Spectroscopy of open systems: proton emitters

Non-adiabatic theory:
Proton radioactivity – decay of the $I^\pi = 10^+$ isomer in $^{54}\text{Ni}$

decay of the excited $10^+$-state by proton emission and $\gamma$-radiation

2-proton radioactivity of $^{45}$Fe

1-proton emission:

$^{45}_{26}Fe_{19} \rightarrow ^{44}_{25}Mn_{19}$

-120 keV < $S_p$ < 70 keV

t$_{1/2}$ > 100s

2-proton emission:

$^{45}_{26}Fe_{19} \rightarrow ^{43}_{24}Cr_{19}$

-1000 keV < $S_{2p}$ < -1300 keV

t$_{1/2}$~10$^{-6}$s – 1s

proposed by V.I. Goldansky; Nucl.Phys. 19 (1960), 482 Nucl.Phys. 27 (1961), 648

discovered by M.Pfützner et al., EPJA 14 (2002) 279
2-proton radioactivity of $^{45}$Fe

**Tunneling through a potential barrier:**

\[ \lambda = S \cdot \omega \cdot P \]

- S spectroscopic factor for 2-proton creation
- $\omega$ frequency, with which both protons hit the barrier
- P is the penetrability, the probability for a tunneling process

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2-proton radioactivity of $^{45}$Fe

Monte Carlo simulation (200 events) of the opening angles between both protons for the $^{45}$Fe decay

Gaseous ionization detector developed to measure the angular and energy correlations between the protons emitted in 2p decay of $^{45}$Fe.
Optical time projection chamber

Gas (1 atm): 49% He + 49% Ar + 1% N₂ + 1% CH₄

Active area 150 mm
1ˢᵗ amplification area 3 mm
Transfer area 20 mm
2ⁿᵈ Amplification area 10 mm

G. Charpak et al., NIM A269 (1988), 142
Optical time projection chamber

CCD Camera
• 1000x1000 pix
• 12-bits
• image amplification (x2000)

Photomultiplier 5”

G. Charpak et al., NIM A269 (1988), 142
Principle of operational of the optical time projection chamber

WLS = wavelength shifter
2p decay of $^{45}$Fe

2p decay 0.53 ms after implantation
2p decay of $^{45}$Fe

2p decay 0.47 ms after implantation
2p decay of $^{45}$Fe

2p decay 5.3 ms after implantation
Event reconstruction

Track coordinates: \((r, \Theta, \varphi)\)

\[
L_0 = r \cos \Theta \\
L_{PM} = r \sin \Theta \\
r^2 = L_0^2 + L_{PM}^2 \\
\Theta = \arctan\left(\frac{L_0}{L_{PM}}\right)
\]
Optical time projection chamber

2-proton radioactivity of $^{45}$Fe

$^{45}\text{Fe}$ decay scheme

$Q_{2p} = 1.15 \pm 0.09$ MeV und $T_{1/2}$ consistent with 2p-emission [sensitive between 1µs (2p-decay) and 10 ms (β-decay)]

The IAS has the isospin \( T = T_Z + 1 = (N-Z)/2 + 1 \)
The isospin of the ground state is \( T = T_Z = (N-Z)/2 \)

\[ ^2\text{He} \quad \text{D} \quad \text{nn} \]

\( T=1, \ S=0 \)

\( T=0, \ S=1 \)

\[ {}_{12}^{22}\text{Mg}_{10} \quad {}_{11}^{22}\text{Na}_{11} \quad {}_{10}^{22}\text{Ne}_{12} \]