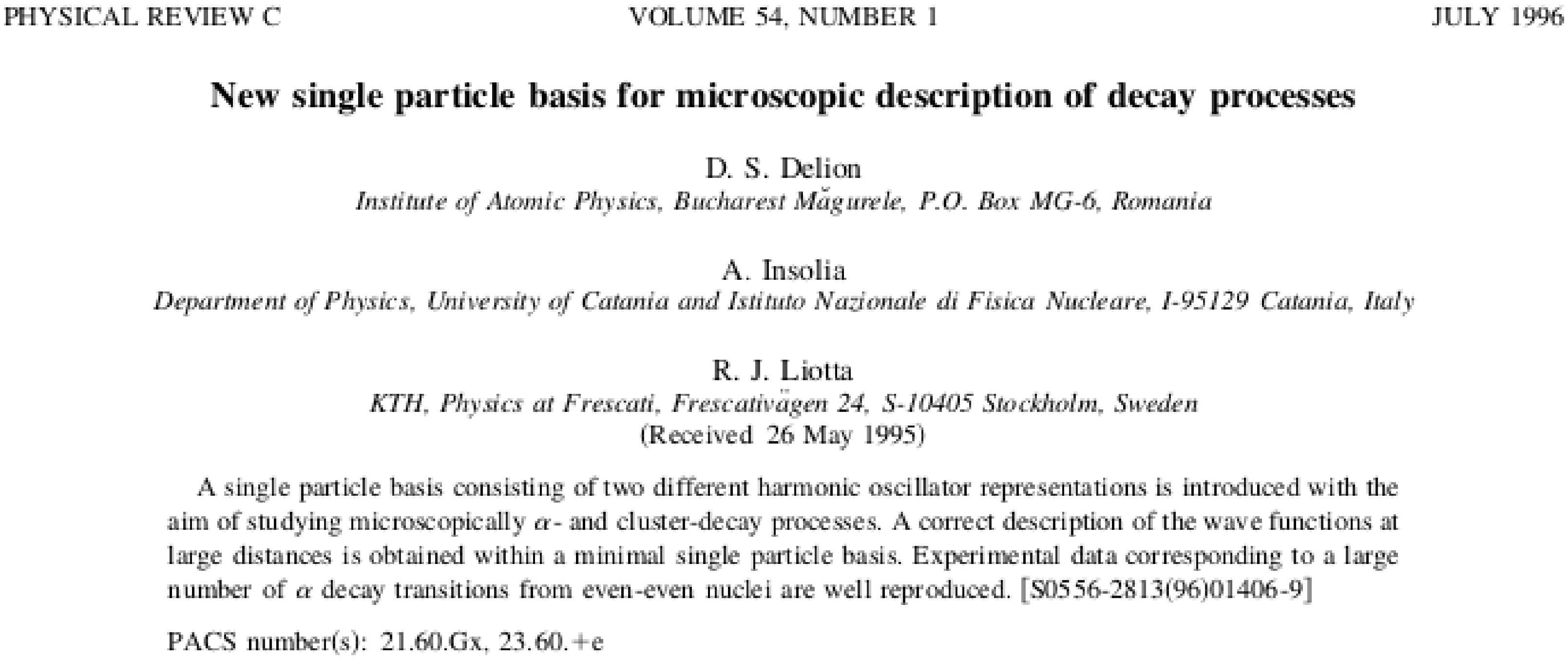


FIG. 4. Square of the alpha-formation amplitude (in fm^{-3}) vs R. The solid line corresponds to the inclusion of quadrupole deformation; the dashed line to the quadrupole + octupole case.

Microscopic description of the decay width requires an increase of the radial tail



PHYSICAL REVIEW C VOLUME 54, NUMBER 1 JULY 1996

New single particle basis for microscopic description of decay processes

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(Received 26 May 1995)

A single particle basis consisting of two different harmonic oscillator representations is introduced with the aim of studying microscopically α- and cluster-decay processes. A correct description of the wave functions at large distances is obtained within a minimal single particle basis. Experimental data corresponding to a large number of α decay transitions from even-even nuclei are well reproduced. [S0556-2813(96)01406-9]

PACS number(s): 21.60.Gx, 23.60.+e

Mixed single particle basis with two ho parameters
Alpha clustering is connected to the second part of the basis

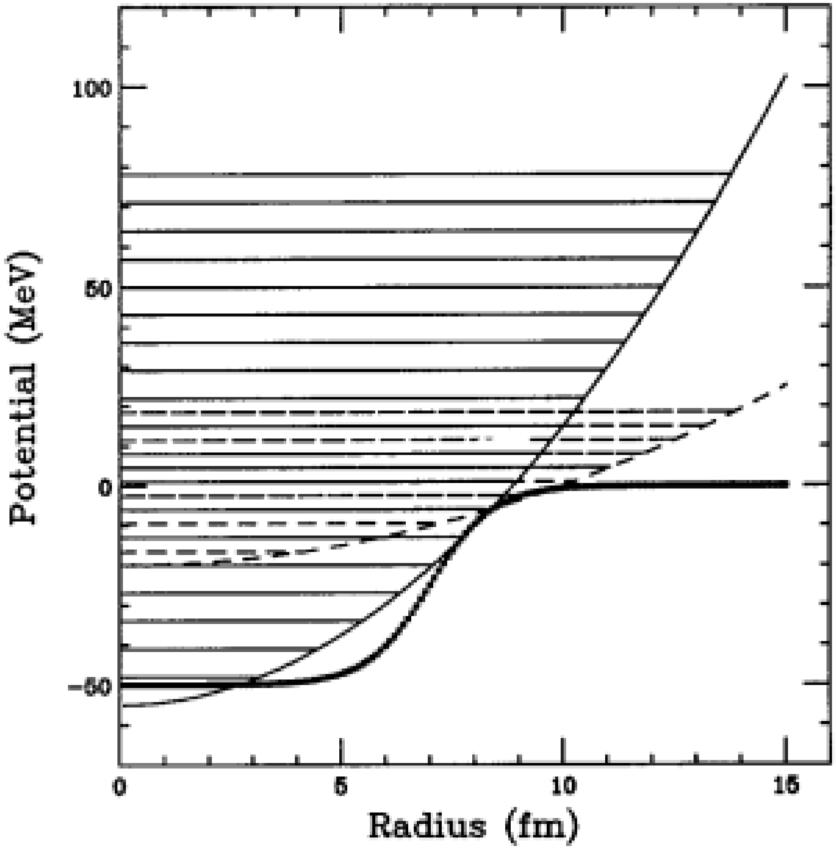


FIG. 1. The harmonic oscillator potentials that define our representation. The full line is the potential that provides the low lying shells of the basis and the dashed line the one that provides the high lying shells. The dark line is the Woods-Saxon potential.

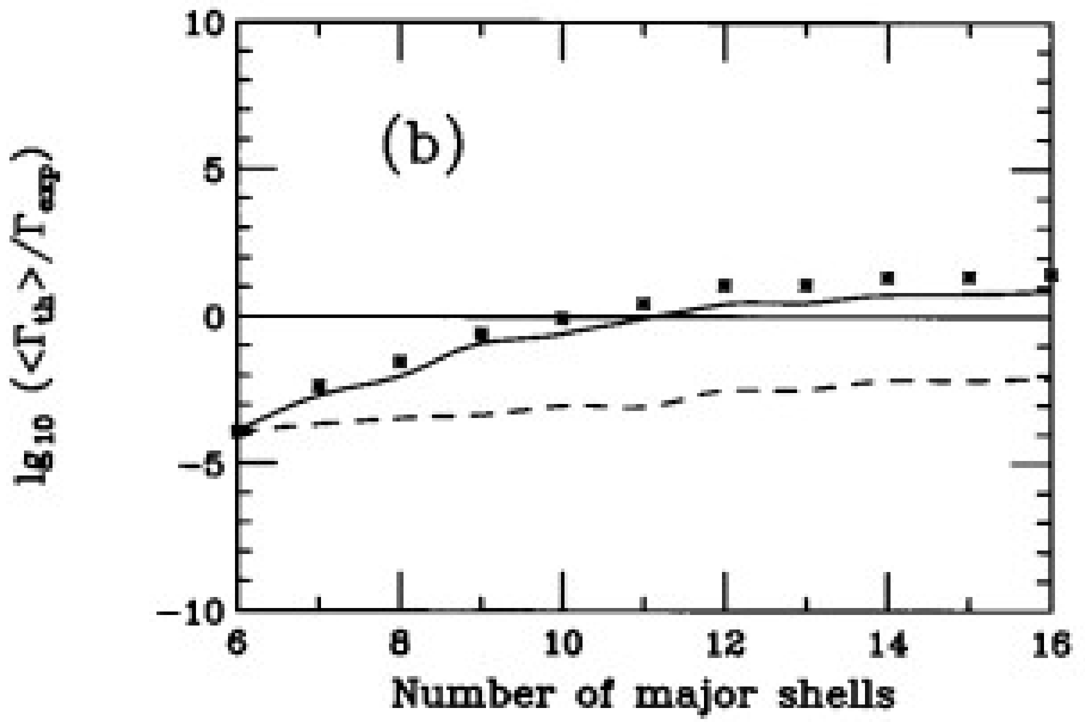
$$\psi_{Elj\Omega}(\xi)=u_{Elj}(r)[i^l Y_l(\hat{r})\chi_{1/2}(s)]_{j\Omega}$$

$$u_\alpha(r)=\sum_{2n_1+l=N_1\leq N_0} c^{(1)}_{\alpha n_1} R^{(\lambda_1)}_{n_1 l}(r)+\sum_{2n_2+l=N_2>N_0} c^{(2)}_{\alpha n_2} R^{(\lambda_2)}_{n_2 l}(r)$$

$$f_k=\frac{\lambda_k}{\lambda_0},\qquad k=1,2.$$

$$\lambda=f\lambda_0=f\frac{M_0\omega}{\hbar}$$

Saturation property of the mixed sp basis versus the number of major shells



$$\lambda = f\lambda_0 = f\frac{M_0\omega}{\hbar}$$

$$f_k = \frac{\lambda_k}{\lambda_0}, \qquad k = 1,2.$$

FIG. 4. Ratio between the theoretical and experimental decay widths calculated as in Fig. 3 as a function of (a) the parameter f_2 and (b) the number of shells N_2.

Improved description of the decay width for deformed emitters

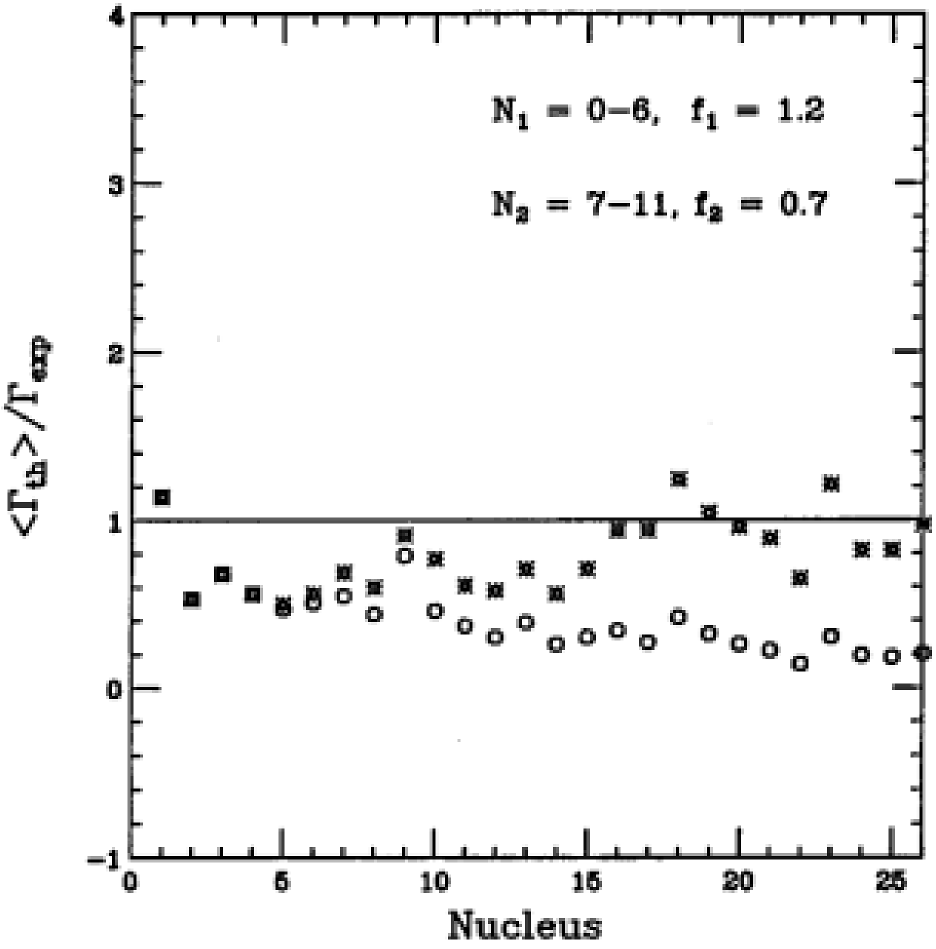


FIG. 6. Ratio between the theoretical and experimental decay widths for spherical (circles) and deformed (stars) barriers corresponding to the decays in Table I. The parameters *N* and *f* defining the minimal basis are also given.

Logarithmic derivative condition implies that the ho parameter should be proportional to the Coulomb parameter

PHYSICAL REVIEW C **69**, 044318 (2004)

Evidence for α clustering in heavy and superheavy nuclei

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(Received 8 October 2003; published 27 April 2004)

We analyze the α decay between ground states along $N-Z$ chains in deformed heavy and superheavy nuclei, by using the pairing approach. We show that the derivative of the preformation amplitude is practically a constant along any α chain, while that of the outgoing wave function changes exponentially upon the Coulomb parameter. This leads to the breakdown of the continuity equation and therefore to wrong decay widths. The behavior cannot be explained within the standard shell model. We significantly correct this deficiency by considering an α-cluster factor in the preformation amplitude, depending exponentially upon the Coulomb parameter. Thus, four-body correlations, connected with the radial shape of the preformation factor, are directly evidenced by the α-decay systematics. Moreover, this procedure, in principle, fully determines the Q value and is an important development in the α-decay theory. It also allows us to analyze the relative α-clustering structure of the emitter. It turns out that the isotopes close to the region $N>126$ and superheavy nuclei have a stronger clustering behavior. For superheavy region an additional dependence upon the number of interacting α particles is necessary.

DOI: 10.1103/PhysRevC.69.044318 PACS number(s): 21.60.Gx, 23.60.+e

Log. derivative condition is equivalent to the "plateau condition" $\gamma_1=0$

$$\log_{10}\left[\frac{\Gamma(R)}{\Gamma_{\rm exp}}\right]=\gamma_0+\gamma_1 R\,,$$

By using the log. der. cond. one obtains the slope γ_1 being proportional to the Coulomb parameter

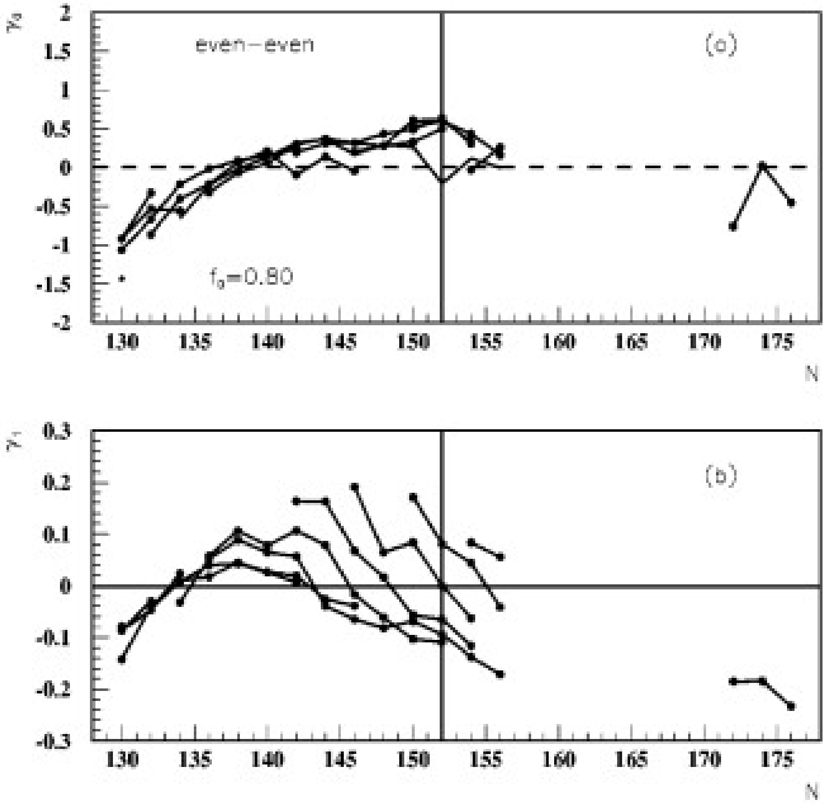
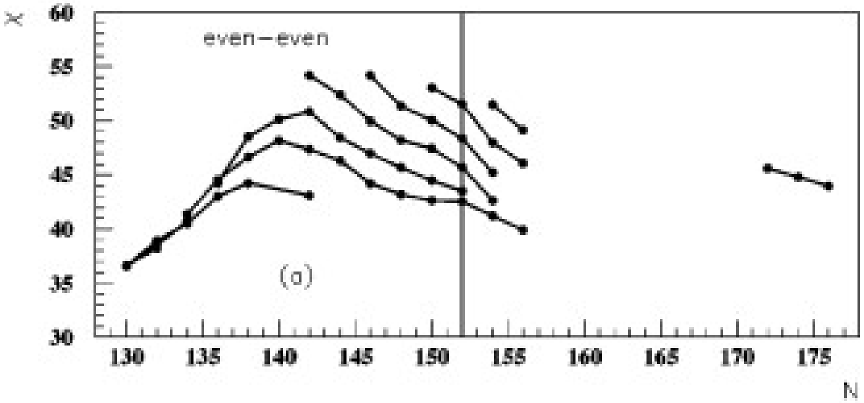


FIG. 7. (a) The parameter γ_0 vs the neutron number for different even-even α-chains in Table II. The preformation parameters are f_0=0.8, $P_{\rm min}$=0.025. (b) The same as in (a), but for the slope parameter γ_1.



$$\begin{aligned}\lg(\Gamma) &= lg(P)+lg(2\gamma^2)\\ &= a\chi-b\beta\sim const\end{aligned}$$

By using an ho parameter proportional to the Coulomb parameter we improve both the decay width description $\gamma_0=0$ and "plateau condition" $\gamma_1=0$

$$\beta - \beta_m = (f - f_m)\beta_N = f_1(\chi - \chi_m)\beta_N .$$

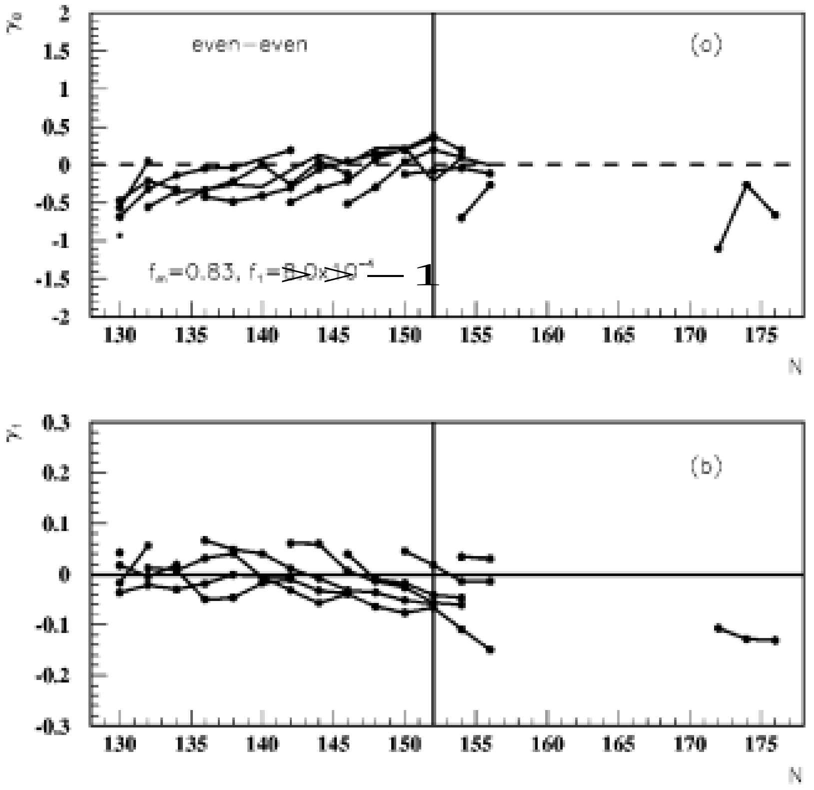
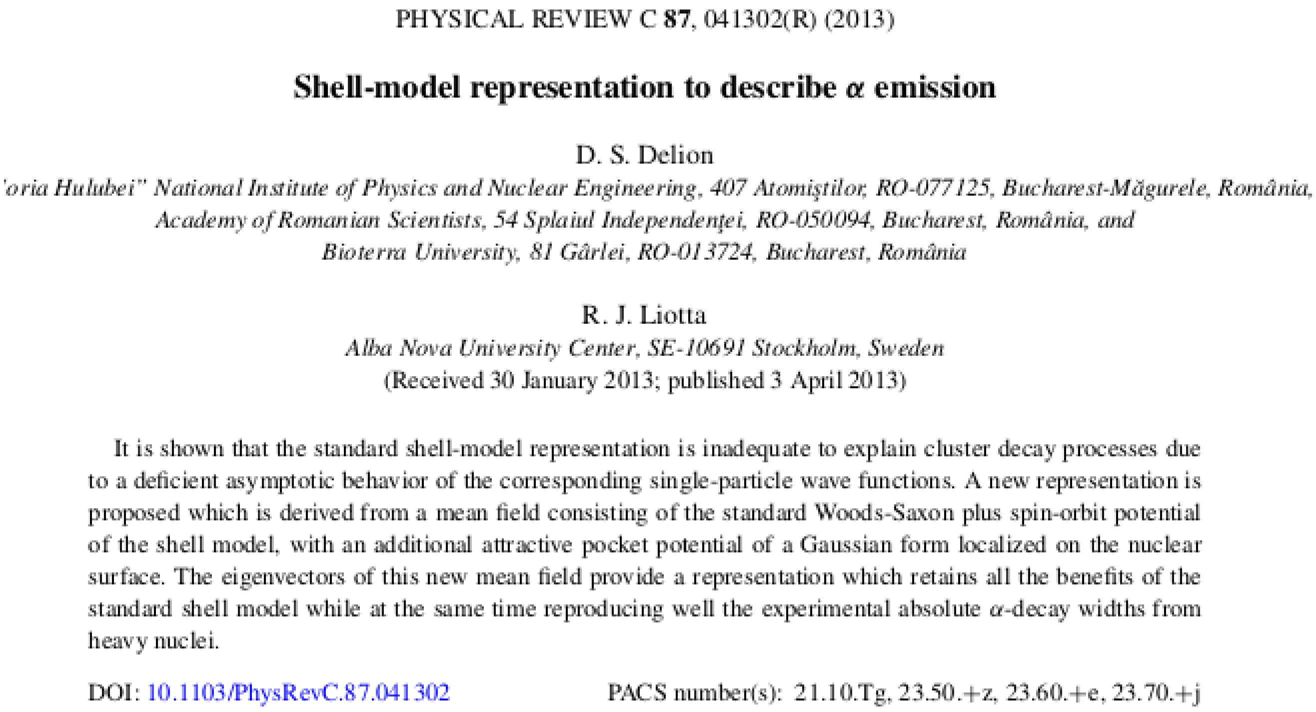


FIG. 10. (a) The parameter γ_0 vs the neutron number for different even-even α-chains in Table II. The preformation parameters are f_m=0.83, f_1=8.0 10^{-4}, P_{min}=0.025. (b) The same as in (a), but for the slope parameter γ_1.

By including beyond mean field correlations on the nuclear surface one obtains in a natural way larger sp tails



PHYSICAL REVIEW C **87**, 041302(R) (2013)

Shell-model representation to describe α emission

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(Received 30 January 2013; published 3 April 2013)

It is shown that the standard shell-model representation is inadequate to explain cluster decay processes due to a deficient asymptotic behavior of the corresponding single-particle wave functions. A new representation is proposed which is derived from a mean field consisting of the standard Woods-Saxon plus spin-orbit potential of the shell model, with an additional attractive pocket potential of a Gaussian form localized on the nuclear surface. The eigenvectors of this new mean field provide a representation which retains all the benefits of the standard shell model while at the same time reproducing well the experimental absolute α-decay widths from heavy nuclei.

DOI: 10.1103/PhysRevC.87.041302 PACS number(s): 21.10.Tg, 23.50.+z, 23.60.+e, 23.70.+j

Single particle mean field with alpha-like correlations The potential pocket corresponds to the peak of the microscopic alpha formation amplitude

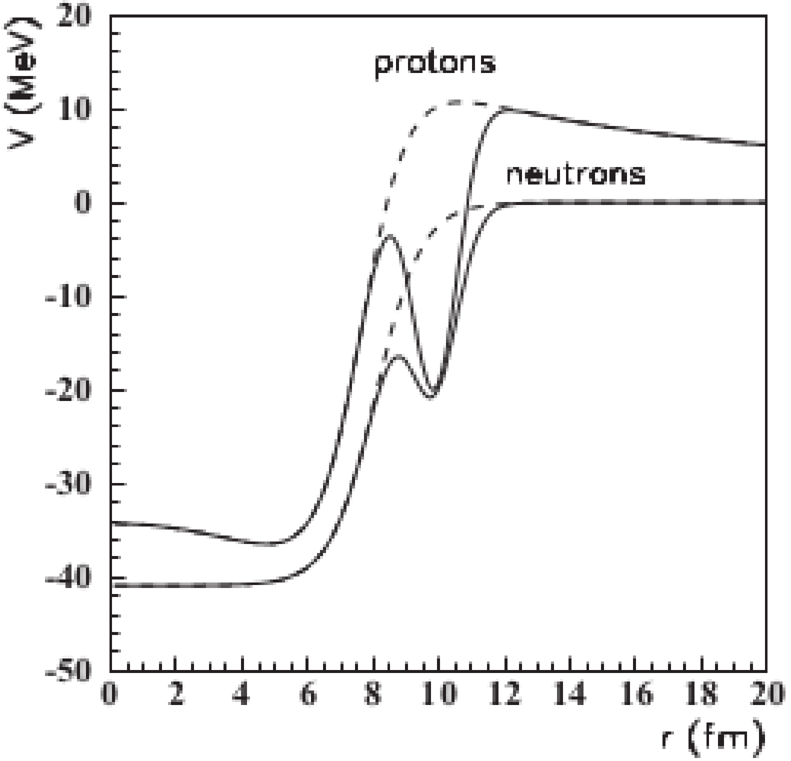
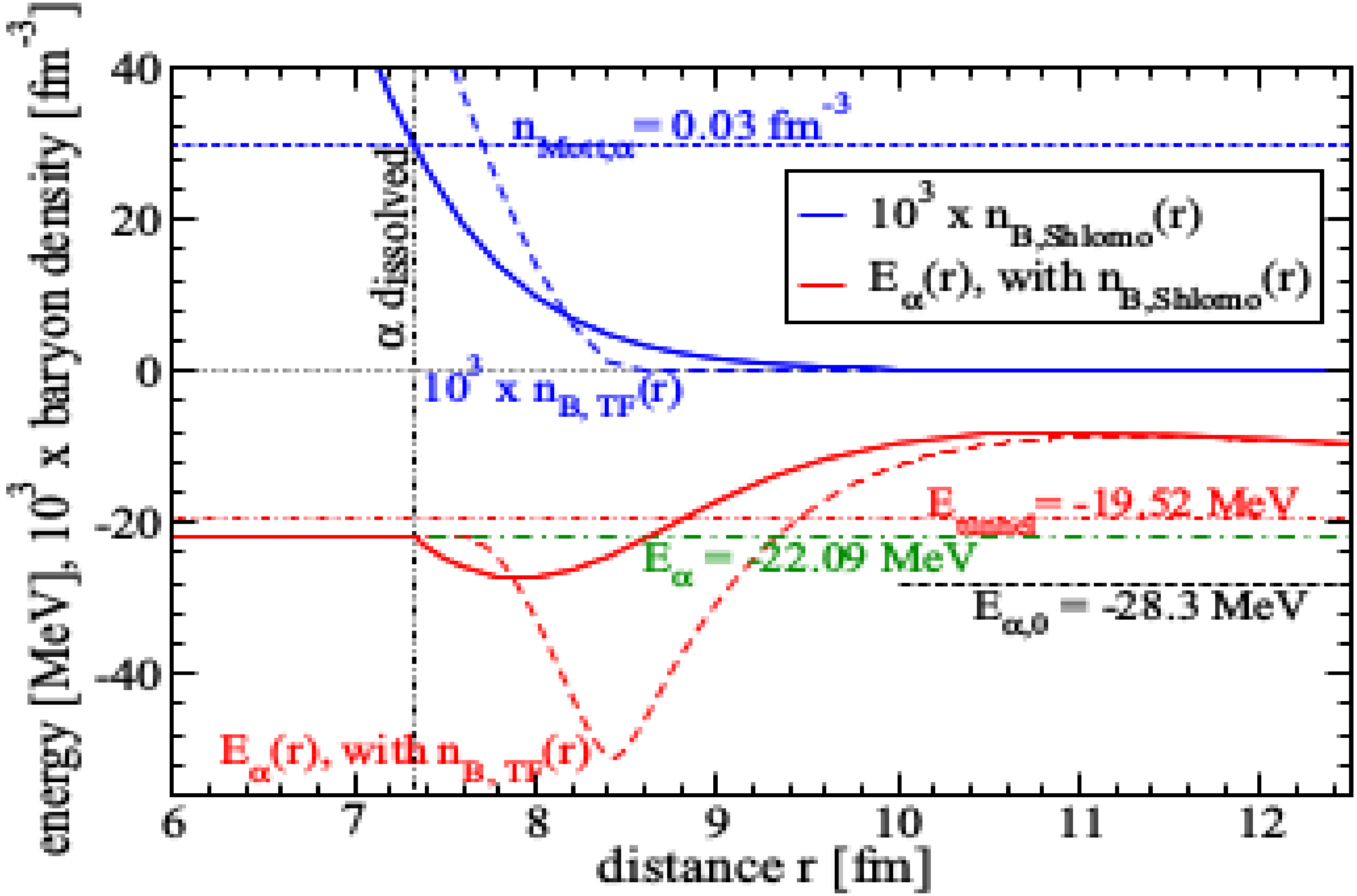


FIG. 2. Proton and neutron potentials [Eq. (9)] in ^{216}Rn (solid lines) and the corresponding Woods-Saxon mean-field potentials [19] (dashed lines). The cluster parts are as in Eq. (9) with parameters $V^n_{\rm clus} - V^p_{\rm clus} = V_C$, $b = 1$ fm, and $r_c = 1.3(A^{1/3} + 4^{1/3})$ fm.

This picture is confirmed by microscopic calculations
G. Roepke, et.al., Phys. Rev. C 90, 034304 (2014)



Pair formation amplitudes are enhanced by surface alpha-like correlations (a)

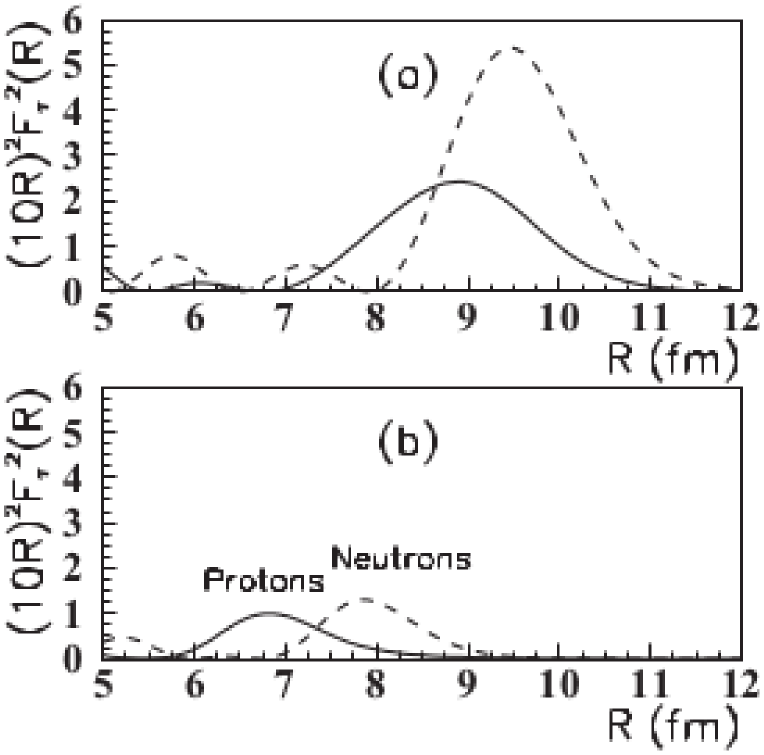


FIG. 5. Proton (solid lines) and neutron (dashed lines) pairing formation probabilities [Eq. (8)] as functions of the c.m. radius corresponding to the decay process $^{220}\mathrm{Ra} \to {}^{216}\mathrm{Rn} + \alpha$. The pocket potential parameters satisfy the conditions (a) $V^n_{\rm clus} = V^p_{\rm clus} + V_C$ and (b) $V^p_{\rm clus} = V^n_{\rm clus} = 0$.

Decay width is strongly enhanced by surface alpha-like correlations and weakly depends on cm radius (a)

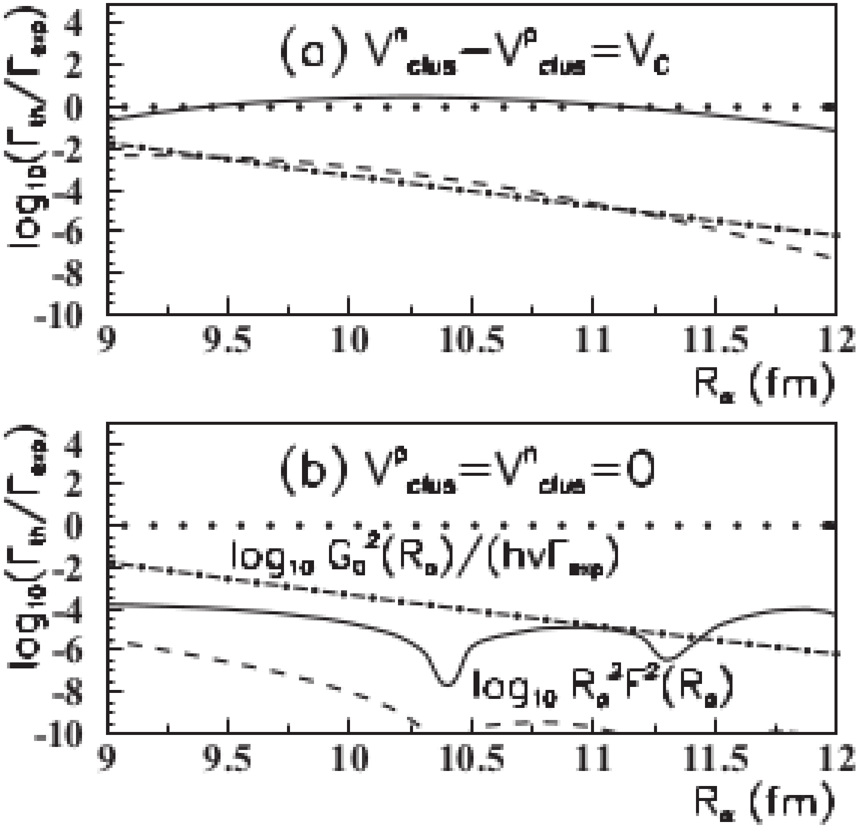
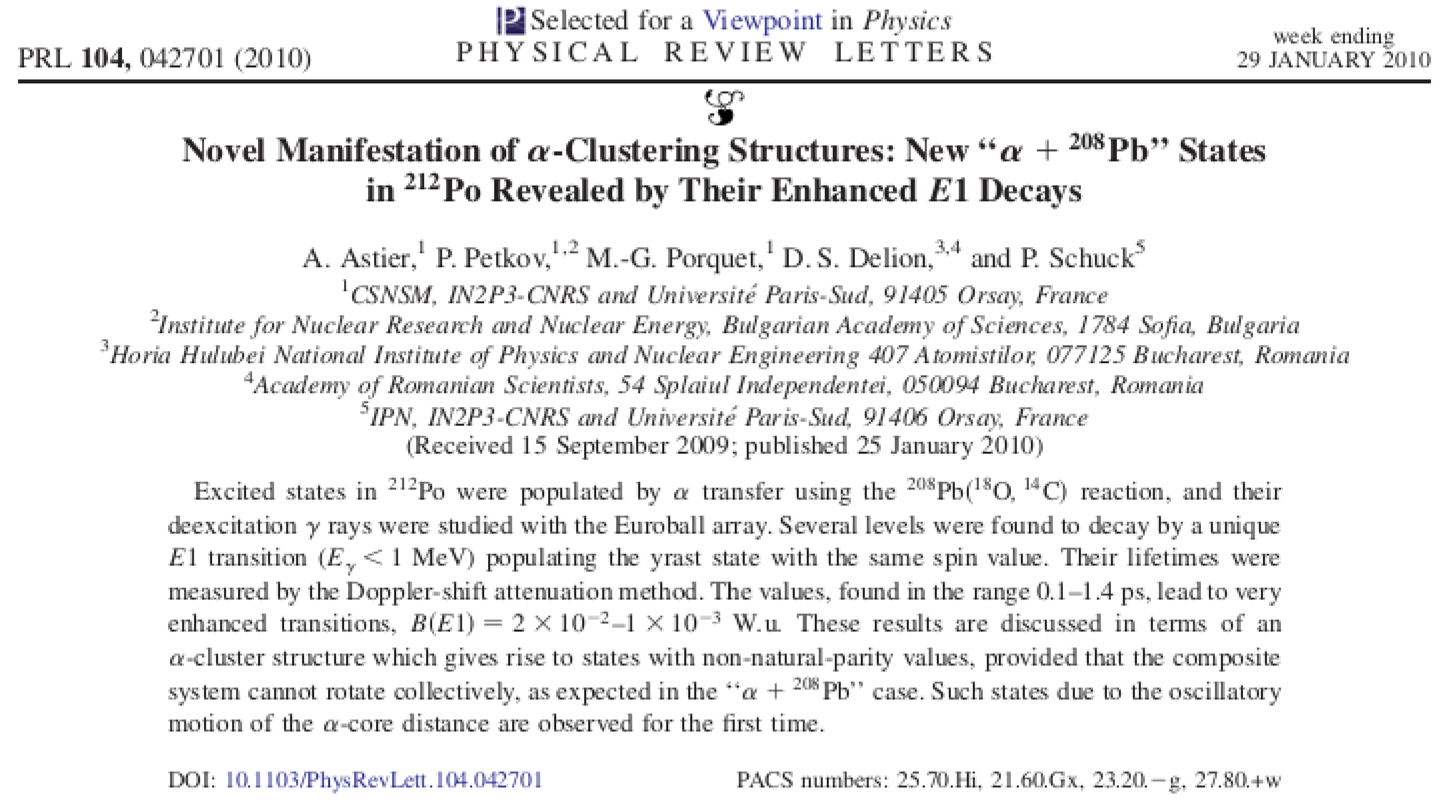


FIG. 6. Logarithm of the theoretical decay width divided by the corresponding experimental value as a function of the matching radius for $^{220}\mathrm{Ra} \rightarrow {}^{216}\mathrm{Rn} + \alpha$ (solid line). The first term in Eq. (10) is given by a dashed line, and the second one by a dot-dashed line.

This approach enabled the description of enhanced E1 transitions from un-natural parity states $2^-,4^-,6^-$ recently evidenced in ^{212}Po



Selected for a Viewpoint in *Physics*
PRL **104,** 042701 (2010) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2010

Novel Manifestation of α-Clustering Structures: New "α + ^{208}Pb" States in ^{212}Po Revealed by Their Enhanced $E1$ Decays

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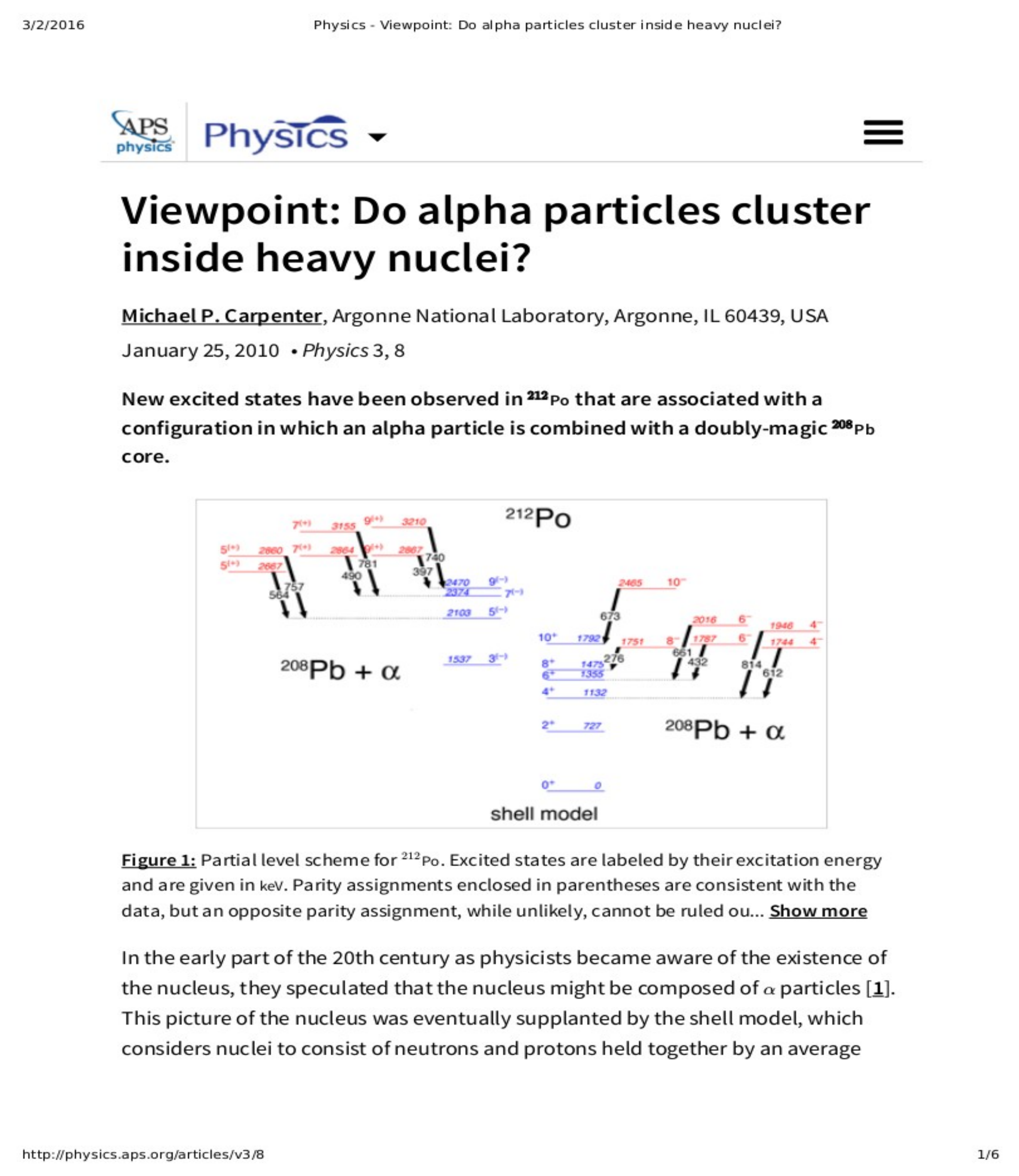
(Received 15 September 2009; published 25 January 2010)

Excited states in ^{212}Po were populated by α transfer using the ^{208}Pb(^{18}O, ^{14}C) reaction, and their deexcitation γ rays were studied with the Euroball array. Several levels were found to decay by a unique $E1$ transition ($E_\gamma < 1$ MeV) populating the yrast state with the same spin value. Their lifetimes were measured by the Doppler-shift attenuation method. The values, found in the range 0.1–1.4 ps, lead to very enhanced transitions, $B(E1) = 2 \times 10^{-2}$–1×10^{-3} W.u. These results are discussed in terms of an α-cluster structure which gives rise to states with non-natural-parity values, provided that the composite system cannot rotate collectively, as expected in the "α + ^{208}Pb" case. Such states due to the oscillatory motion of the α-core distance are observed for the first time.

DOI: 10.1103/PhysRevLett.104.042701 PACS numbers: 25.70.Hi, 21.60.Gx, 23.20.−g, 27.80.+w



Viewpoint: Do alpha particles cluster inside heavy nuclei?

Michael P. Carpenter, Argonne National Laboratory, Argonne, IL 60439, USA

January 25, 2010 • *Physics* 3, 8

New excited states have been observed in ^{212}Po that are associated with a configuration in which an alpha particle is combined with a doubly-magic ^{208}Pb core.

Figure 1: Partial level scheme for ^{212}Po. Excited states are labeled by their excitation energy and are given in keV. Parity assignments enclosed in parentheses are consistent with the data, but an opposite parity assignment, while unlikely, cannot be ruled ou… **Show more**

In the early part of the 20th century as physicists became aware of the existence of the nucleus, they speculated that the nucleus might be composed of α particles [1]. This picture of the nucleus was eventually supplanted by the shell model, which considers nuclei to consist of neutrons and protons held together by an average

PHYSICAL REVIEW C **85**, 064306 (2012)

Shell model plus cluster description of negative parity states in ^{212}Po

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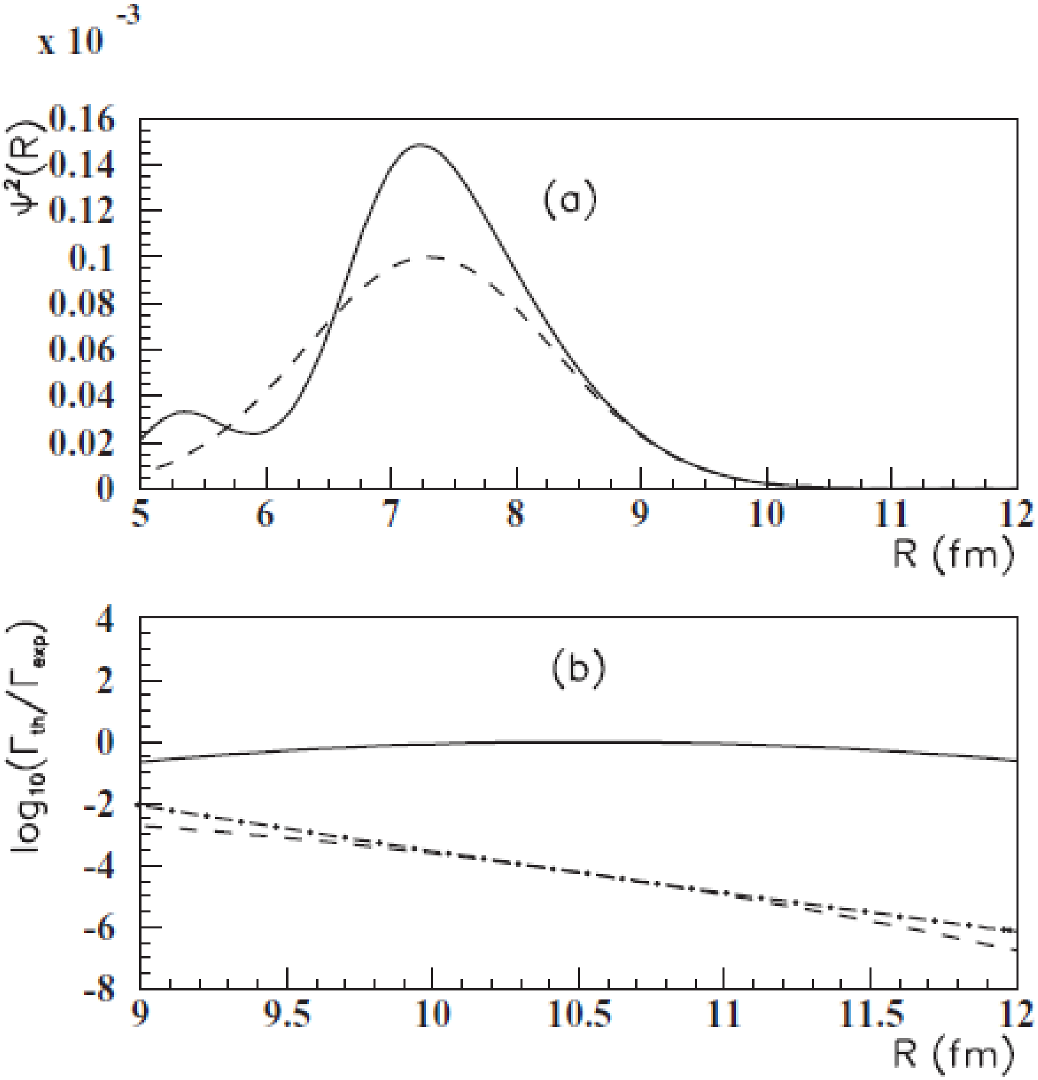
The intraband electromagnetic transitions in ^{210}Po and ^{210}Pb are well described within the shell model approach. In contrast, similar transitions in ^{212}Po are one order of magnitude smaller than the experimental values, suggesting the existence of an α-cluster component in the structure of this nucleus. To probe this assumption we introduced Gaussian-like components in the single-particle orbitals. We thus obtained an enhancement of intraband transitions, as well as a proper description of the absolute α-decay width in ^{212}Po. We analyzed the recently measured unnatural parity states I^- in ^{212}Po in terms of the collective octupole excitation in ^{208}Pb coupled to positive parity states in ^{210}Pb. They are connected by relatively large dipole transitions to yrast positive natural parity states. We described $E1$ transitions by using the same α-cluster component and an effective neutron dipole charge $e_\nu = -eZ/A$. $B(E2)$ values and absolute α-decay width in ^{212}Po are simultaneously described within the shell model plus a cluster component depending upon one free strength parameter.

DOI: 10.1103/PhysRevC.85.064306 PACS number(s): 21.60.Jz, 23.20.Js, 23.60.+e, 27.80.+w

Surface α-clustering in ^{212}Po explains decay width between ground states



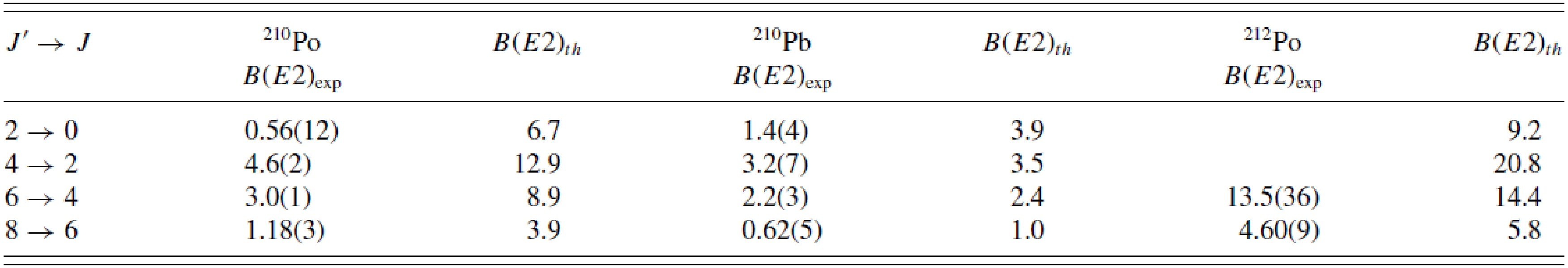
Formation probability versus cm radius
total: solid line
cluster comp: dashes

Log (width / exp.) versus cm radius

The same cluster amplitude ≈ 0.3 explains B(Eλ) values and absolute α-decay width

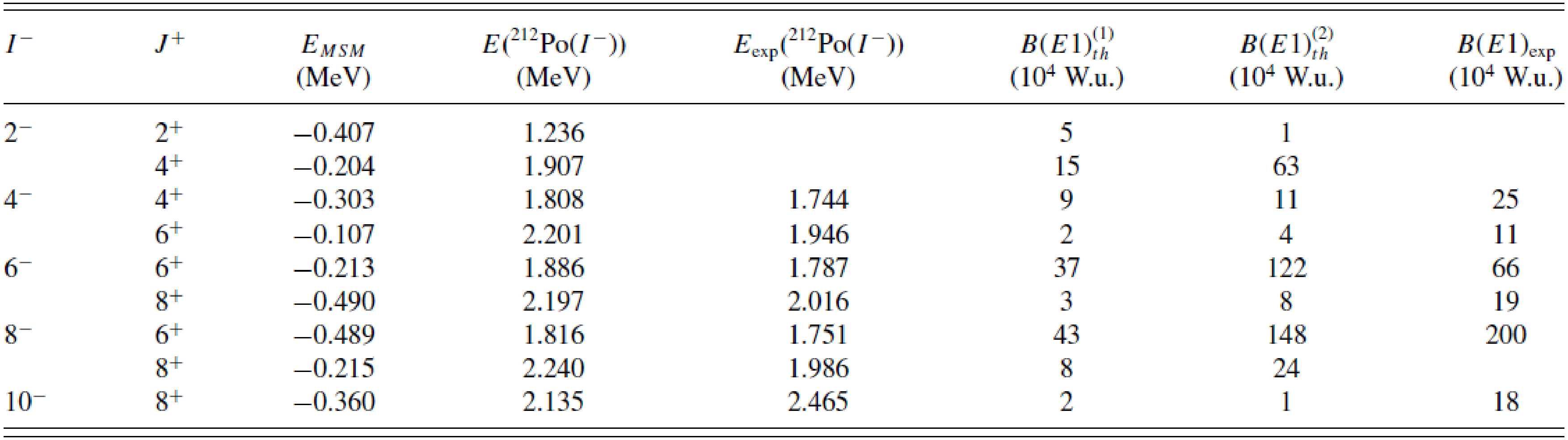
Surface α-clustering term with the amplitude ≈ 0.3 explains large electromagnetic E1 transitions in ^{212}Po

B(E2:J+2→J)-values



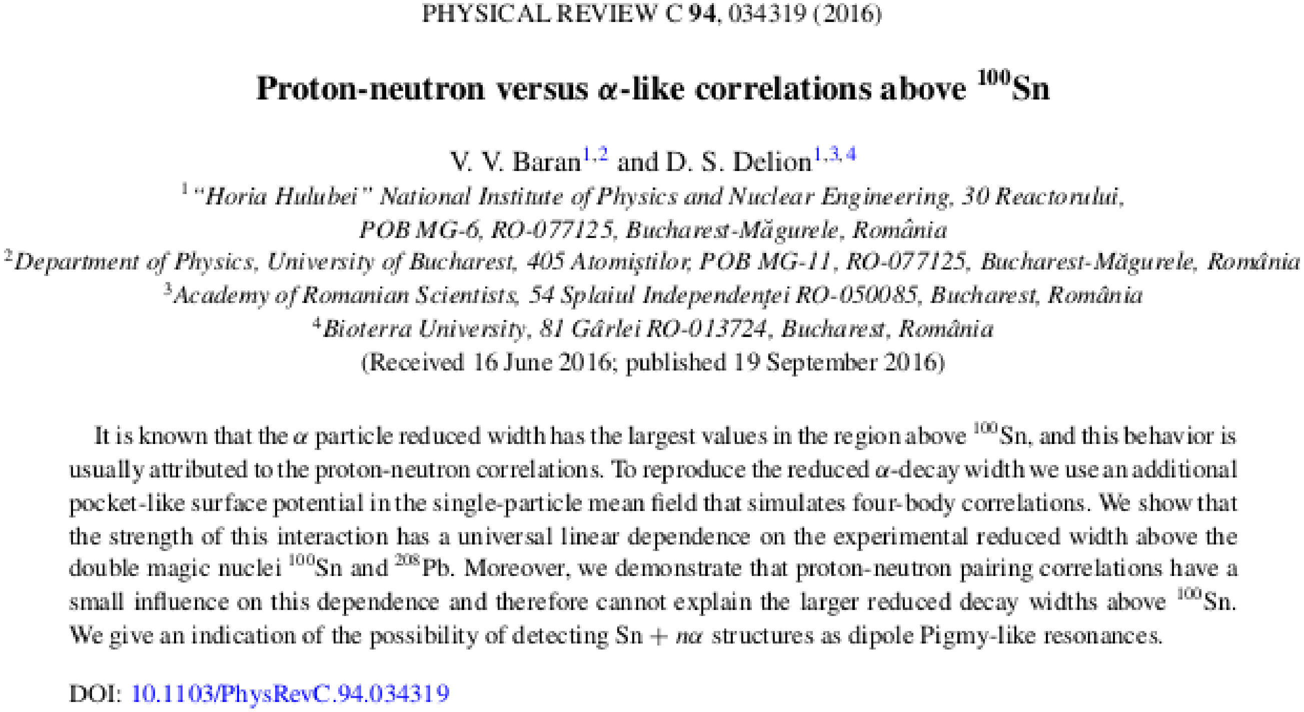
$J' \to J$	^{210}Po $B(E2)_{\mathrm{exp}}$	$B(E2)_{th}$	^{210}Pb $B(E2)_{\mathrm{exp}}$	$B(E2)_{th}$	^{212}Po $B(E2)_{\mathrm{exp}}$	$B(E2)_{th}$
$2 \to 0$	0.56(12)	6.7	1.4(4)	3.9		9.2
$4 \to 2$	4.6(2)	12.9	3.2(7)	3.5		20.8
$6 \to 4$	3.0(1)	8.9	2.2(3)	2.4	13.5(36)	14.4
$8 \to 6$	1.18(3)	3.9	0.62(5)	1.0	4.60(9)	5.8

B(E1:I⁻→J⁺)-values



I^-	J^+	E_{MSM} (MeV)	$E(^{212}\mathrm{Po}(I^-))$ (MeV)	$E_{\mathrm{exp}}(^{212}\mathrm{Po}(I^-))$ (MeV)	$B(E1)^{(1)}_{th}$ (10^4 W.u.)	$B(E1)^{(2)}_{th}$ (10^4 W.u.)	$B(E1)_{\mathrm{exp}}$ (10^4 W.u.)
2^-	2^+	−0.407	1.236		5	1	
	4^+	−0.204	1.907		15	63	
4^-	4^+	−0.303	1.808	1.744	9	11	25
	6^+	−0.107	2.201	1.946	2	4	11
6^-	6^+	−0.213	1.886	1.787	37	122	66
	8^+	−0.490	2.197	2.016	3	8	19
8^-	6^+	−0.489	1.816	1.751	43	148	200
	8^+	−0.215	2.240	1.986	8	24	
10^-	8^+	−0.360	2.135	2.465	2	1	18

Surface alpha-like correlations have an universal behavior for alpha decays



PHYSICAL REVIEW C **94**, 034319 (2016)

Proton-neutron versus α-like correlations above ^{100}Sn

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It is known that the α particle reduced width has the largest values in the region above ^{100}Sn, and this behavior is usually attributed to the proton-neutron correlations. To reproduce the reduced α-decay width we use an additional pocket-like surface potential in the single-particle mean field that simulates four-body correlations. We show that the strength of this interaction has a universal linear dependence on the experimental reduced width above the double magic nuclei ^{100}Sn and ^{208}Pb. Moreover, we demonstrate that proton-neutron pairing correlations have a small influence on this dependence and therefore cannot explain the larger reduced decay widths above ^{100}Sn. We give an indication of the possibility of detecting Sn + $n\alpha$ structures as dipole Pigmy-like resonances.

DOI: 10.1103/PhysRevC.94.034319

Systematics of the surface clustering strength versus the reduced width is given by similar dependencies for Z>50 and Z>82 regions

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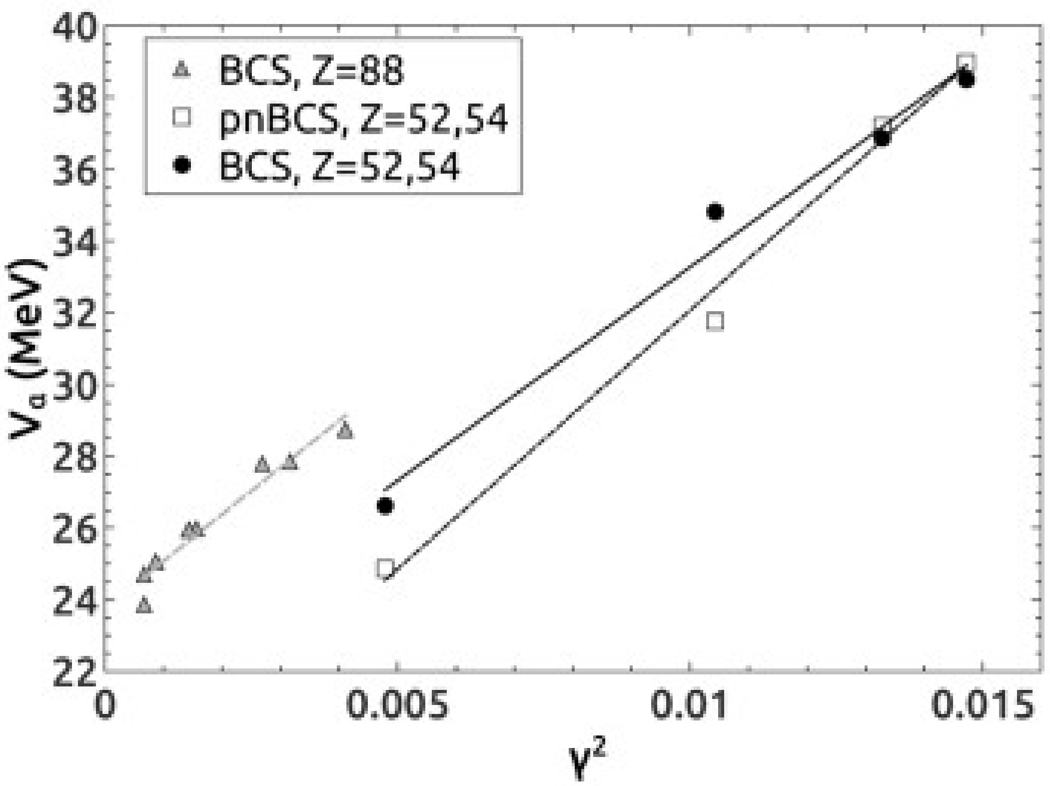
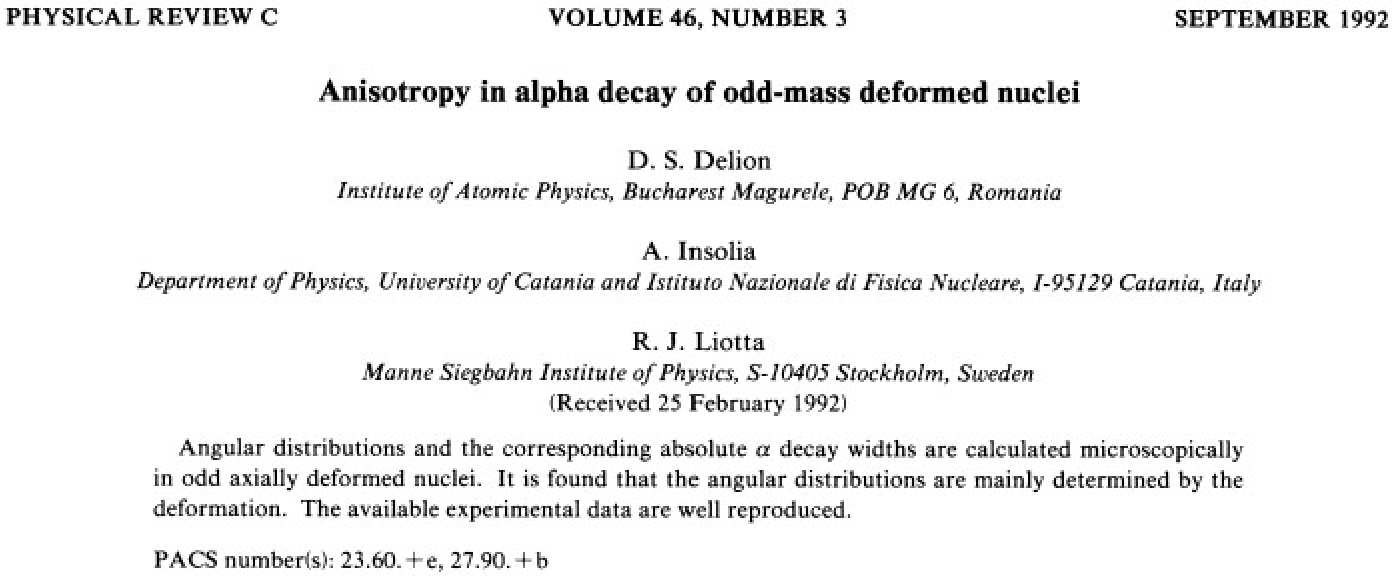


FIG. 6. The strength of the α-clustering additional part of the mean-field potential V_α versus the reduced width.

Anisotropy of the alpha emission in deformed odd-mass nuclei



PHYSICAL REVIEW C VOLUME 46, NUMBER 3 SEPTEMBER 1992

Anisotropy in alpha decay of odd-mass deformed nuclei

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(Received 25 February 1992)

Angular distributions and the corresponding absolute α decay widths are calculated microscopically in odd axially deformed nuclei. It is found that the angular distributions are mainly determined by the deformation. The available experimental data are well reproduced.

PACS number(s): 23.60.+e, 27.90.+b

Anisotropy is enhanced by the quadrupole deformation

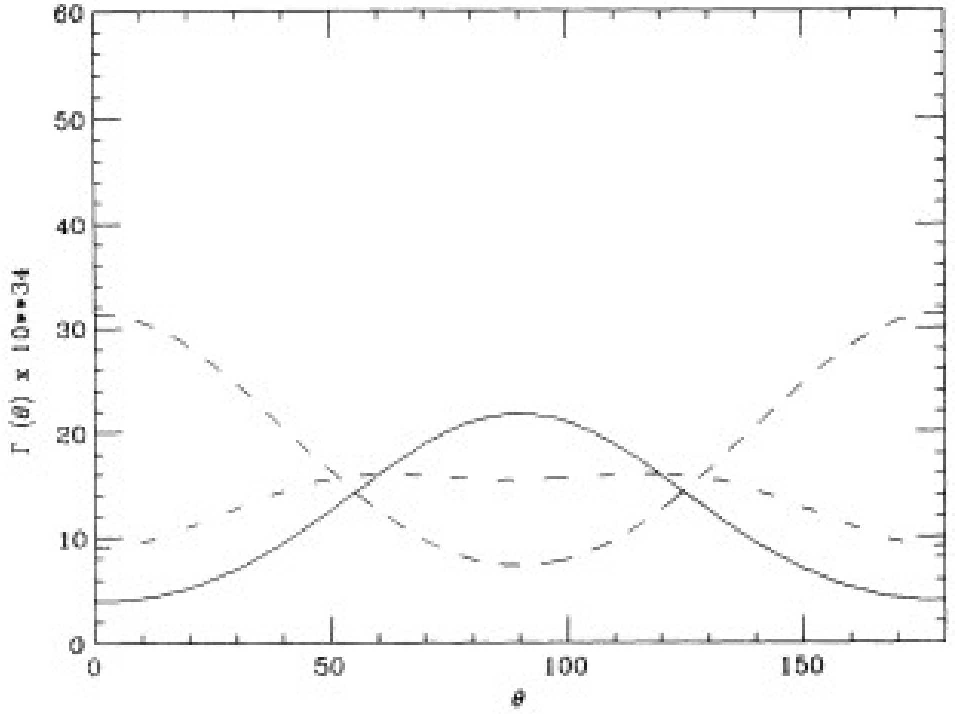
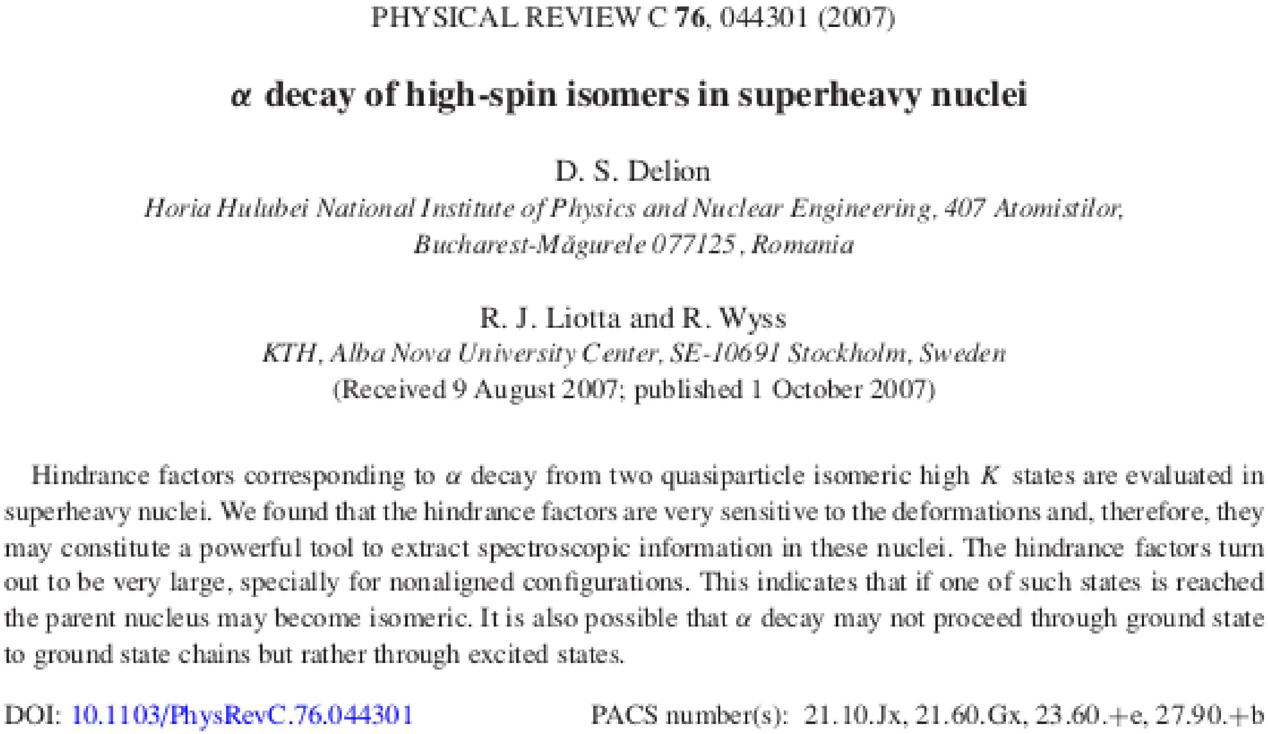


FIG. 1. Angular distributions corresponding to initial angular momentum projections $M_i = 1/2$ (solid line), 3/2 (dash-dotted line), and 5/2 (dashed line) for the case $\beta_2 = 0.2$, $\beta_3 = \beta_4 = 0$.

Superheavy nuclei live longer in high spin alpha-decaying 2qp isomeric states with higher hindrance factors



PHYSICAL REVIEW C **76**, 044301 (2007)

α decay of high-spin isomers in superheavy nuclei

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(Received 9 August 2007; published 1 October 2007)

Hindrance factors corresponding to α decay from two quasiparticle isomeric high K states are evaluated in superheavy nuclei. We found that the hindrance factors are very sensitive to the deformations and, therefore, they may constitute a powerful tool to extract spectroscopic information in these nuclei. The hindrance factors turn out to be very large, specially for nonaligned configurations. This indicates that if one of such states is reached the parent nucleus may become isomeric. It is also possible that α decay may not proceed through ground state to ground state chains but rather through excited states.

DOI: 10.1103/PhysRevC.76.044301 PACS number(s): 21.10.Jx, 21.60.Gx, 23.60.+e, 27.90.+b

Hindrance factors
(ratio between reduced widths of ground and excited states)

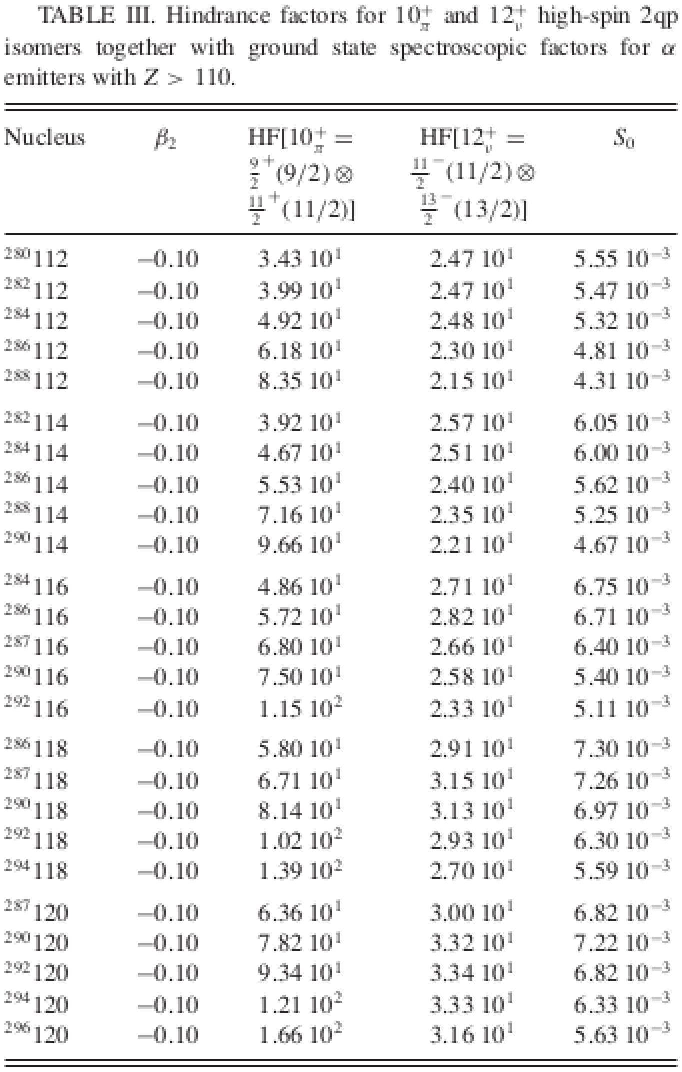
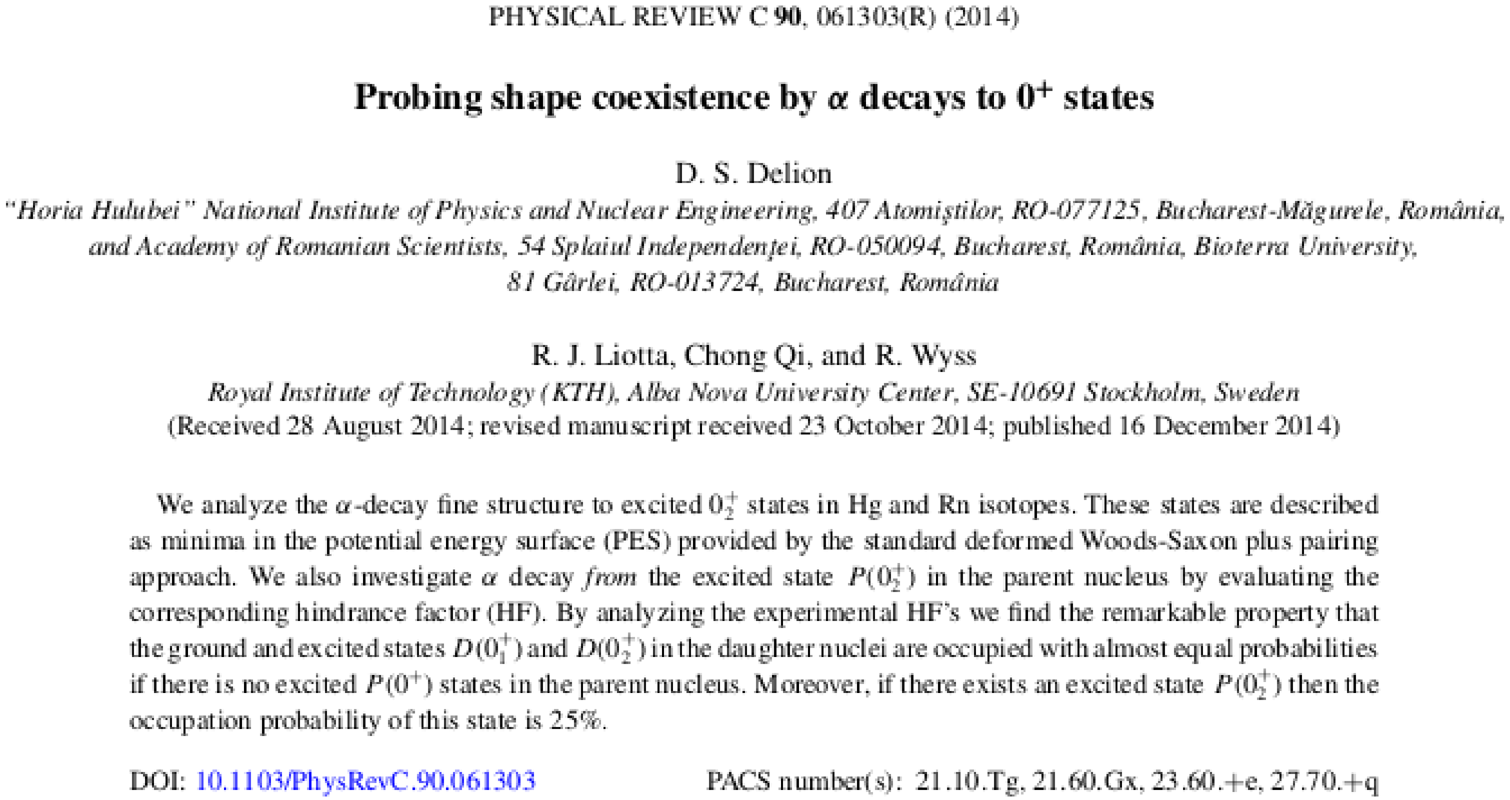


TABLE III. Hindrance factors for 10^+_π and 12^+_ν high-spin 2qp isomers together with ground state spectroscopic factors for α emitters with $Z > 110$.

Nucleus	β_2	HF[$10^+_\pi = \frac{9}{2}^+(9/2) \otimes \frac{11}{2}^+(11/2)$]	HF[$12^+_\nu = \frac{11}{2}^-(11/2) \otimes \frac{13}{2}^-(13/2)$]	S_0
$^{280}112$	−0.10	$3.43\ 10^1$	$2.47\ 10^1$	$5.55\ 10^{-3}$
$^{282}112$	−0.10	$3.99\ 10^1$	$2.47\ 10^1$	$5.47\ 10^{-3}$
$^{284}112$	−0.10	$4.92\ 10^1$	$2.48\ 10^1$	$5.32\ 10^{-3}$
$^{286}112$	−0.10	$6.18\ 10^1$	$2.30\ 10^1$	$4.81\ 10^{-3}$
$^{288}112$	−0.10	$8.35\ 10^1$	$2.15\ 10^1$	$4.31\ 10^{-3}$
$^{282}114$	−0.10	$3.92\ 10^1$	$2.57\ 10^1$	$6.05\ 10^{-3}$
$^{284}114$	−0.10	$4.67\ 10^1$	$2.51\ 10^1$	$6.00\ 10^{-3}$
$^{286}114$	−0.10	$5.53\ 10^1$	$2.40\ 10^1$	$5.62\ 10^{-3}$
$^{288}114$	−0.10	$7.16\ 10^1$	$2.35\ 10^1$	$5.25\ 10^{-3}$
$^{290}114$	−0.10	$9.66\ 10^1$	$2.21\ 10^1$	$4.67\ 10^{-3}$
$^{284}116$	−0.10	$4.86\ 10^1$	$2.71\ 10^1$	$6.75\ 10^{-3}$
$^{286}116$	−0.10	$5.72\ 10^1$	$2.82\ 10^1$	$6.71\ 10^{-3}$
$^{287}116$	−0.10	$6.80\ 10^1$	$2.66\ 10^1$	$6.40\ 10^{-3}$
$^{290}116$	−0.10	$7.50\ 10^1$	$2.58\ 10^1$	$5.40\ 10^{-3}$
$^{292}116$	−0.10	$1.15\ 10^2$	$2.33\ 10^1$	$5.11\ 10^{-3}$
$^{286}118$	−0.10	$5.80\ 10^1$	$2.91\ 10^1$	$7.30\ 10^{-3}$
$^{287}118$	−0.10	$6.71\ 10^1$	$3.15\ 10^1$	$7.26\ 10^{-3}$
$^{290}118$	−0.10	$8.14\ 10^1$	$3.13\ 10^1$	$6.97\ 10^{-3}$
$^{292}118$	−0.10	$1.02\ 10^2$	$2.93\ 10^1$	$6.30\ 10^{-3}$
$^{294}118$	−0.10	$1.39\ 10^2$	$2.70\ 10^1$	$5.59\ 10^{-3}$
$^{287}120$	−0.10	$6.36\ 10^1$	$3.00\ 10^1$	$6.82\ 10^{-3}$
$^{290}120$	−0.10	$7.82\ 10^1$	$3.32\ 10^1$	$7.22\ 10^{-3}$
$^{292}120$	−0.10	$9.34\ 10^1$	$3.34\ 10^1$	$6.82\ 10^{-3}$
$^{294}120$	−0.10	$1.21\ 10^2$	$3.33\ 10^1$	$6.33\ 10^{-3}$
$^{296}120$	−0.10	$1.66\ 10^2$	$3.16\ 10^1$	$5.63\ 10^{-3}$

Probing shape coexistence by alpha decay



PHYSICAL REVIEW C **90**, 061303(R) (2014)

Probing shape coexistence by α decays to 0^+ states

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(Received 28 August 2014; revised manuscript received 23 October 2014; published 16 December 2014)

We analyze the α-decay fine structure to excited 0_2^+ states in Hg and Rn isotopes. These states are described as minima in the potential energy surface (PES) provided by the standard deformed Woods-Saxon plus pairing approach. We also investigate α decay *from* the excited state $P(0_2^+)$ in the parent nucleus by evaluating the corresponding hindrance factor (HF). By analyzing the experimental HF's we find the remarkable property that the ground and excited states $D(0_1^+)$ and $D(0_2^+)$ in the daughter nuclei are occupied with almost equal probabilities if there is no excited $P(0^+)$ states in the parent nucleus. Moreover, if there exists an excited state $P(0_2^+)$ then the occupation probability of this state is 25%.

DOI: 10.1103/PhysRevC.90.061303 PACS number(s): 21.10.Tg, 21.60.Gx, 23.60.+e, 27.70.+q

Minima on the potential energy surface (PES) have different quadrupole deformations

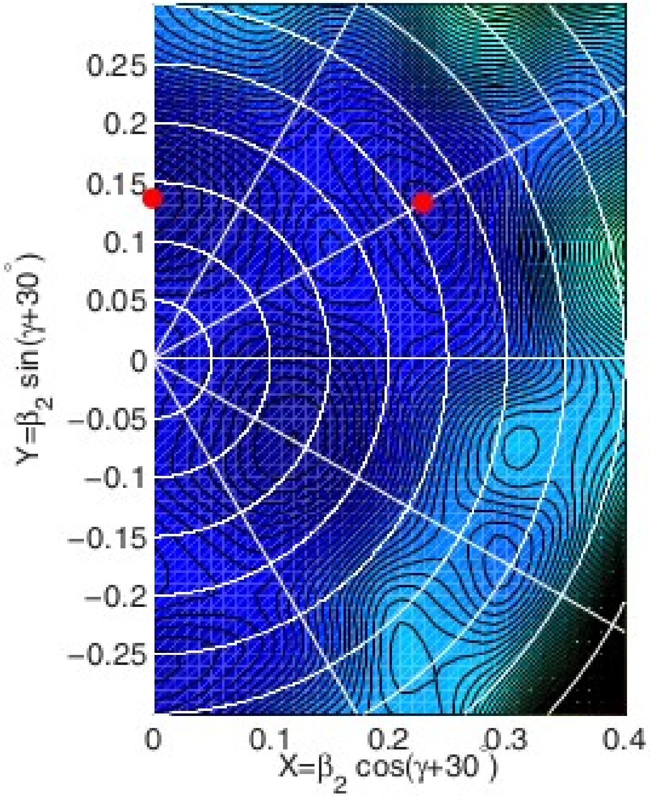


FIG. 1. (Color online) PES of ^{182}Hg. Local minima for the ground state (gs) ($\beta_2 = -0.13$) and excited 0_2^+ state ($\beta_2 = 0.27$) are shown by circles.

Spectroscopic factor versus daughter quadrupole deformation

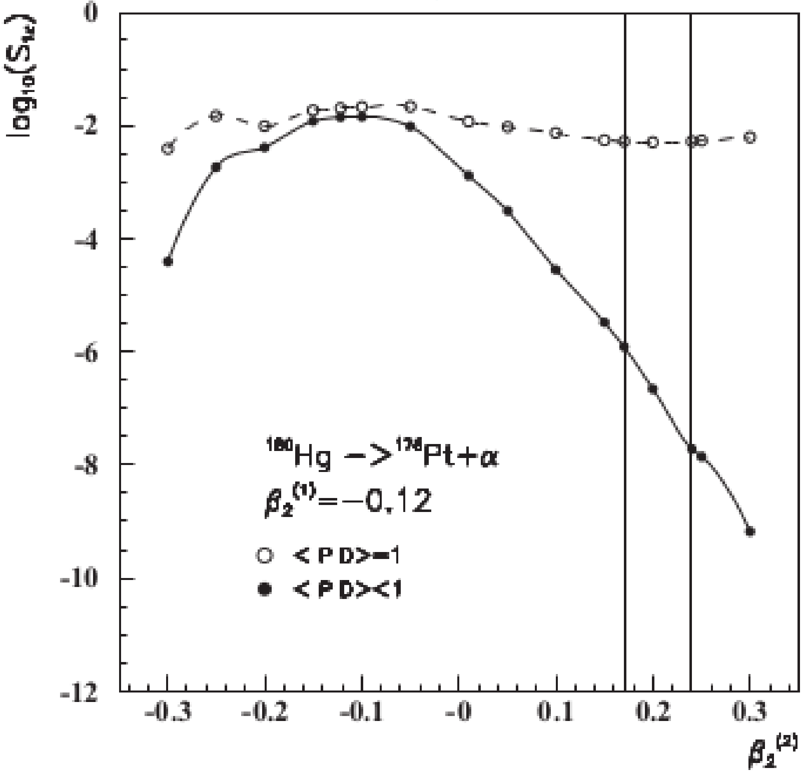


FIG. 2. Spectroscopic factor for the transition ^{180}Hg(gs) → ^{176}Pt(0_2^+) + α between BCS states with $k = 1$ in Eq. (4). The parent (initial) state corresponds to an oblate deformation with $\beta_2^{(1)}B = -0.12$. The daughter (final) state carries a deformation $\beta_2^{(2)}$ as given in the abscissa. The dashed curve was obtained by considering the overlap between the parent and daughter BCS states as unity (i.e., $\langle P|D\rangle = 1$) while for the full curve that overlap is the one provided by our calculation. Vertical lines denote the deformations provided by the PES calculation for the minima corresponding to the 0_1^+ ($k' = 1$) and 0_2^+ ($k' = 2$) states.

The key ingredient is the overlap between BCS wave functions

$$\langle \psi_k^P | \psi_{k'}^D \rangle = \sum_{m>0} \left[u_m^P(\beta_2^{(k)}) u_m^D(\beta_2^{(k')}) + v_m^P(\beta_2^{(k)}) v_m^D(\beta_2^{(k')}) \right].$$

Shape mixing of wave functions

$$|\varphi_1^A\rangle = X_A|\psi_1^A\rangle + Y_A|\psi_2^A\rangle,$$

$$|\varphi_2^A\rangle = -Y_A|\psi_1^A\rangle + X_A|\psi_2^A\rangle, \quad A = P, D,$$

in terms of the mixing angle

$$\left\{ \begin{matrix} X_A^2 \\ Y_A^2 \end{matrix} \right\} = \frac{1}{2} \pm \delta_A .$$

Hindrance factor
in terms of spectroscopic factors

---

experimental

$$\mathrm{H}_{\exp}(k) = \left| \frac{\langle \varphi_1^D | \hat{T} | \varphi_k^P \rangle}{\langle \varphi_2^D | \hat{T} | \varphi_k^P \rangle} \right|^2 .$$

$$\langle \psi_{k'}^D | \hat{T} | \psi_k^P \rangle \equiv T_{k'k} = \sqrt{\langle S_{kk'} \rangle}.$$

theoretical

$$\mathrm{H}_{th}(k) = \left| \frac{\langle \psi_1^D | \hat{T} | \psi_k^P \rangle}{\langle \psi_2^D | \hat{T} | \psi_k^P \rangle} \right|^2 \equiv \left| \frac{T_{1k}}{T_{2k}} \right|^2$$

Spectroscopic factor

$$S_{kk'} = \int_0^{R_\alpha} R^2 dR \int d\hat{R}\, |\mathcal{F}_{kk'}(\mathbf{R})|^2$$
$$\approx \sum_{N_\alpha L_\alpha} W^2_{N_\alpha L_\alpha}\left(\beta_2^{(k)}, \beta_2^{(k')}\right).$$

is the integral of the formation amplitude squared, written in terms of spherical orbitals

$$\mathcal{F}_{kk'}(\mathbf{R}) = \sum_{L_\alpha N_\alpha} W_{N_\alpha L_\alpha}\left(\beta_2^{(k)}, \beta_2^{(k')}\right) \Phi^{(4\lambda)}_{N_\alpha L_\alpha}(\mathbf{R}),$$

Experimental HF determines shape mixing angles for parent and daughter nuclei

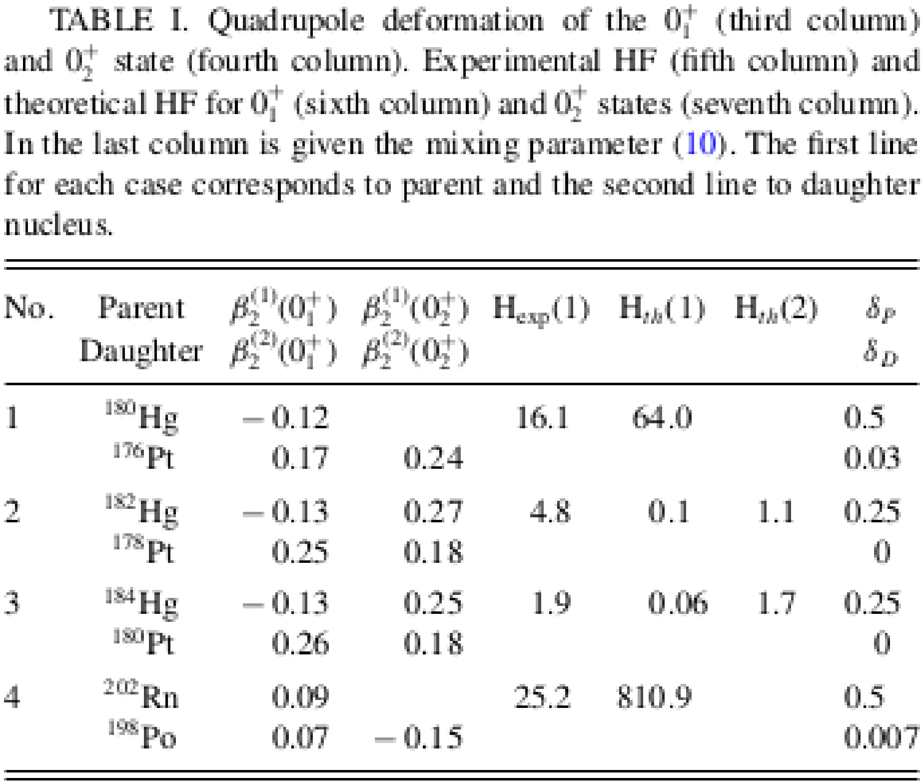
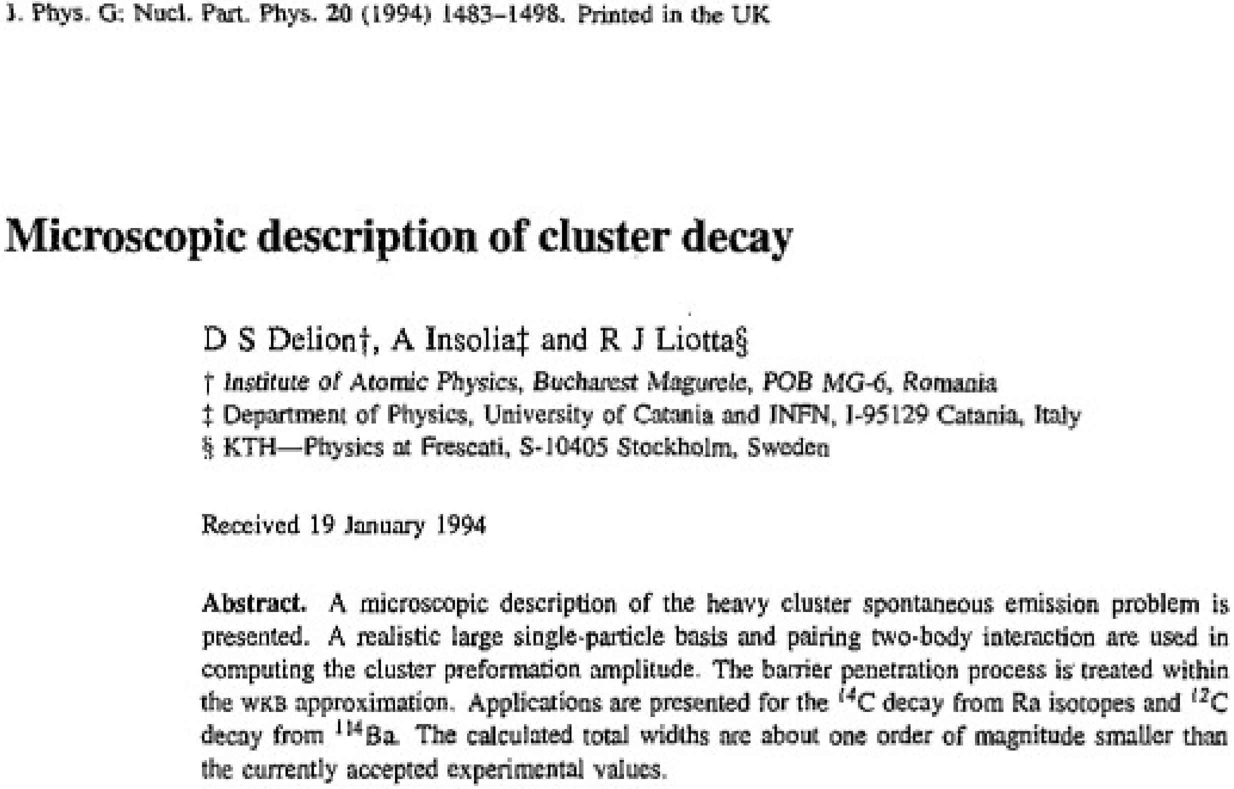


TABLE I. Quadrupole deformation of the 0_1^+ (third column) and 0_2^+ state (fourth column). Experimental HF (fifth column) and theoretical HF for 0_1^+ (sixth column) and 0_2^+ states (seventh column). In the last column is given the mixing parameter (10). The first line for each case corresponds to parent and the second line to daughter nucleus.

No.	Parent	$\beta_2^{(1)}(0_1^+)$	$\beta_2^{(1)}(0_2^+)$	$H_{exp}(1)$	$H_{th}(1)$	$H_{th}(2)$	δ_P
	Daughter	$\beta_2^{(2)}(0_1^+)$	$\beta_2^{(2)}(0_2^+)$				δ_D
1	^{180}Hg	−0.12		16.1	64.0		0.5
	^{176}Pt	0.17	0.24				0.03
2	^{182}Hg	−0.13	0.27	4.8	0.1	1.1	0.25
	^{178}Pt	0.25	0.18				0
3	^{184}Hg	−0.13	0.25	1.9	0.06	1.7	0.25
	^{180}Pt	0.26	0.18				0
4	^{202}Rn	0.09		25.2	810.9		0.5
	^{198}Po	0.07	−0.15				0.007

3. Heavy cluster emission



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Microscopic description of cluster decay

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Abstract. A microscopic description of the heavy cluster spontaneous emission problem is presented. A realistic large single-particle basis and pairing two-body interaction are used in computing the cluster preformation amplitude. The barrier penetration process is treated within the WKB approximation. Applications are presented for the ^{14}C decay from Ra isotopes and ^{12}C decay from ^{114}Ba. The calculated total widths are about one order of magnitude smaller than the currently accepted experimental values.

Cluster formation amplitude

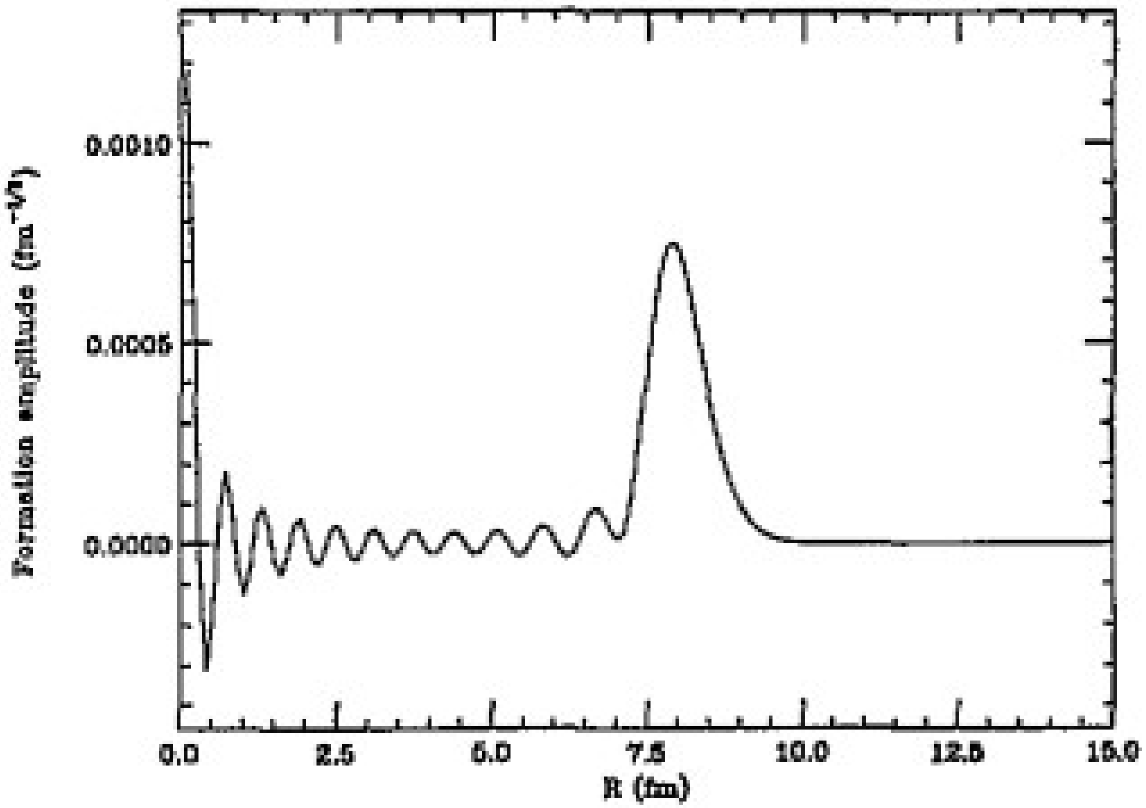


Figure 4. The preformation amplitude given by relation (2.34) as a function of the CM rad between daughter nucleus and cluster $^{114}\mathrm{Ba} \rightarrow {}^{12}\mathrm{C} + {}^{102}\mathrm{Sn}$.

Cluster spectroscopic factor and decay width

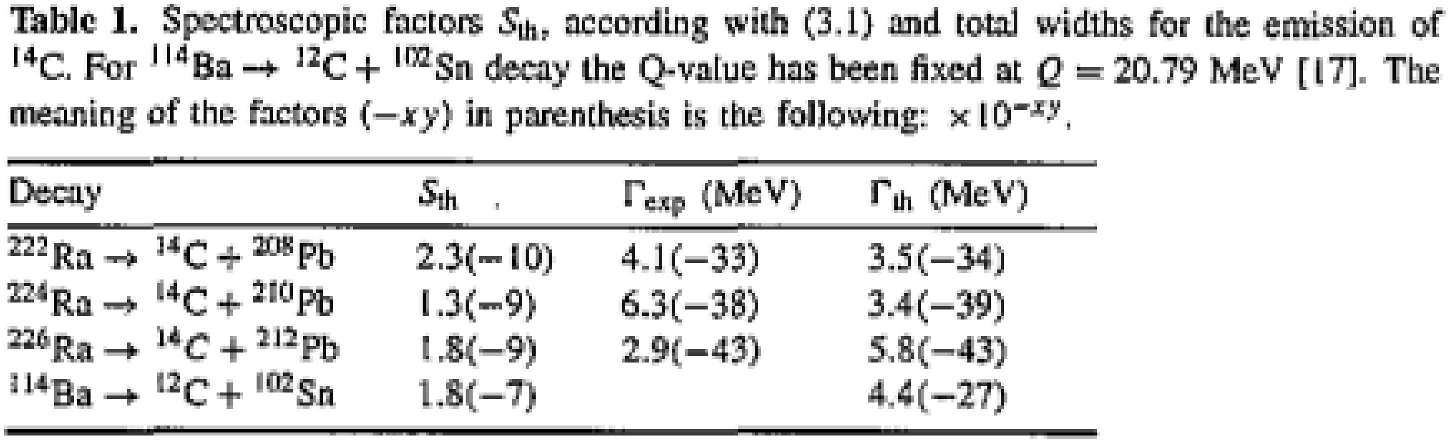
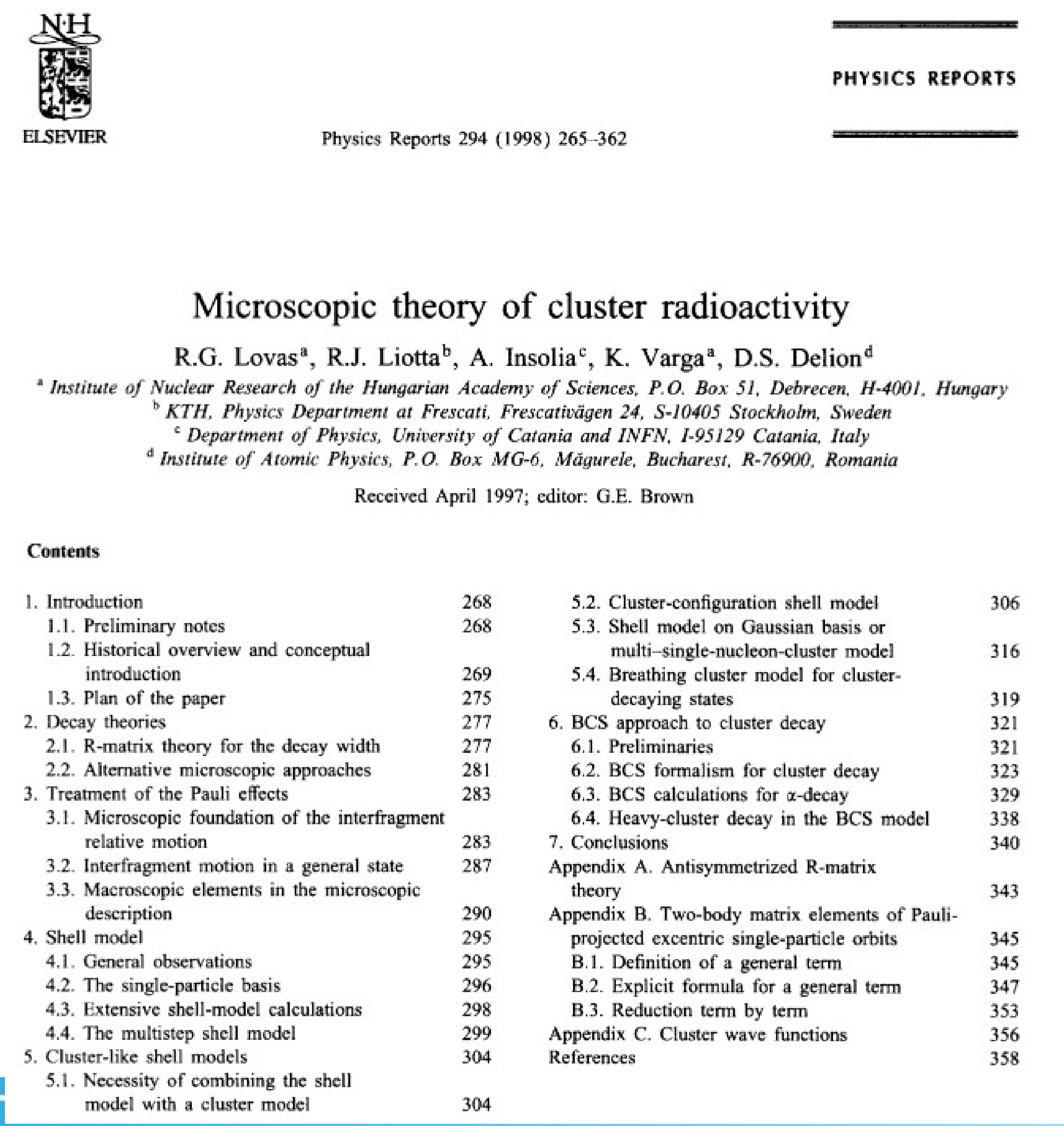


Table 1. Spectroscopic factors S_{th}, according with (3.1) and total widths for the emission of ^{14}C. For $^{114}\mathrm{Ba} \to {}^{12}\mathrm{C} + {}^{102}\mathrm{Sn}$ decay the Q-value has been fixed at $Q = 20.79$ MeV [17]. The meaning of the factors $(-xy)$ in parenthesis is the following: $\times 10^{-xy}$.

Decay	S_{th}	Γ_{exp} (MeV)	Γ_{th} (MeV)
$^{222}\mathrm{Ra} \to {}^{14}\mathrm{C} + {}^{208}\mathrm{Pb}$	2.3(−10)	4.1(−33)	3.5(−34)
$^{224}\mathrm{Ra} \to {}^{14}\mathrm{C} + {}^{210}\mathrm{Pb}$	1.3(−9)	6.3(−38)	3.4(−39)
$^{226}\mathrm{Ra} \to {}^{14}\mathrm{C} + {}^{212}\mathrm{Pb}$	1.8(−9)	2.9(−43)	5.8(−43)
$^{114}\mathrm{Ba} \to {}^{12}\mathrm{C} + {}^{102}\mathrm{Sn}$	1.8(−7)		4.4(−27)



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Microscopic theory of cluster radioactivity

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Contents

Conclusions

Our collaboration reported important results for

- proton emission systematics

  PRL & Phys. Rep. with ~ 150 citations

- microscopic description of the alpha emission

  4 Phys. Rev. C with ~ 200 citations

- microscopic description of heavy cluster decays

  Phys. Rep. with ~ 300 citations

- anisotropic alpha emission from odd-mass nuclei

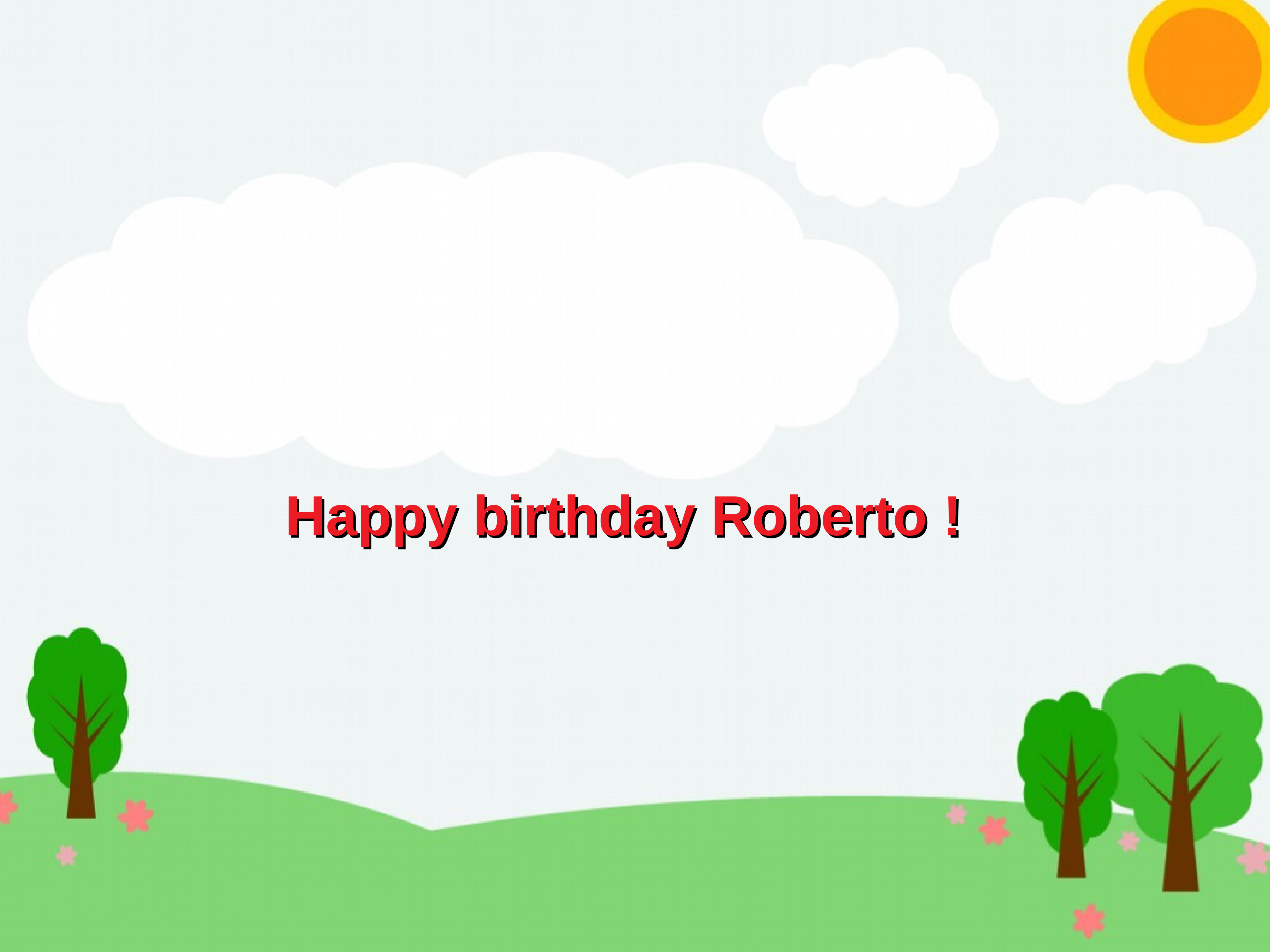
  2 Phys. Rev. C with ~ 100 citations

- enhanced formation of superheavy nuclei in isomeric states

  Phys. Rev. C with ~ 60 citations

- shape coexistence evidenced by alpha decay

  Phys. Rev. C with ~ 15 citations



Happy birthday Roberto !