Time-dependent Approach to Two-proton Radioactivity and Di-proton Correlation

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I. Two-proton Radioactivity

- General properties
  - The novel decay-mode of proton-excessive nuclei.
  - Two protons are emitted sequentially or simultaneously.
  - Famous two-nucleon emitters; \(^{6}\text{Be},^{14}\text{Ne},^{41}\text{Fe},^{52}\text{Zn},^{16}\text{Be}(2n),\text{etc.}\)

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>(^{6}\text{Be}(Z=6))</th>
<th>(^{14}\text{Ne}(Z=10))</th>
<th>(^{41}\text{Fe}(Z=26))</th>
<th>(^{52}\text{Zn}(Z=30))</th>
<th>(^{16}\text{Be}(N=10))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay mode</td>
<td>2p (100%)</td>
<td>2p (100%)</td>
<td>2p (70%)</td>
<td>2p (90%)</td>
<td>2n (?)</td>
</tr>
<tr>
<td>Q(_{\text{m}}) (MeV)</td>
<td>1.37</td>
<td>1.40</td>
<td>1.14</td>
<td>1.51</td>
<td>1.35</td>
</tr>
<tr>
<td>Decay width (MeV)</td>
<td>0.092</td>
<td>0.11</td>
<td>9.7 \times 10(^{-2})</td>
<td>2.1 \times 10(^{-2})</td>
<td>?</td>
</tr>
<tr>
<td>Lifetime [s]</td>
<td>(= 10^{-18})</td>
<td>(= 10^{-19})</td>
<td>(6.8 \times 10^{-4})</td>
<td>(3.2 \times 10^{-4})</td>
<td>?</td>
</tr>
</tbody>
</table>

- \(^{6}\text{Be}\) nucleus
  - The most simple 2p-emitter (alpha + p + p).
  - The sequential decay through \(^{4}\text{Li} + p\) is forbidden.

II. Two Important Factors of 2p-decay

- Final State Interactions (FSIs)
  \[ H_{\text{FSI}} = H_{\text{core-p}} + H_{\text{p-p}} + H_{\text{ppc}} \]

- Initial configuration
  - Decay-aspects are dominated not only by interactions but also by how two protons are before the emission.

  \[ \text{e.g. with } \text{“Confining Potential” at } t=0, \]

- Decay probability and width
  \[ \text{Decay probability and width} \]
  \[ \text{Advantage of this method} \]

III. Time-dependent Approach

- Formalism
  \[ |\Psi(t)\rangle = \exp\left(-\frac{i}{\hbar} H_{\text{3-body}} t\right) |\Psi(0)\rangle \]
  \[ \Rightarrow \text{decay state}: \ |\Psi_{\text{f}}(t)\rangle = |\Psi(t)\rangle - \beta(t) |\Psi(0)\rangle, \ \beta(t) = \langle \Psi(0) |\Psi(t)\rangle \]
  \[ \Rightarrow \text{decay probability}: \ \Gamma_{\text{f}}(t) = \langle \Psi_{\text{f}}(t) |\Psi_{\text{f}}(t)\rangle = 1 - |\Psi(t)^{\dagger} |\Psi(0)\rangle |^{2} \]
  \[ \Rightarrow \text{decay width}: \ \Gamma(t) = -\frac{d}{dt} \ln[1 - N_{\text{f}}(t)] = \frac{\hbar}{1 - N_{\text{f}}(t)} \frac{d}{dt} N_{\text{f}}(t) \]

- Advantage of this method
  - TD-approach makes it possible to detect the role of the initial configuration and the di-proton correlation in 2p-decay.

IV. Results (2p-decay of \(^{6}\text{Be}\))

- Decay probability and width
  \[ \text{The calculated } Q_{\text{2p,Thr.}} \text{is adjusted to } Q_{\text{2p,Exp.}} = 1.37 \text{ (MeV).} \]

- Time-development of density of probability
  \[ \text{di-proton correlation in the initial configuration.} \]

V. Summary

- Conclusions
  - Decay width; \(\Gamma_{\text{Thr.}}\) is in excellent agreement with experiments.
  - Di-proton correlation in 2p-decay is apparent, as the result of both p-p FSI and initial configuration.

- Future Work
  - It is needed to distinguish the effect of initial configuration, which is critical to discuss the intrinsic di-proton correlation inside stable nuclei.