Large scale evaluation of $\beta$-decay rates of r-process nuclei

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Introduction

Masses (Sn) (location of the path)

β-decayed n-emission branchings (final abundances)

β-decay half-lives (abundance and process speed)

Fission rates and distributions:
- n-induced
- spontaneous
- β-delayed

n-capture rates
- for A>130 in slow freezeout
- for A<130 maybe in a “weak” r-process?

Seed production rates (ααα, ααn, α2n, ..)

ν-physics?

Masses (Sn) (location of the path)
Transitions are obtained by solving the pn-RQRPA equations

\[
\begin{pmatrix}
A & B \\
B^* & A^*
\end{pmatrix}
\begin{pmatrix}
X^\lambda \\
Y^\lambda
\end{pmatrix}
= E_\lambda
\begin{pmatrix}
1 & 0 \\
0 & -1
\end{pmatrix}
\begin{pmatrix}
X^\lambda \\
Y^\lambda
\end{pmatrix}
\]

Residual interaction is derived from the same density functional used to obtain the ground state

\[
\mathcal{L}_{\rho+\pi} = -g_\rho \bar{\psi} \gamma_\mu \rho^\mu \tau \psi - \frac{f_\pi}{m_\pi} \bar{\psi} \gamma_5 \gamma^\mu \partial_\mu \pi \tau \psi
\]

Total strength of a particular transition

\[
B_{\lambda,J} = \left| \sum_{pn} \langle p \| \hat{O}_J \| n \rangle \left( X_{pn}^{\lambda,J} u_p v_n - Y_{pn}^{\lambda,J} v_p u_n \right) \right|^2
\]
Decay rate:

\[ \lambda_i = D \int_1^{W_{0,i}} W \sqrt{W^2 - 1} \left( W_{0,i} - W \right)^2 F(Z, W) C(W) dW \]

\[ T_{1/2} = \frac{\ln 2}{\lambda}, \quad D = \frac{(G_F V_{ud})^2}{2\pi^3} \frac{(m_e c^2)^5}{\hbar} \]

Allowed decay shape factor:

\[ C(W) = B(GT) \]

First-forbidden decay shape factor:

\[ C(W) = k \left( 1 + aW + bW^{-1} + cW^2 \right) \]
\[ \bar{r} = \frac{1}{N} \sum_i \log \frac{T_{\text{th}}}{T_{\text{exp}}} \]

\[ \sigma = \left[ \frac{1}{N} \sum_i (r_i - \bar{r})^2 \right]^{1/2} \]

G. Audi et al., CPC 36, 1157 (2012)
FRDM + QRPA predicts erratic behaviour of the half-lives along isotopic (and isotonic) chains
Half-lives of medium mass nuclei (from Kr to Tc) are reproduced well with both models.

Deformation plays a significant role in some nuclei (e.g. Re isotopes).

Description of heavy nuclei, with long $T_{1/2}$ is still challenging.


P. Möller, J. R. Nix, and K.-L. Kratz, Atomic Data and Nuclear Data Tables 66, 131 (1997)

\[ P_{xn} = \frac{1}{\lambda_{\text{tot}}} \sum_{E_i = S_{xn}} S_{(x+1)n} \]

\[ \langle n \rangle = \sum_i iP_{in} \]
All things being equal, different half-lifes have a significant impact on the resulting abundances.

Additionally changing other input, such as masses will result with even larger differences in the final results.

There is a need for microscopic, fully self-consistent calculations of all relevant nuclear input for use in r-process simulations.
Future developments

\[ \hat{O} = \left( \sigma_T - \frac{q^2 r^2}{6} \sigma_T + \cdots \right) \]

- p-h\(\otimes\)phonon components enrich the spectrum
- additional states lead to fragmentation
- significant contribution of the 0\(\hbar\omega\) component of the IVSM at the resonance
- low energy strength remains unaffected
