Nuclear excitation by two-photon electron transition

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Synopsis A new mechanism of nuclear excitation via two-photon electron transitions (NETP) is proposed and studied theoretically. As a generic example, detailed calculations are performed for the E1E1 $1s2s\,^1S_0 \rightarrow 1s^2\,^1S_0$ two-photon decay of He-like $^{225}Ac^{87+}$ ion with resonant excitation of the 3/2+ nuclear state at energy 40.09(5) keV. The probability that the two-photon decay will happen via the nuclear excitation is found to be $P_{\rm NETP} = 3.5 \times 10^{-9}$. The possibility for the experimental observation of the proposed mechanism is thoroughly discussed.

Atomic physics has kept a tenable position for many decades in the foundation and development of our knowledge on nuclear properties. In particular, much informations about the nuclear spins, nuclear magnetic moments, and mean-square charge radii originate from atomic spectroscopy. Apart from the properties of the nuclear ground or isomeric states, atomic spectroscopy provides access also to the internal nuclear dynamics, e.g., to single nuclear resonances that can be accessed via certain electron transitions.

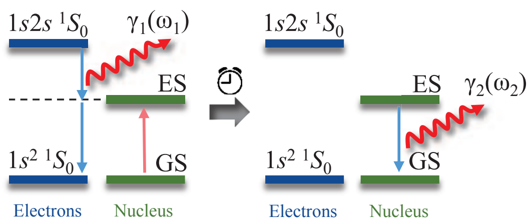

Figure 1. NETP mechanism.

In Ref. [1], we presented and discussed a new mechanism for nuclear excitation to which we refer as nuclear excitation by two-photon electron transition (NETP). An electron transition can proceed not only via the emission of one photon but also the simultaneous emission of two photons that just share the transition energy. In contrast to the one-photon transitions, where the photon frequency equals the transition energy, the energy distribution of the spontaneously emitted photons then forms a continuous spectrum. This implies, that some of the photons exactly match in their frequency with the nuclear transition energy as long as the nuclear excitation energy is smaller than the total electron transition energy. In this way, a nucleus may resonantly absorb the photon and gets excited. A key advantage of the NETP process is that such resonant nuclear excitations may happen for all nuclear levels with an access energy smaller than the total transition energy. The NETP process is shown in Fig. 1 in a more picturesque way. The initial state (left panel), which is characterized by the $1s2s\,^1S_0$ electronic state and the nuclear ground state (GS), decays into the final state (right panel) where both, the electrons and nucleus are in their $1s^2\,^1S_0$ nuclear ground states, respectively. This decay occurs however via the intermediate cascade state with the nucleus being in the excited state (ES). During this process, again, two photons γ_1 (electron decay photon) and the delayed γ_2 (nuclear fluorescence photon) are emitted.

For the given example of the E1E1 two-photon transition $1s2s\,^1S_0 \rightarrow 1s^2\,^1S_0$ in He-like $^{225}Ac^{87+}$ ion, we found that the probability of the two-photon decay via nuclear excitation is surprisingly large, $P_{\rm NETP} = 3.5 \times 10^{-9}$. In order to verify the proposed mechanism, the observation of the delayed emission of the nuclear fluorescence γ_2 photons is suggested. We expect to stimulate up to few hundreds nuclear fluorescence photons per day of beamtime at the current GSI (Darmstadt) facility. This looks very feasible for the successful observation and characterization of the NETP process.

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References

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