Neutrino Mass, Neutrinoless Double EC and Rare Beta Decays

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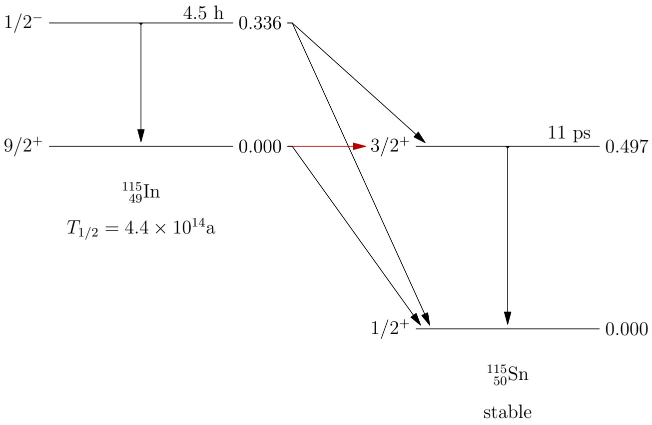
- The 0νECEC Decay of ^{112}Sn

Topic I

^{115}In: Beta decay with an ultra-low Q value

^{115}In: Beta decay with an ultra-low Q value

First discovered by Cattadori et al. (Nucl. Phys. A 748 (2005) 333)



Suggested as a possible independent experiment to look for the neutrino mass

Experimental results

LNGS (C.M. Cattadori et al.)	first observation
	$b = 1.18(31) \times 10^{-6}$
	$T_{1/2}^{\text{partial}} = 3.73(98) \times 10^{20}$ a
HADES (J.S.E. Wieslander et al.)	$b = 1.07(17) \times 10^{-6}$
	$T_{1/2}^{\text{partial}} = 4.1(6) \times 10^{20}$ a
JYFLTRAP (T. Eronen et *al*.)	$Q_{\beta^-} = 0.35(17)$ keV

Lowest Q value recorded so far!
Previous record: ^{187}Re $Q_{\beta^-} = 2.469(4)$ keV [1]

[1] M.S. Basunia, Nucl. Data Sheets 110 (2009) 999.

Theory

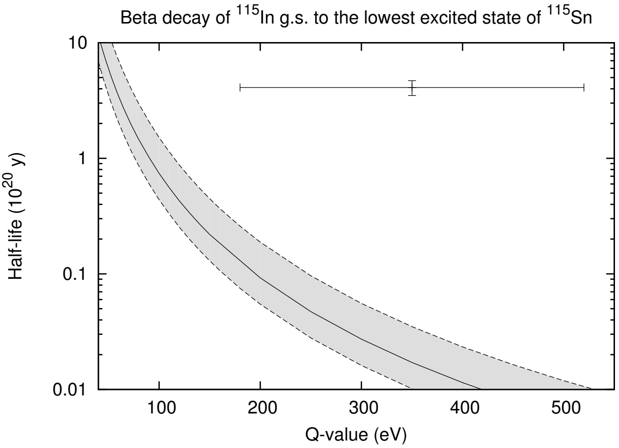
- 2nd-forbidden unique $^{115}\text{In}(9/2^+) \rightarrow {}^{115}\text{Sn}(3/2^+)$ decay
- dependent on only one nuclear matrix element (NME) M

$$T_{1/2} = \frac{1}{M^2 f_K(w_0, Z_f, R)}$$

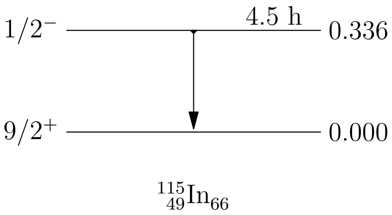
- wave functions from the proton-neutron microscopic quasiparticle-phonon model (pnMQPM)
- pnMQPM was previously successfully applied to the 4th-forbidden non-unique $^{115}\text{In}(9/2^+) \rightarrow {}^{115}\text{Sn}(1/2^+)$ g.s.-to-g.s. decay ($\log ft$, half-life, electron spectrum) [2]

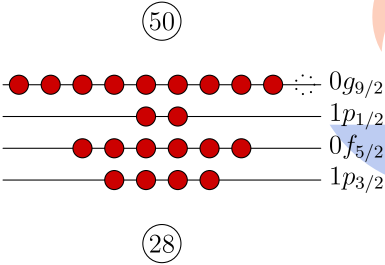
[2] M.T. Mustonen and J. Suhonen, Phys. Lett. B 657 (2007) 38.

Experiments meet theory

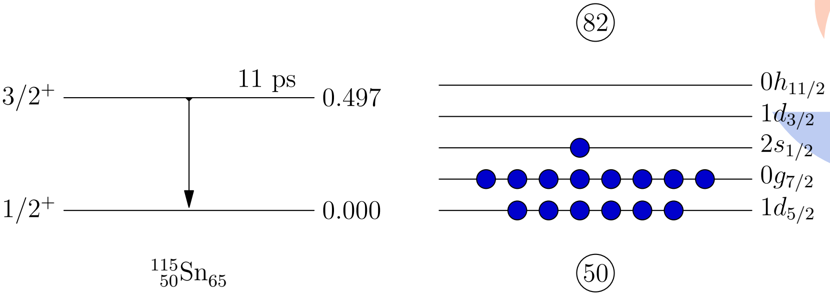


Nuclear wave functions: Naïve picture for protons (In)





Nuclear wave functions: Naïve picture for neutrons (Sn)



Possible sources of the discrepancy

Nuclear wave functions?

- MQPM and pnMQPM take also into account the 3-qp degrees of freedom
  $\Rightarrow$ Relevant states still dominantly 1-qp states
- To explain the discrepancy, the NME should be wrong by an order of magnitude!
- Maybe the problem lies in the *lepton* wave functions...

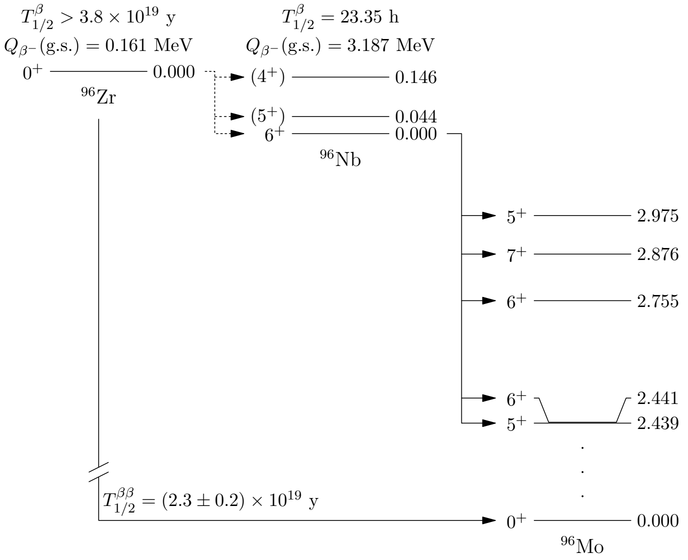
Atomic effects for ultra-low Q values

- electron screening (not estimated for forbidden decays)
- atomic overlap (previous approximations break down)
- exchange effects (contradictory results for low Q values)
- final-state interactions (estimates only for tritium beta decay)

Topic II

^{96}Zr: Competition of beta and double beta decays

^{96}Zr decay channels



Results and conclusion for ^{96}Zr

- Transitions from pnQRPA vacuum to pnQRPA excitations

J_f	Forbiddeness	Q value [keV]	$T_{1/2}$ [a]
6^+	6*th* non-unique	161	4.9×10^{29}
5^+	4*th* unique	117	2.6×10^{20}
4^+	4*th* non-unique	15	2.3×10^{23}

- Calculated total $T_{1/2}^{\beta} = 2.6 \times 10^{20}$ a
- Experimental $T_{1/2}^{\beta\beta} = (2.3 \pm 0.2) \times 10^{19}$ a
- Published in J. Phys. G: Nucl. Part. Phys. 34 (2007) 837.
- Conclusion: The single beta-decay rate is much slower than the double-beta-decay rate!

Topic III

The 0νECEC Decay of ^{112}Sn

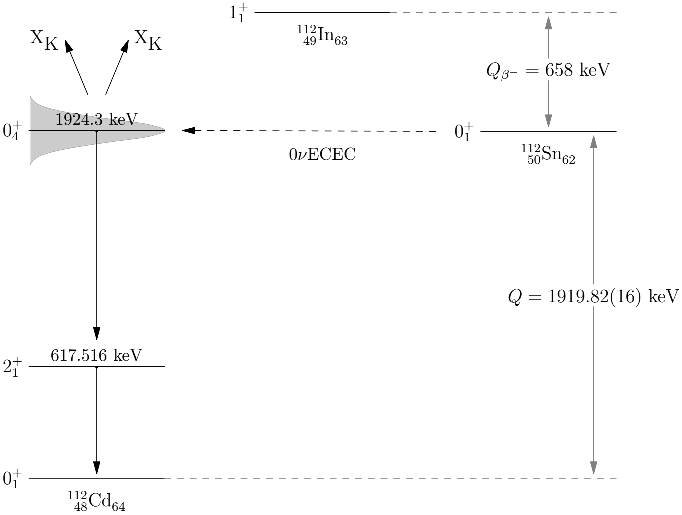
The 0νECEC decay rate is enhanced by the resonance condition:

$$\frac{1}{T_{1/2}} = \frac{(\Delta M)^2}{(Q-E)^2 + \Gamma^2/4}\Gamma \,, \quad Q - E = \text{ degeneracy parameter}$$

- ΔM = atom-mixing parameter containing the nuclear matrix element
- $Q = M(Z,A) - M(Z-2,A)$ = difference between the initial and final atomic masses
- $E = E^* + E_H + E_{H'}$ = nuclear excitation energy + electron binding
- $\Gamma = \Gamma^* + \Gamma_H + \Gamma_{H'}$ = nuclear and atomic radiative widths

Candidates: $^{74}\text{Se} \rightarrow {}^{74}\text{Ge}(2^+)$, $^{78}\text{Kr} \rightarrow {}^{78}\text{Se}(2^+)$, $^{112}\text{Sn} \rightarrow {}^{112}\text{Cd}(0^+)$, ...

Resonance decay of ^{112}Sn



Resonance 0νECEC decay of ^{112}Sn

Γ = few tens of eV

Q value measured by S. Rahaman et *al.* in JYFLTRAP

$Q-E$	$=$	$-4.5\,\mathrm{keV}$	for	KK capture
	$=$	$18.2\,\mathrm{keV}$	for	KL capture
	$=$	$40.9\,\mathrm{keV}$	for	LL capture

Hence:

$$T_{1/2} > \frac{5.9\times 10^{29}}{(m_\nu[\mathrm{eV}])^2}\ \mathrm{years}$$

Conclusion: Decay rate much suppressed by the rather large degeneracy parameter

Conclusions and Outlook

Conclusions:

- ^{115}In decays by an ultra-low Q value $\longrightarrow$ ATOMIC effects important
- In the case of ^{96}Zr decay The single beta-decay rate is much slower than the double-beta-decay rate
- The 0νECEC decay of ^{112}Sn is NOT OBSERVABLE due to badly fulfilled resonance condition

Outlook:

- Much work needed to chart the magnitudes of the atomic effects in beta decays with ultra-low Q values
- Other resonant 0νECEC decays should be studied for their Q values using the atom trap techniques (e.g. the case of ^{74}Se)