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Lifetimes of the 0_2^+ Configuration in ^{186}Hg and ^{188}Hg

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Abstract. A new picosecond lifetime measurement system developed at UNISOR was used to determine the lifetime of the well-deformed 0_2^+ levels in ^{188}Hg and ^{186}Hg. The half-life values were measured to be 288 $\pm$ 63 ps in ^{188}Hg and $\leq$ 52 ps in ^{186}Hg. The corresponding values of $\rho^2(E0)$ x 10^3 obtained from the E0 partial half-lives are $5.5^{+1.5}_{-2.3}$ and $\geq$ 32, respectively. Additionally, the half-lives of the 2_2^+ levels were determined to be 199 $\pm$ 44 ps in ^{188}Hg and 66 $\pm$ 37 ps in ^{186}Hg.

1. Introduction

Coexisting bands of quite different deformation in ^{184,186,188}Hg have been known for some time from in-beam reaction [1, 2] and radioactive decay [3, 4] studies. The latter work also observed electric monopole (E0) transitions in these neutron deficient Hg isotopes and precipitated the evolution of this region into a classic example of widely-occurring, nearly degenerate, nuclear shape coexistence. These data have been extended to include ^{180}Hg [5], ^{182}Hg [6], and ^{190}Hg [7].

A direct measure of the mixing of coexisting shapes in even-even nuclei is the E0 strength between the intruder state and the ground state [8]. Electric monopole transitions carry direct information on the nuclear wavefunction. Changes in the nuclear radius lead to non-vanishing values for the monopole strength function, $\rho(E0)$, provided there is mixing between the initial and final nuclear states [8]. To measure $\rho(E0)$ experimentally, all that is needed is a measurement of the partial half-life of the 0_2^+ level.

Half-life limits of < 180 ps for the 0_2^+ level in ^{188}Hg and < 200 ps in ^{186}Hg have been reported [9]; and another rough measurement yielded a half-life of 0.9 ± 0.3 ns for the 0_2^+ level in ^{184}Hg [4]. These Hg isotopes present a unique challenge to the measurement of 0_2^+ lifetimes in the picosecond range since the complexity of the decay demands a triple coincidence and the major depopulating transition from the 0_2^+ (deformed, $\beta \approx 0.25$)[10] levels to the 0_1^+ (spherical, $\beta \approx 0.13$) [10], is E0 internal conversion .

2. Experimental Techniques

A picosecond lifetime measurement system, based on the design at TRISTAN [11], was developed at UNISOR to measure the lifetimes of the 0_2^+ configurations in ^{188}Hg and ^{186}Hg. The ^{188}Tl and ^{186}Tl parent nuclei were produced as recoils from the reaction of 181-MeV ^{16}O on ^{181}Ta. Four detectors employed in various combinations were used in the collection of triple coincidences using a fast-slow timing system. The fast signal was established in one case by a plastic scintillator for β^+ particles and a BaF_2 crystal for x-rays, and in the other case by two BaF_2 crystals for x-rays. A Ge γ-ray detector or a Si(Li) e^- detector were used to select the energy information via the slow timing circuit.

For lifetime measurements in ^{186}Hg, fast timing was achieved via the coincidences between β^+-particles and the x-rays which follow internal conversion. Specific E0 conversion events were selected via the slow timing circuit by gating on the appropriate internal conversion line in the Si(Li) detector. It is this $(\beta^+ - x) - e^-$ triple coincidence which enables one to determine the lifetime of the 0_2^+ state.

The decay of ^{188}Tl populates levels in ^{188}Hg predominantly by electron capture. In this case two BaF_2 detectors were used to establish the fast timing. The lifetime for the 0_2^+ level in ^{188}Hg was then measured using the triple coincidence $(x - x) - e^-$, where one x-ray follows electron capture and the second internal conversion. This unique system is thoroughly described in ref. [12].

3. Results

The centroids of the time-to-amplitude converter (TAC) signals from triple coincidences of $(\beta^+ - x) - e^-$ for the 523-keV ($0_2^+ \longrightarrow 0_1^+$) and 215-keV ($2_2^+ \longrightarrow 2_1^+$) transitions in ^{186}Hg were compared to the centroids of the TACs from transitions of known lifetimes [12]. The comparisons, using the centroid shift method, yield a half-life for the 0_2^+ level of ≤ 52 ps and 66 ± 37 ps for the 2_2^+ level. The timing resolution for $(\beta^+ - x) - e^-$ coincidences was 1.19 ns, measured as FWHM (full width at half maximum).

The $(x - x) - e^-$ TAC widths for the 413-keV ($2_1^+ \longrightarrow 0_1^+$), 824-keV ($0_2^+ \longrightarrow 0_1^+$)and the 468-keV ($2_2^+ \longrightarrow 2_1^+$) transitions in ^{188}Hg were compared in order to extract the lifetime of the 0_2^+ and 2_2^+ levels respectively [12]. The lifetime for the 0_2^+ and 2_2^+ levels were determined to be 288 ± 63 ps and 199 ± 44 ps, respectively. The timing resolution achieved for $(x - x) - e^-$ events was 1.58 ns, FWHM.

For ^{188}Hg, it is difficult to determine the $0_2^+ \longrightarrow 2_1^+$ branching because this transition energy (411 keV) is nearly identical to that of the intense $2_1^+ \longrightarrow 0_1^+$ transition. By using a sum-peak analysis it was determined that the 411 keV, $0_2^+ \longrightarrow 2_1^+$ E2 branch is $\leq 42\%$. In ^{186}Hg the $0_2^+ \longrightarrow 2_1^+$ branch was equally difficult to measure but determined to be $\leq 28\%$. Since both of the $0_2^+ \longrightarrow 0_1^+$ branches could actually be 100%, the E0 partial half-lives are expressed as 288^{+207}_{-63} ps in ^{188}Hg and ≤ 72 ps in ^{186}Hg. Hence the $\rho^2(E0)$ x 10^3 values for ^{188}Hg and ^{186}Hg were calculated, using the method of Kantele [13], to be $5.5^{+1.5}_{-2.\text{[illegible]}}$ and ≥ 32, respectively.

Nucleus	$E(0_2^+)$ keV	$T_{1/2}(0_2^+)$ ps	E0 branch	$T_{(1/2)p}(0_2^+)$ ps	$\rho^2(E0)$ [1] x 10^3	V_0 keV	$E(2_2^+)$ keV	$T_{1/2}(2_2^+)$ ps
^{188}Hg	824	288 ± 63	$\geq 58\%$	288^{+207}_{-63}	$5.5^{+1.5}_{-2.3}$	73^{+9}_{-18}	881	199 ± 44
^{186}Hg	523	≤ 52	$\geq 72\%$	≤ 72	≥ 32	≥ 111	620	66 ± 37

1) calculated using the method of Kantele [13]

Large E0 strength is an indication of strong mixing between nuclear states with quite different mean-square radii. The results determined here for $\rho^2(E0)$ in ^{188}Hg and ^{186}Hg are consistent [8, 14] with the coexistence of shapes built upon a proton 2-hole configuration (near spherical) and a proton 2-particle, 4-hole configuration (deformed). Based on these $\rho^2(E0)$ values, the mixing matrix element V_0, calculated using the formalism of ref [15], are 73^{+9}_{-18} keV for the 0_2^+ level in ^{188}Hg and ≥ 111 keV for the 0_2^+ level in ^{186}Hg . These results suggest that the early measurement of the half-life of the 0_2^+ state in ^{184}Hg [4], 0.9 ± 0.3 ns, should be reinvestigated, and that stricter limits on the $0_2^+ \longrightarrow 2_1^+$ branching in all these Hg isotopes should be determined.

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