The controlled excitation of the ^{229}Th nucleus via atomic processes

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Synopsis In this contribution we give an overview over possible mechanisms for the excitation of atomic nuclei via processes in the electron shell. We use multiconfiguration Dirac-Fock calculations and b-spline solutions of the Dirac equation to investigate these processes with regard to their applicability for the controlled excitation of the low lying isomeric state in doubly and triply charged ^{229}Th.

The thorium isotope with mass number 229 is unique in the sense that its nucleus has a very low first excited (isomeric) state. This state has been found by analyzing the fluorescence photons from a highly excited ^{229}Th nucleus for different decay paths allowing for the determination of its energy to about ten electronvolts [1]. Only recently the low lying isomeric state in ^{229}Th has been directly detected for the first time [2]. The exact energy of the state however remains unknown and could only be narrowed down to the interval between 6.3eV and 18.3eV.

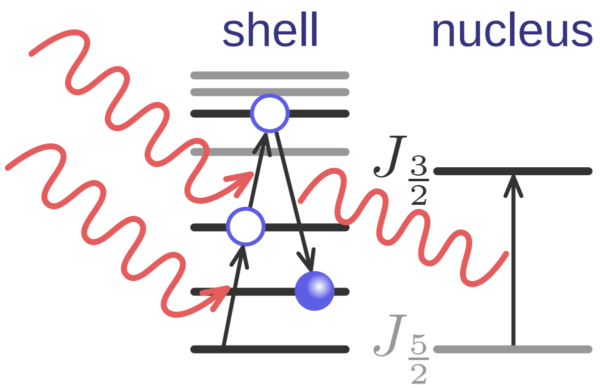

Figure 1. Scheme of the NEET process as implemented experimentally for the excitation of ^{229}Th^{2+}.

After its detection, the next essential step to make the nuclear clock transition in ^{229}Th accessible for application is its controlled excitation from the nuclear ground state. Because of the extremely narrow linewidth of nuclear levels it is not favourable to directly photoexcite the nucleus. More promising in contrast are processes where electrons couple to the nucleus and excite it. One of these processes is called *nuclear excitation by electron transition* (NEET) that has been already observed experimentally in ^{197}Au. Currently NEET is investigated for ^{229}Th^{2+} using the scheme displayed in Fig. 1. The thorium atom is brought to an excited state in two steps and the excess energy from the subsequent deexcitation excites the nucleus. Up to now a theoretical investigation of this three step process has only been performed for the case of triply charged thorium. For the planning and guidance of current and future experiments with ^{229}Th^{2+}, however, liable theoretical predictions are necessary. In this contribution we will discuss the influence of e.g. different excitation paths, finite nuclear size effects and interference between the contributing processes on the nuclear excitation probability in the process sketched in Fig. 1.

Yet another promising candidate for the excitation of atomic nuclei is the so called nuclear excitation by two-photon electron transition (NETP) [3]. This process starts with the preparation of the atom in an excited state that mainly deexcites via two-photon emission. When this state deexcites one of the photons can transfer energy to the nucleus and excite it. Such an excitation becomes visible as two peaks in the time integrated spectrum of emitted photons. NETP has two major advantages compared to NEEP: (i) Because the energy share between the photons is continuous it is not necessary that an atomic transition is in resonance with the nuclear isomeric state as for NEET and (ii) NETP works also for highly charged or even helium-like systems and thus it can be treated theoretically with much higher precision. We will present calculations for NETP and discuss possible challenges for its usage to excite ^{229}Th.

References

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