Resonance conditions of neutrinoless double-electron capture in cadmium and osmium isotopes investigated at TRIGA-TRAP

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Introduction and motivation: An open question in neutrino physics is whether the neutrino is its own antiparticle, i.e. of Majorana type. The observation of a neutrinoless double-beta transition could give the answer to that question [1]. However, such transitions are difficult to observe due to their long half-life. For nuclides undergoing double-electron capture, the decay rate is resonantly enhanced in case of an energy degeneracy of the ground state of the mother nuclide and the nuclear and/or atomic excited state of the daughter nuclide [2, 3]. In this case the double-electron capture can take place without the emission of an additional photon to carry away the excess energy, which leads to a significantly higher decay rate. The resonance condition for double-electron capture is fulfilled if the excess energy $\Delta = \left(Q - E_\gamma - B_{2h}\right)$ is smaller than the sum of widths of the two-electron-hole state and the nuclear excited state of the daughter nucleus Γ_{2h}. Q denotes the Q-value, i.e. the mass difference of the atomic masses $(M_m - M_d)$ of the mother and daughter nuclides, E_γ the nuclear excitation energy, and B_{2h} is the energy of the double-electron hole state. The uncertainty of the Q-value is often the limitation for the identification of resonantly enhanced transitions. High-precision measurements of the Q-value with Penning-trap mass spectrometers such as TRIGA-TRAP [4] can provide direct measurements of double-electron capture Q-values with the precision of a few hundred electron volts or better [5]. Thereby, resonantly enhanced transitions can be identified. In 2011 we have investigated three double-electron capture Q-values of the transitions ^{106}Cd-^{106}Pd, ^{108}Cd-^{108}Pd, and ^{184}Os-^{184}W.

Experimental setup and results: The mass and Q-value measurements were performed offline with TRIGA-TRAP using the laser ablation ion source [6] equipped with cadmium, palladium and tungsten foils with natural isotopic abundance. Due to the low isotopic abundance of ^{184}Os (0.02%) a target was prepared from a sample enriched in ^{184}Os (1.5% abundance) and pressed into a pellet using silver powder as adhesive material. The Q-values were measured by recording alternately the cyclotron frequency of the mother and daughter nuclide with the time-of-flight ion-cyclotron resonance (TOF-ICR) method. A Ramsey excitation scheme was used with two excitation pulses of 100 ms and a waiting time of 800 ms in between for cadmium and palladium, and two excitation pulses of 200 ms excitation and 1600 ms waiting time for osmium and tungsten. The Q-value is obtained from the frequency ratio $r = \nu_m/\nu_d$ from the mother to the daughter nuclide:

$$Q = M_m - M_d = (M_m - m_e)(1 - r),$$

where m_e denotes the electron mass. The Q-values obtained from the measurements are listed in Table 1.

Transition	Q_{exp} / keV	$Q_{AME2003}$ / keV
^{106}Cd-^{106}Pd	2775.01 (0.56)	2770 (6)
^{108}Cd-^{108}Cd	272.04 (0.55)	272 (7)
^{184}Os-^{184}W	1453.68 (0.58)	1451.2 (1.0)

Table 1: Q-values of double-electron capture transitions determined by TRIGA-TRAP and the literature Q-value from the Atomic-Mass Evaluation (AME) 2003.

Q-values of three double-electron capture transitions were determined. In case of ^{106}Cd the Q-value from a previous experiment [7] was confirmed. An energy degeneracy to an excited $(2, 3)^-$ state at 2748.2(4) keV excitation energy was found [7, 8], but the decay rate is suppressed due to the negative parity of the excited state and the double-electron capture probability from KL_3 orbitals. The Q-values of the double-electron capture in ^{108}Cd and ^{184}Os were measured by Penning-trap mass spectrometry for the first time and their uncertainties were reduced. No resonant enhancement was found for ^{108}Cd. ^{184}Os has an excited 0^+ state at 1322.152(22) keV excitation energy and an energy excess of 11.3(1.0) keV for the capture of two K-shell electrons. The upper limit for the half-life predicted for this transition is about 10^{27} years [8], which is rather short compared to other double-electron capture transitions. Our measurement yields a smaller excess energy of 8.83 (0.58) keV suggesting the half-life to be shorter. Our data will be useful for a recalculation of the half-life.

Conclusion and outlook: Three Q-values of double-electron capture nuclides were measured. For ^{106}Cd the value from [7] was confirmed. For ^{108}Cd and ^{184}Os, the uncertainty was significantly improved. Our result can be used to recalculate the half-life of ^{184}Os in order to decide whether it is a suitable nuclide to observe the neutrinoless double-electron capture.

References

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