

Proton and heavier charged particles emission

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Motivation

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Cluster radioactivity

The model

Gamow model of α -decay

Decay constant

Half-lives formula

Results

α -decay half-lives

Cluster radioactivity half-lives

Proton emission

Conclusions

Simple model as a useful tool for:

- ▶ preliminary determination of basic properties of unknown isotopes
- ▶ estimation of the most probable decay mode
- ▶ evaluation whether new synthesized isotope lives long enough to be observed

Cluster radioactivity

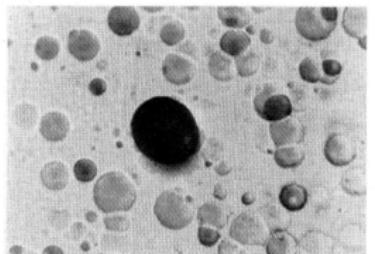


FIG. 1. Photomicrograph showing one etch pit due to a 56 MeV ^{24}Ne ion striking a Cronar detector nearly head on. About 3×10^6 alpha particles passed through this field of view.

Barwick et al., PRC 31, 1984 (1985)

H. J. Rose, G. A. Jones, Nature 307, 245 (1984).

A. Sandulescu, D. Poenaru, W. Greiner, Fiz. Elem. Chastits At. Yadra 11, 1334 (1980). [Sov. J. Part. Nucl. 11, 528 (1980)].



- ▶ $T_{1/2} \sim 10^{11} \div 10^{26}$ s
- ▶ Emitters: $^{221}\text{Fr} - ^{242}\text{Cm}$
- ▶ Daughter nucleus: $^{208}\text{Pb} \pm 4$ nucleons
- ▶ Branching ratios to α -decay: $10^{-9} \div 10^{-16}$

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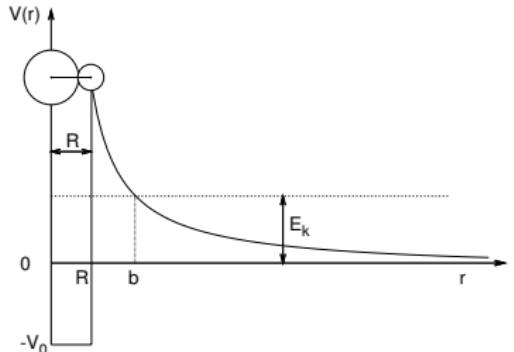
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Gamow model of α -decay



$$V(r) = \begin{cases} -V_0 & 0 \leq r \leq R \\ \frac{Z_1 Z_2 e^2}{r} & r > R \end{cases}$$

Turning points:

$$R = r_0(A_1^{1/3} + A_2^{1/3})$$

$$b = \frac{Z_1 Z_2 e^2}{E_k}$$

Tunnelling probability:

$$P = \exp \left[-\frac{2}{\hbar} \int_R^b \sqrt{2\mu(V(x) - E_k)} dx \right],$$

$$P = \exp \left\{ -\frac{2}{\hbar} \sqrt{2\mu Z_1 Z_2 e^2 b} \left[\arccos \sqrt{\frac{R}{b}} - \sqrt{\frac{R}{b} - \left(\frac{R}{b} \right)^2} \right] \right\}$$

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Decay constant

$$\lambda = P\nu S$$

1. Tunnelling probability

- ▶ Gamow theory

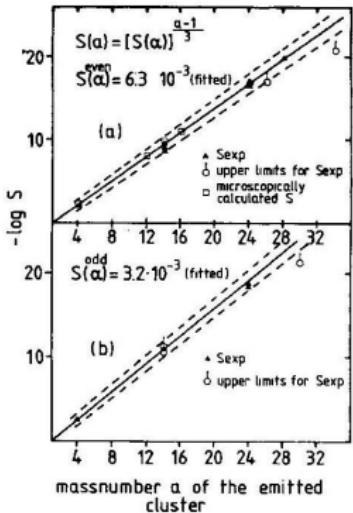
2. Frequency of assaults

$$\nu = \frac{1}{2R} \sqrt{\frac{2(E_k + V_0)}{\mu}}$$

$$V_0 = 25 \cdot A_c \text{ MeV}$$

3. Preformation factor

- ▶ $S_{\alpha}^{\text{even}} = 6.3 \times 10^{-3}$
- ▶ $S_{\alpha}^{\text{odd}} = 3.2 \times 10^{-3}$
- ▶ $S_c = S_{\alpha}^{(A_c - 1)/3}$



R. Blendowske, H. Walliser, *Phys. Rev. Lett.* **61**, 1930 (1988).

D. N. Poenaru, W. Greiner, *Phys. Scr.* **44**, 427 (1991).

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Parameter correlations

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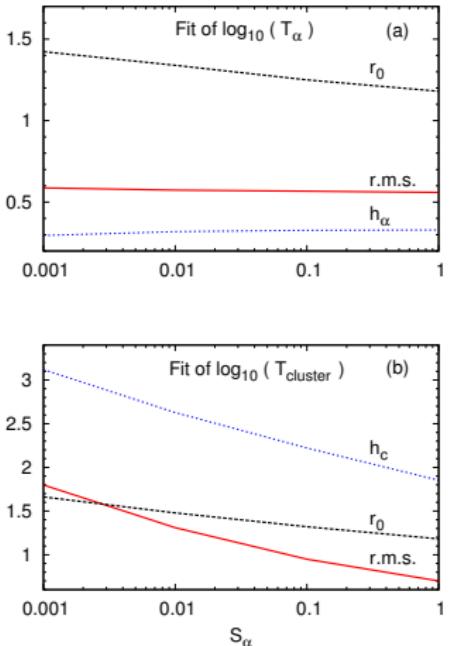
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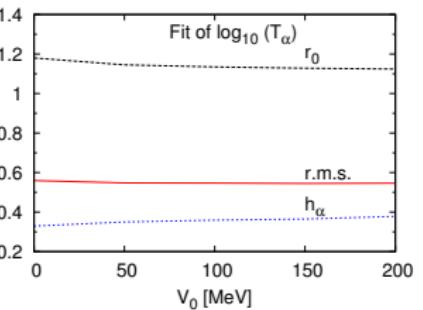
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$$\blacktriangleright S_c = S_\alpha^{(A_c - 1)/3}$$

$$\blacktriangleright \nu = \frac{1}{2R} \sqrt{\frac{2(E_k + V_0)}{\mu}},$$



Half-lives formula

α and cluster radioactivity

Alpha + cluster radioactivity (2 parameters)¹

$$T_{1/2} = \frac{\ln 2}{P\nu} \cdot 10^h$$

$$\nu = \frac{\pi \hbar}{2\mu R^2}$$

1. $r_0 = 1.21 \text{ fm}$
2. $h = h_p = h_n = 0.216, \quad h_{pn} = 2h$
clusters: $h = 1.973$

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¹ A. Zdeb, M. Warda, K. Pomorski, *Phys. Rev.* **C87** 024308 (2013).

Half-lives formula

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clusters: $h = 1.973$

Viola-Seaborg formulae

Alpha decay - Parkhomenko-Sobiczewski (4 parameters)²

$$\log_{10} T_{1/2}^\alpha(Z, N) = aZ(Q_\alpha - E_i)^{-1/2} + bZ + c ,$$

Cluster emission - Xu-Ren (4 parameters)³

$$\log_{10} T_{1/2}^c = aZ_1 Z_2 Q^{-1/2} + cZ_1 Z_2 + d + h$$

¹ A. Zdeb, M. Warda, K. Pomorski, *Phys. Rev.* **C87** 024308 (2013).

² A. Parkhomenko, A. Sobiczewski, *Acta Phys. Pol.* **B36**, 3095 (2005).

³ Z. Ren, C. Xu, Z. Wang, *Phys. Rev.* **C70**, 034304 (2004).

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$\pi_Z - \pi_N$	n	h	V-S r.m.s.	WKB r.m.s.
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α -decay

Parkhomenko
-Sobiczewski

e - e	96		0.54	0.39
e - o	85	0.216	0.78	0.68
o - e	65	0.216	0.53	0.47
o - o	52	0.432	0.72	0.68

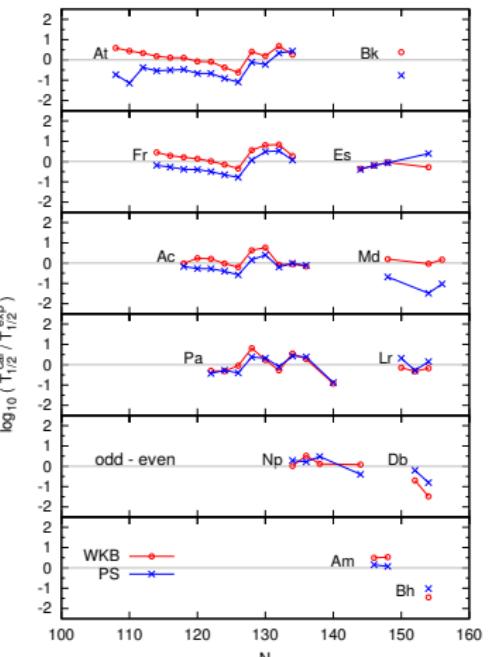
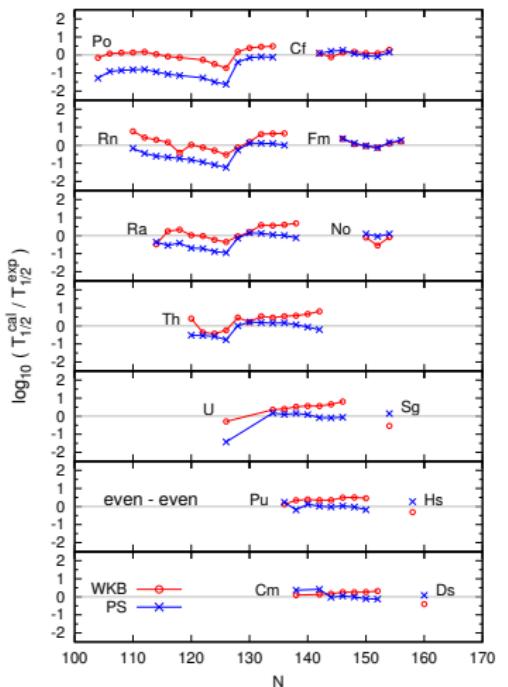
Cluster emission

Ren-Xu-Wang

e - e	16		0.80	0.85
o - A	10	1.973	0.64	0.45

α -decay half-lives

$84 \leq Z \leq 110$



A. Zdeb, M. Warda, K. Pomorski, *Phys. Rev. C* **87** 024308 (2013).

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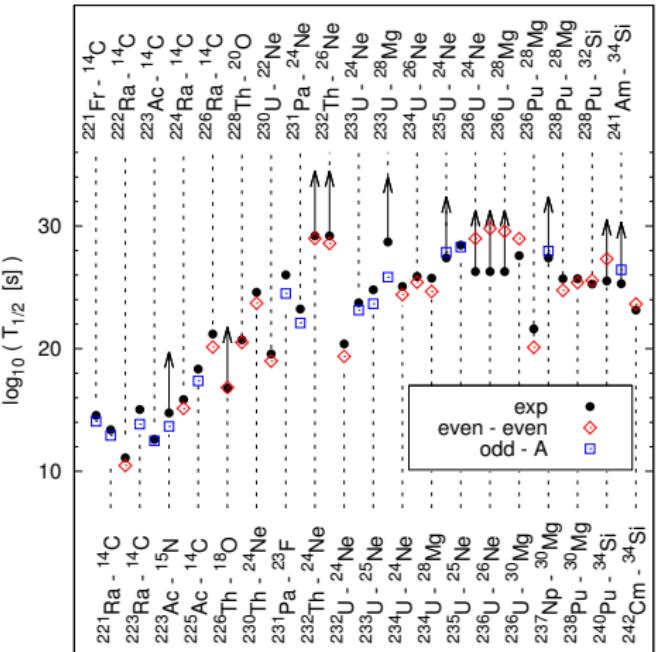
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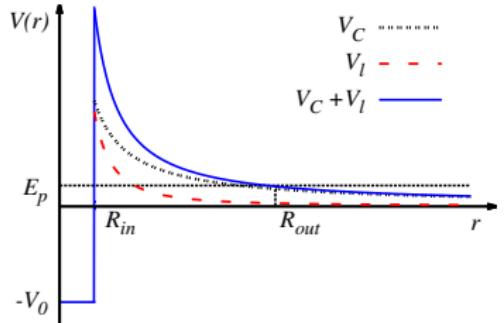
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Cluster radioactivity half-lives



Proton emission



$$V(r) = \begin{cases} -V_0 & 0 \leq r \leq R \\ V_C(r) + V_l(r) & r > R \end{cases}$$

Coulomb energy:

$$V_C(r) = \frac{Z_p Z_d e^2}{r}$$

Centrifugal term:

$$V_l(r) = \frac{\hbar^2 l(l+1)}{2\mu r^2}$$

Tunnelling probability:

$$P = \exp \left[-\frac{2}{\hbar} \int_{R_{in}}^{R_{out}} \sqrt{2\mu(V(x) - E_k)} dx \right],$$

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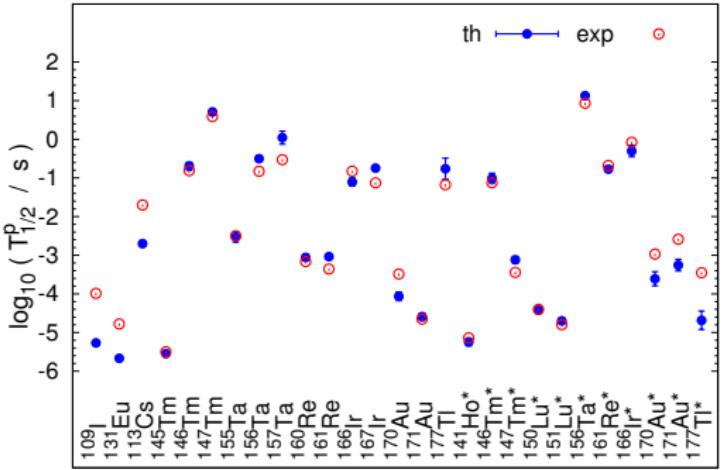
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Proton emission half-lives

Results obtained for the same value of nuclear radius constant:

$$r_0 = 1.21 \text{ fm (r.m.s.=0.52)}$$



A. Zdeb, M. Warda, K. Pomorski, C.M. Petrache, Eur. Phys. J. A52 323 (2016).

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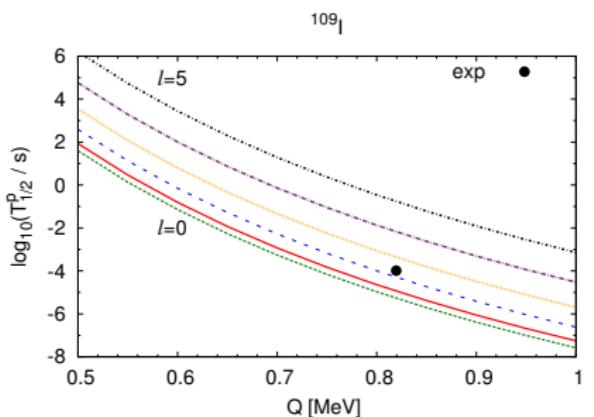
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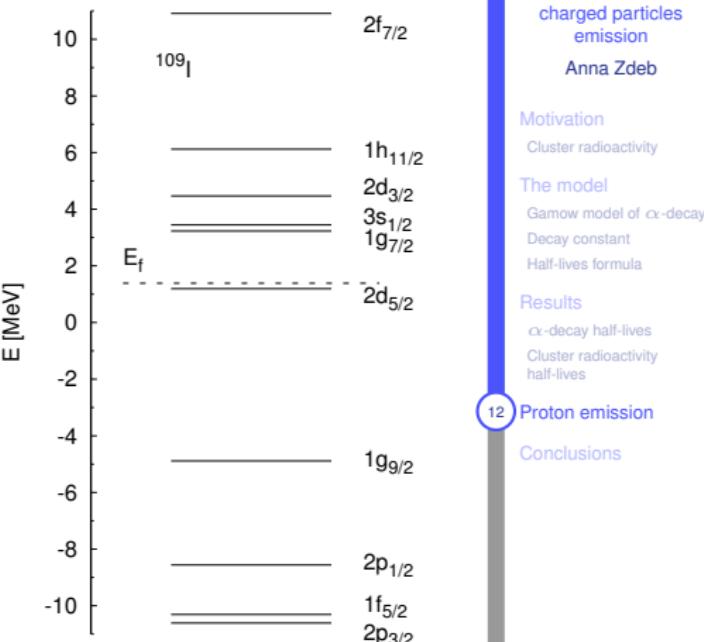
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Model sensitivity for angular momentum value



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- ▶ Alpha, cluster and proton emission described within one model
- ▶ The same value of nuclear radius constant for all considered decays.
- ▶ Good accuracy was obtained in comparison with the multi-parameter Viola-Seaborg-like formulae fitted separately to the data for each decay modes.

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Thank you!



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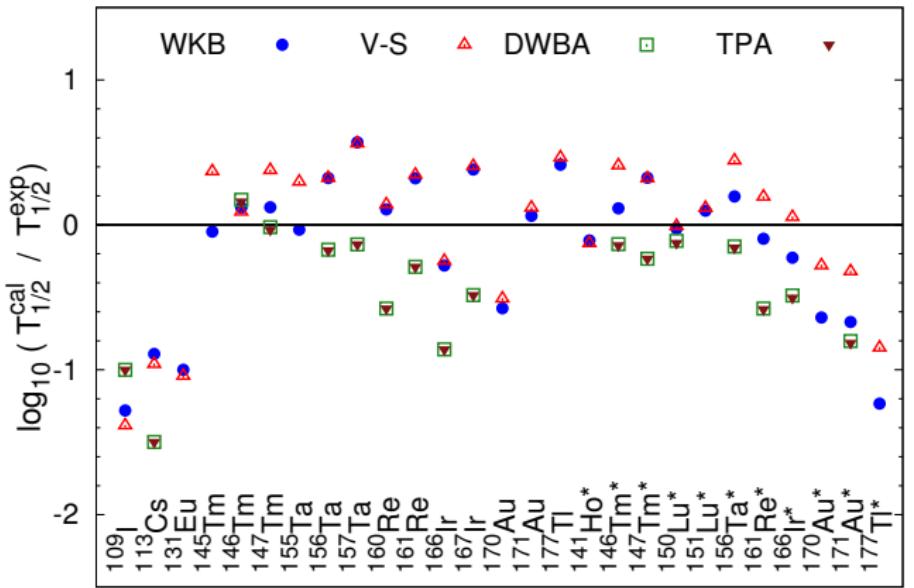
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Viola-Seaborg: J. M. Dong, H. F. Zhang, G. Royer, Phys. Rev. C79, 054330(2009).

Distorted Wave Born Approximation: H. Feshbach, Theoretical Nuclear Physics: Nuclear Reactions Wiley, New York (1992).

Two-Potential Approach S. A. Gurvitz, Phys. Rev. A 38, 1747 (1988).