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FAST ELECTRIC DIPOLE TRANSITIONS IN Ra-Ac NUCLEI

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Abstract:

Lifetimes of levels in ^{225}Ra, ^{225}Ac, and ^{227}Ac have been measured by delayed coincidence techniques and these have been used to determine the E1 gamma-ray transition probabilities. The reduced E1 transition probabilities in ^{225}Ra and ^{225}Ac are about two orders of magnitude larger than the values in mid-actinide nuclei. On the other hand, the E1 rate in ^{227}Ac is similar to those measured in heavier actinides. Previous studies suggest the presence of octupole deformation in all the three nuclei. The present investigation indicates that fast E1 transitions occur for nuclei with octupole deformation. However, the studies also show that there is no one-to-one correspondence between E1 rate and octupole deformation.

1. Introduction

Recent theoretical calculations [Cha80, Lea82, Lea84a] and measurements [Ahm82, She83, Ahm84] show that strong octupole correlation and/or octupole deformation effects play an important role in the description of nuclides in the mass 220-230 region. A signature of octupole deformation in an odd-mass deformed nucleus is the occurrence of a parity doublet which consists of two almost degenerate levels with the same spin but opposite parities. It has been observed [She83, Ahm84] that the presence of strong octupole correlations in the nuclear ground state modifies many single particle properties considerably. Nuclear properties which are affected are M1 transition rates, decoupling parameters, Coriolis matrix elements, and E1 transition rates.

In heavy elements the E1 transition probabilities are typically 1.0×10^{-6} Weisskopf units for $\Delta K=1$ transitions and 1.0×10^{-4} w.u. for $\Delta K=0$ transitions. We define fast E1 transitions as transitions with rates of $>1.0 \times 10^{-3}$ w.u. Recently we have measured [Ish85] level lifetimes in ^{225}Ra and ^{225}Ac which indicte the presence of fast E1 transitions in these nuclei. In the present article we present the measurements of these fast E1 transitions and discuss recent theoretical calculations.

2. Source preparation

Thin sources of the radioactive materials on thin backing were prepared for the alpha-electron and electron-electron delayed coincidence measurements. Sources of ^{229}Th and ^{231}Pa were prepared in the Argonne electromagnetic isotope separator by depositing the material on 40-μg/cm^2 carbon foils. The ^{225}Ra samples were obtained by depositing freshly purified ^{225}Ra on 100 μg/cm^2 polypropylene films. The 14.8-d ^{225}Ra was obtained by separating it from approximately one mg of ^{229}Th (7300 y). The Th sample had almost equal amount of alpha activity from ^{229}Th and the shorter lived ^{228}Th (1.91 y). The purified sample was allowed to decay for 2 months so that the shorter lived ^{224}Ra could decay out. After this decay period the sample was repurified to remove any Th left over from the frst separation. This material was placed on a 100 μg/cm^2 polypropylene film and dried. Gamma-ray analysis showed that the sample contained less than 1% ^{224}Ra activity.

3. Experimental results

The level lifetimes described here were measured by delayed coincidence techniques. Since the electron energies involved in the measurement were quite low (up to 10 keV) and high resolution was needed to isolate the individual levels, the source and the detectors were placed in a vacuum chamber. Two bare pilot B detectors (1 mm and 2 mm thick), each mounted on an RC8575 photomultiplier tube, were used to detect the electrons. For the α-e^- coincidence setup, one of the Pilot B detectors was replaced by a high-resolution Si detector. Fast timing signals, derived with constant fraction discriminators, were used to start and stop a time-to-amplitude converter (TAC). The TAC linear output and the two energy signals were connected to ADC's which, in turn, were interfaced to a PDP 11/23 computer. The strobe signal was provided by the triple (two energy signals and the TAC output) coincidence output. The three parameter events were collected on a tape in the event-by-event mode and were later sorted out with appropriate gates. The TAC spectra were calibrated with a time calibrator unit and the half-lives were computed with a least-squares analysis program.

3.1 Half-life of the 40.0-keV state in ^{225}Ac

A freshly prepared ^{225}Ra source on a 100 μg/cm^2 polypropylene backing was used for the measurement of the level lifetime in ^{225}Ac. The decay scheme of ^{225}Ra is shown in Fig. 1. The excited state at 40.0 keV receives most of the

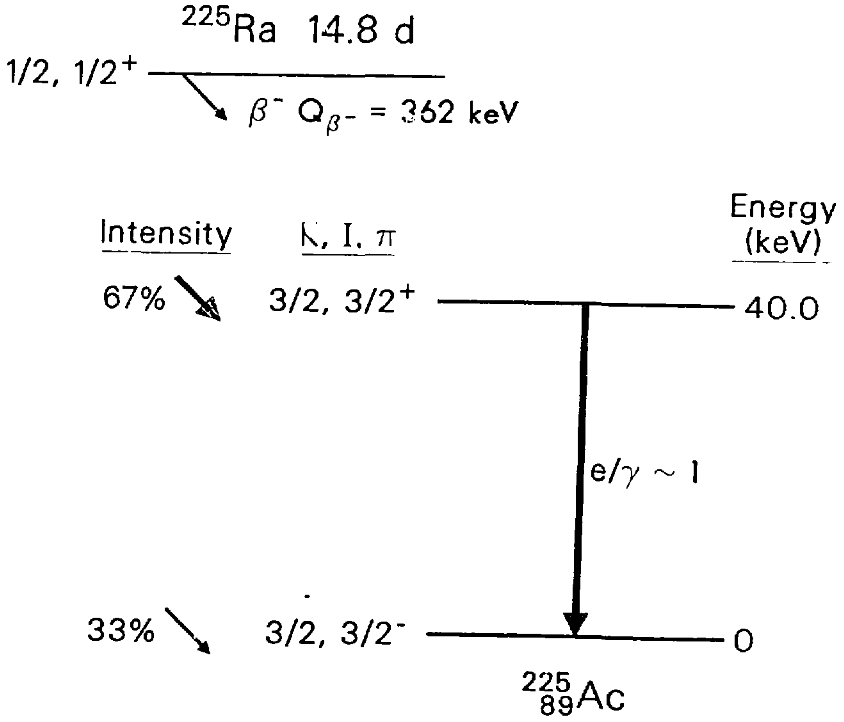

Fig. 1. Decay scheme of ^{225}Ra.

β^- population and it deexcites by a 40.0 keV E1 transition which has a total conversion coefficient of ~1. Since the Pilot B detector is sensitive to α-particles (6 Mev α-particles produce signals of the same size as 500 keV electrons), a 12 mg/cm^2 Al foil was used to prevent the α-particles from reaching the start detector. This foil also absorbed electrons upto 60 keV energy. No absorber, except the source backing, was used on the stop side; the threshold on this detector was set at 10 keV. The three parameter events were collected over a three-day period producing several spectra. The TAC spectrum measured during the first half hour of the experiment is displayed in Fig. 2. A least-squares fit to the data gave a half-life of 0.72 ± 0.03 ns.

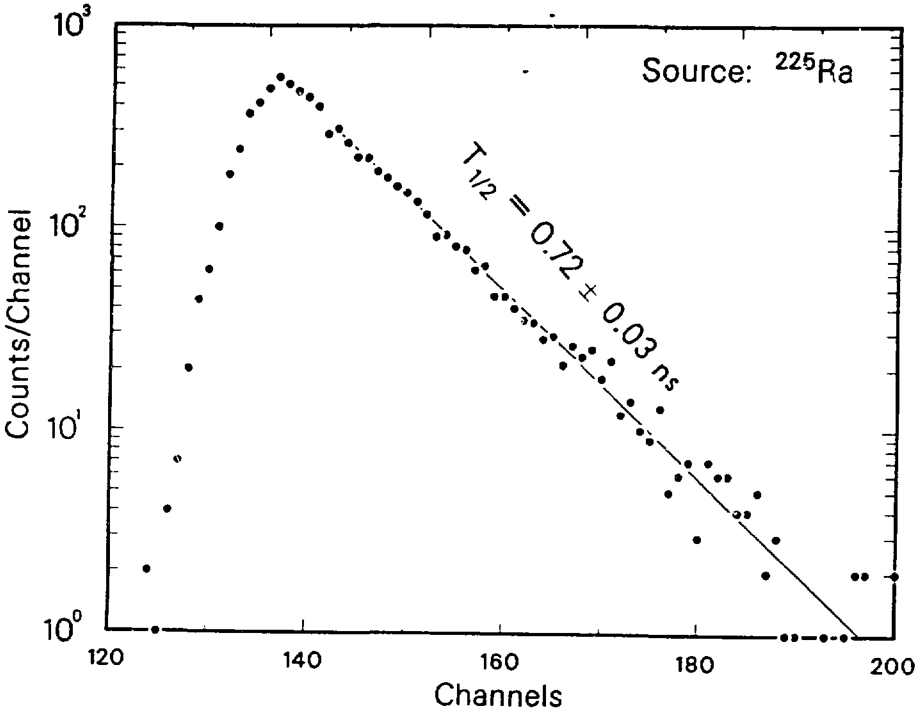

Fig. 2. Time spectrum showing the decay of the 40.0-keV level in ^{225}Ac. Start signals included 80-300 keV electrons and stopo stop signals were 20-40 keV electrons.

3.2. Half-life of the 31.6-keV state in ^{225}Ra

The half-lives of levels in ^{225}Ra were measured by α-e$^-$ delayed coincidence technique. The α-particles were detected with a 6-mm diameter Au-Si surface barrier detector and the elctrons were detected with the 1 mm thick pilot B detector. α-particle singles [Bar70, Hel85] and coincidence [Hel85] studies show that only < 0.2% alpha intensity occurs at the 31.6-keV level. Therefore the start signals were obtained from the α_{236} peak (the 236 keV level partly decays via the 31.6-keV level). The time spectrum obtained in coincidence with α_{236} peak and 15-25 keV electrons contained three main components. The longest component in the spectrum was not present when the electron gate was set above 35 keV. This clearly indicates that the longest lifetime belongs to the 25.4 or 31.6 keV level. The half-life of the 25.4-keV level was obtained by measuring the TAC spectrum in coincidence with α_{25} and 15-25 keV electrons and was found to be 0.88 ± 0.04 ns. Therefore, the longest component in the *spectrum belongs to the 31.6 keV level. A least-squares analysis gave a half-*life of 2.1 ± 0.2 ns.

3.3 Half-life of the 27.4 keV state in ^{227}AC

We have performed coincidence measurements to establish that the 38 ns half-life previously measured [Led78] belongs to the 27.4 keV level. The relevant portion of the ^{231}Pa decay scheme is shown in Fig.3. The major alpha transitions populate the 29.9 and 46.4 keV levels; very little intensity occurs at the 27.4 keV level. The 29.9 keV level decays to the ground state by a fast highly converted M1 transition and the 46.4 keV level decays via the 27.4 keV level. Both the 29.9 and 18.9 (46.4-27.4) keV transitions generates Ac L X-rays.

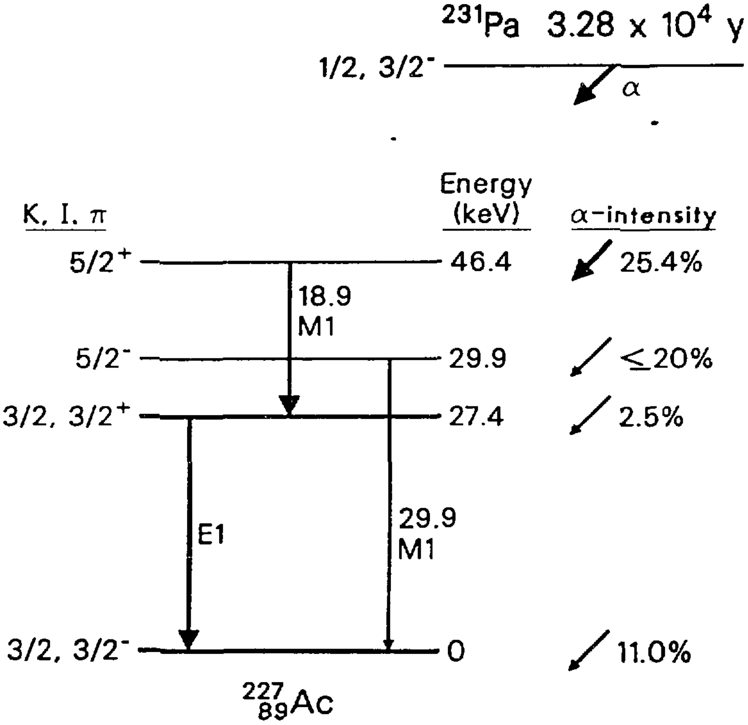

Fig. 3. Partial decay scheme of ^{231}Pa.

An α-γ coincidence experiment was performed using a cooled Si(Li) detector for the detection of photons and a Si detector for the detection of α-particles. Three parameter events were collected on tape and one dimensional spectra were later generated in coincidence with various gates. The spectra showed that the α_{46} and α_{30} are in prompt coincidence with L X-rays and the delay occurs at the 27.4 keV level. The analysis of the time spectrum between the α_{46} group and the 27.4 keV photopeak gave a half-life of 38.3 ± 0.3 ns, in agreement with previous measurements.

Discussion

From the measured level half-life, $T_{1/2}$, we have derived the gamma transition probabilities, T_{ex}, of the El γ-rays. These are given by the equation

$$T_{ex} = \frac{0.693.f}{T_{1/2} \cdot C^2} , \qquad (1)$$

where f is the fraction of the total decay from the particular level which occurs by the given transition, and C^2 is the square of the appropriate Clebsch-Gordon coefficient between the two levels. In cases, where a single transition deexcites the level, $f = (1 + \alpha_T)^{-1}$, α_T being the total conversion coefficient. The above transition rate was divided by the Weisskopf estimate (w.u.) to obtain an energy-independent quantity. We have plotted this quantity for all known ΔK=0 E1 transitions in heavy elements against the mass number in Fig. 4. The values for ^{225}Ac, ^{227}Ac, and ^{225}Ra are from the present work; other data are taken from literature [Led78, Asa60]. In Fig. 4 there is a definite enhancement in the E1 rate for the ^{225}Ac, ^{225}Ra, and ^{229}Pa nuclei.

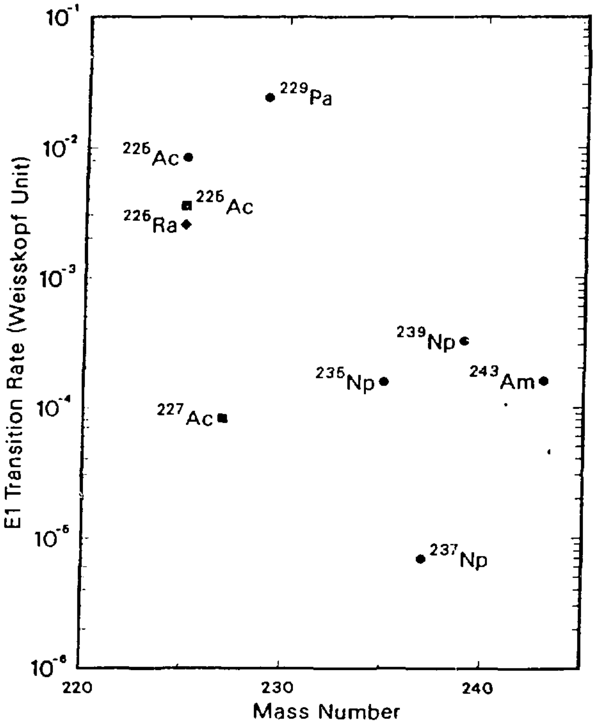

Fig. 4. Known transition rates of the ΔK = 0 E1 transitions in odd-mass heavy nuclei.

Theoretical calculations [Cha77] indicate that the E1 matrix elements do not change much with the decreasing β_2 deformation between a given pair of states. One, therefore, expects that the E1 rate should not change with mass number. Thus the large enhancement in E1 rates for nuclei with A<230 suggests that these nuclei have some different nuclear structure properties. It has been established in previous studies that these three nuclei possess strong octuplole correlations in their ground states. This indicates that enhancements in E1 rate are associated with octupole deformation. However, in ^{227}Ac, which also has strong ground state octupole deformation related properties, there is no such enhancement. Thus the present data on E1 rates in odd-mass nuclei show that there is no one-to-one correspondence between octupole deformation and the enhanced E1 rates.

So far, E1 transition rates have not been calculated with wavefunctions including octupole deformation. However, semiquantitative calculations performed by Chasman [Ahm84] and Leander [Lea84b] indicate that octupole deformation causes large enhancemets and large fluctuations in E1 rates.

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