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Remeasurement of the half-life of the 615 keV level in ^{181}Ta

C.C. Dey[a]

Saha Institute of Nuclear Physics 1/AF, Bidhannagar, Kolkata, 700 064, India

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Abstract. The lifetimes of the 615 and 619 keV levels in ^{181}Ta have been remeasured by using a β-γ delayed coincidence set up with fast plastic (Pilot U) and BaF_2 detectors. The presently measured values for both levels have been found to be in strong disagreement with results reported earlier. For the 615 keV level, the half-life has been found to be $T_{1/2} = 12.1 \pm 0.1$ ns in striking contrast to the earlier reported value of 17.6 μs. The half-life of the 619 keV level has been found to be $T_{1/2} \leqslant 230$ ps, whereas values of 0.87 ns and 2.4 ns were reported previously. The nanosecond half-life of the 615 keV level has been confirmed from a separate measurement by employing a NaI(Tl)-Pilot U detector combination. The importance of lifetime measurements for the 615 keV level in perturbed angular correlation studies is discussed.

PACS. 23.20.-g Electromagnetic transitions – 21.10.Tg Lifetimes

1 Introduction

The measurement of nuclear lifetimes is important to determine the structure of nuclear levels. From the measured lifetime, the reduced transition probabilities $B(M1)$ and $B(E2)$ for different γ-transitions depopulating this level can be determined. These values can be compared with the corresponding Weisskopf single-particle estimates in order to study enhancement or retardation effects.

The lifetimes for the 619 and 615 keV levels in the ^{181}Ta deformed nucleus were measured earlier. For the 619 keV level, two values of lifetimes were reported. These are 0.87 ± 0.02 ns [1] and 2.4 ± 0.5 ns [2]. Clearly, these two values are not in agreement with each other. For the 615 keV level, a value of $T_{1/2} = 17.83 \pm 0.10$ μs was reported by Lindstrom *et al.* [3] in 1959. This result has been adopted in the Table of Isotopes [4]. The data compiled in the Nuclear Data Sheets [5] and also the on-line compilation of Evaluated Nuclear Data Structure Files (ENDSF) from Brookhaven National Laboratory show a variation of the experimental results of the half-life of the 615 keV level. From the data of ^{181}Hf β^--decay, an average half-life of $T_{1/2} = 17.6 \pm 0.2$ μs has been adopted in the ENDSF. Although other results have been reported for this half-life [5] which agree with that given in ref. [3], the observation of atomic "after effects" in the angular correlation for the 133–482 keV γ-γ cascade of ^{181}Ta following the β^--decay of ^{181}Hf [6] suggests a much shorter half-life for this level. This is due to the following consideration. The ^{181}Hf source ($T_{1/2} = 42.4$ d) is widely used for perturbed angular-correlation (PAC) studies where the 133–482 keV cascade passing through the 482 keV level ($T_{1/2} = 10.8$ ns) is used. The initial 133 keV γ-ray depopulates the 615 keV level. In general, after β^- or electron capture decay, the atom of the decaying nucleus gets excited or ionized. While the atomic recovery process goes on, a strong interaction between the nuclear moments and the electron shell is expected [7] and if there is an appreciable probability for the nucleus to remain in its intermediate state during the recovery time, the angular correlation will be strongly perturbed. However, if the lifetime of the initial state in the cascade (615 keV for ^{181}Hf) is very long, the excited atom gets sufficient time to reach the ground state before emitting the first γ-ray and hence the appearance of the above-mentioned perturbation is not expected. Based on these considerations, we have remeasured the lifetime of the 615 keV level by using a β-γ delayed coincidence set up with fast plastic (Pilot U) and BaF_2 detectors. The lifetime of the 619 keV level has also been measured using the same set up.

2 Experimental procedure

The lifetimes have been measured by using a standard slow-fast coincidence set up. The 619 and 615 keV levels are directly fed by the β^--decay of ^{181}Hf with β feedings of 7 and 93%, respectively [5]. There are no other β^- feeding to any other ^{181}Ta level. A BaF_2 detector of crystal size 38×25 mm (cylindrical) was used for the detection of γ-rays. Since, the BaF_2 scintillator emits ultraviolet light,

[a] e-mail: ccd@niss.saha.ernet.in

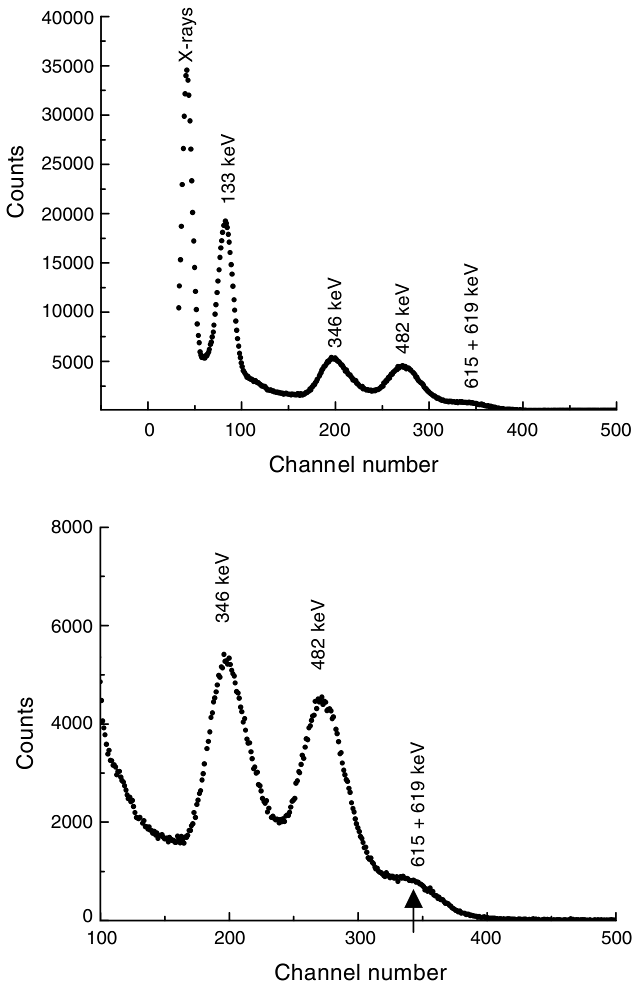

Fig. 1. A γ-ray spectrum of ^{181}Hf measured by using the BaF_2 detector (top). An expanded part of the spectrum (bottom) shows the composite 615 and 619 keV peaks. The arrow indicates the energy threshold chosen for measuring the half-lives of these two lines.

it was coupled to a Philips XP2020/Q photomultiplier tube (PMT). A γ-ray spectrum of ^{181}Hf measured by the BaF_2 detector is shown in fig. 1. The composite 615 and 619 keV γ-ray peaks were selected in the γ-channel. For detection of β^--particles, we have used a fast plastic scintillator (Pilot U) of 1 mm thickness which was coupled to a Philips XP2020 PMT. A β-ray spectrum of ^{181}Hf measured by using the Pilot U plastic detector is shown in fig. 2. In the β-ray spectrum no enhancement of any γ-ray peak of ^{181}Ta was observed. Therefore, any γ-γ coincidence is not expected to contribute in the β-γ coincidence spectrum. The ^{181}Hf source was prepared by depositing a drop of $HfCl_4$ solution in H_2O on a thin Mylar foil (thickness 3.7 μm). This liquid source on Mylar was dried and placed over the plastic scintillator. The scintillator was then covered with a thin aluminium foil which serves as a reflector for the scintillation light. The plastic detector was set to select β energies above approximately 100 keV. For both detectors, the anode pulses were used for timing and were directly fed to constant-fraction discriminators.

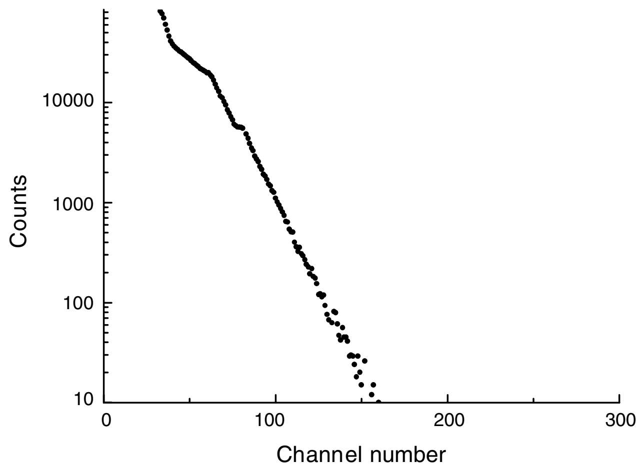

Fig. 2. A β-ray spectrum of ^{181}Hf measured by using the Pilot U detector.

The dynode pulses were used for energy measurements. Thus, in these settings of the detectors, lifetimes of both the 615 and 619 keV levels are expected to appear in the spectrum of the time-to-amplitude conversion (TAC) if the range of the latter is properly set.

3 Results and discussions

The delayed coincidence spectrum corresponding to a range of 500 ns in the TAC is displayed in fig. 3 (top). The spectrum shows a prompt peak followed by a long exponential decay. Since, in the present setting, only the lifetimes of the 619 and 615 keV levels can appear in the TAC spectrum and the possibility of inclusion of other lifetimes is negligibly small, the prompt and the delayed curves can be assigned to two lifetimes corresponding to the 619 and 615 keV levels. According to earlier results, the lifetime of the 619 keV level is expected to be in the picosecond range. Therefore, the prompt peak can be assigned to the 619 keV level and the delayed curve can be assigned to the 615 keV level. An analysis of the delayed curve yields $T_{1/2} = 12.6 \pm 0.4$ ns. For the 200 ns range of the TAC also, a prompt peak followed by a long exponential was observed (fig. 3). In this case, the delayed part gives a value of $T_{1/2} = 12.1 \pm 0.1$ ns, in good agreement with the value measured for a TAC range of 500 ns. The delay has been accurately measured by using a time calibrator (ORTEC 462). Since, in any case, there is no difference in slope between the left and right sides of the prompt part, the value of the half-life of the 619 keV level can be taken lower than the prompt half-life. The prompt half-life has been measured accurately by setting a delay of 77 ps/ch. In this case, again a similar prompt curve followed by a long exponential was found and no difference in the slope of the two sides of the prompt curve was observed. The value of the prompt half-life was found to be 230 ps. The slope of the prompt part gives the prompt half-life which sets the limit of the half-life that can be measured by the slope method. Here, the prompt slope was found by fitting

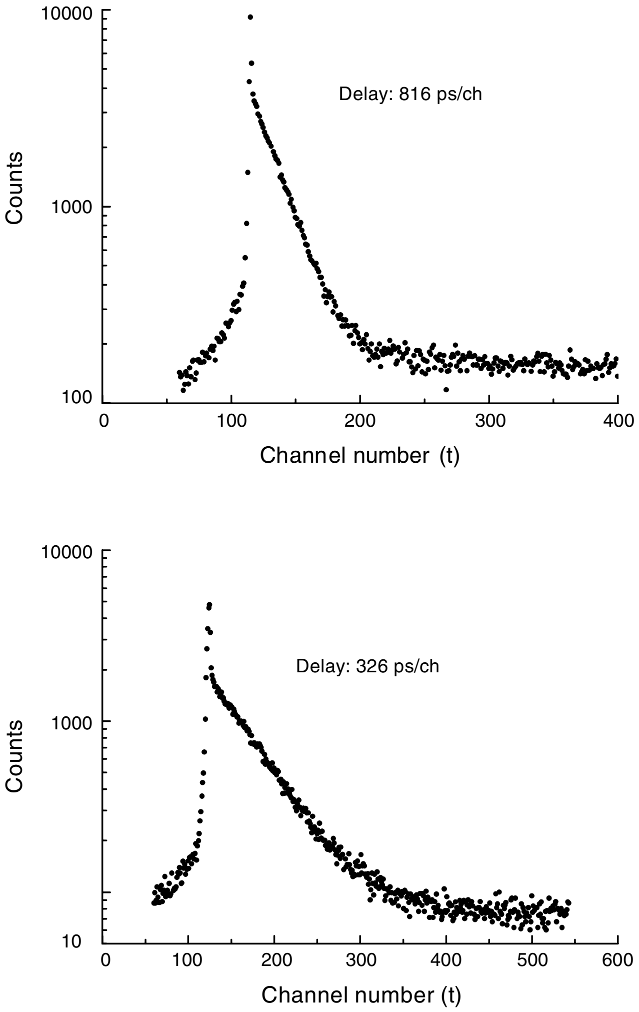

Fig. 3. Beta-γ delayed coincidence spectra using the BaF_2-Pilot U set up for the TAC ranges of 500 ns (top) and 200 ns (bottom) showing lifetimes for the 619 and 615 keV levels in ^{181}Ta. The prompt component yields the lifetime of the 619 keV level, whereas the delayed component gives that of the 615 keV state.

Table 1. Results of lifetime measurements for the 619 and 615 keV levels in ^{181}Ta.

Level (keV)	Values of $T_{1/2}$ (ns)	Reference
619	0.87 (2)	[1]
	2.4 (5)	[2]
	$\leqslant$ 0.23	Present work
615	17830 (100)	[3]
	17600 (200)	[5]
	12.1 (1)	Present work

the prompt part of the delayed spectrum. The half-life of the 619 keV level can, therefore, be set as $T_{1/2} \leqslant 230$ ps. This upper limit disagrees with any of the earlier reported results (table 1). However, the presently obtained half-life can be considered as more accurate, since a coincidence set up with a better time resolution was used, involving an ultrafast BaF_2 detector in the γ-channel. For the 615 keV level, the result obtained in this work is also in strong disagreement with the earlier reported values. In this work the half-life for this level has been remeasured many times for different TAC ranges. All these measurements have yielded the same half-life within the respective experimental uncertainties. Thus, the present value can be considered to be reliable.

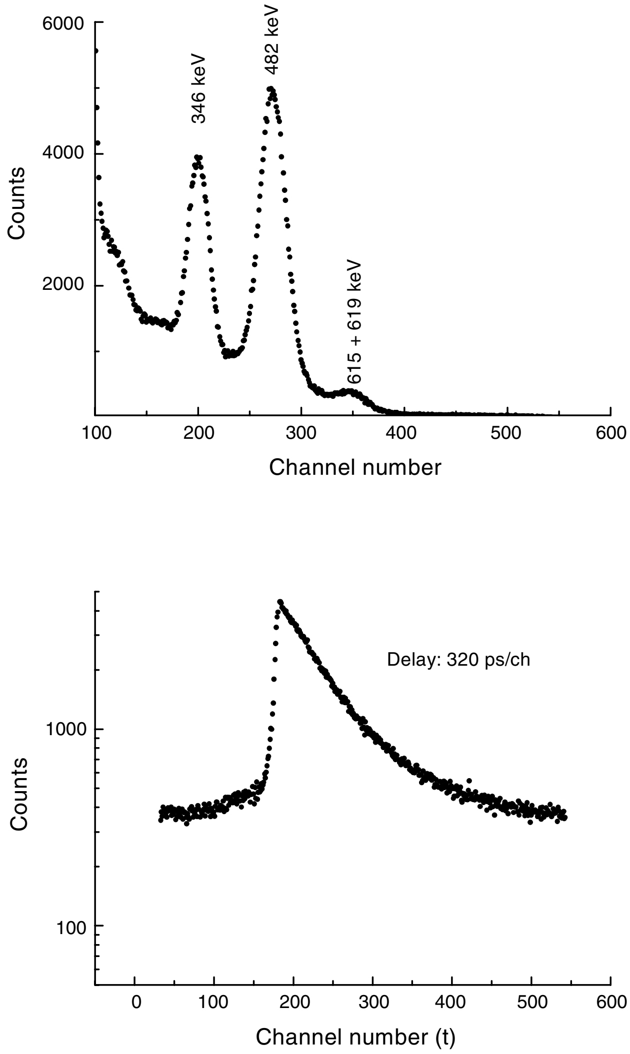

Fig. 4. The spectrum displayed in the upper part is the γ-ray spectrum of ^{181}Hf measured by using the NaI (Tl) detector which shows a better separation between the 482 keV and (615 + 619) keV γ-rays. The lower part shows the β-γ delayed coincidence spectrum measured by using the NaI(Tl)-Pilot U detector combination for the TAC range of 200 ns.

To confirm the half-life result of the 615 keV level, we have measured it using a separate NaI(Tl)-Pilot U detector set up where the BaF_2 detector in the γ-channel was replaced by a NaI(Tl) detector. In this case, the size of the NaI(Tl) crystal was larger (51 $\times$ 51 mm) and, therefore, it produced a higher detection efficiency for the weak (615 + 619) keV γ-rays as well as a better energy resolution (fig. 4). The better energy resolution helps to exclude the contribution from the 482 keV γ-rays in the energy window setting of the above composite γ-rays. The results of this measurement also do not support the microsecond half-life of the 615 keV level (fig. 4). On the contrary, it agrees with the result obtained by us using the BaF_2-Pilot U detector combination. For measurement with the NaI(Tl)-Pilot U combination, any γ-γ coincidences through detections of γ-rays in the Pilot U and the tail part of the strong 482 keV in the NaI(Tl) detector is more unlikely and, therefore, avoids the contribution of half-life of the 482 keV level in the TAC spectrum. Due to poor time resolution of the NaI(Tl)-Pilot U set up, the prompt component is not pronounced here.

The value of $T_{1/2} = 17.6$ μs for the 615 keV level adopted in the Nuclear Data Sheets [5] is difficult to understand considering the fact that the predominant 133 keV intraband γ-transition from this level with 99.5% branching ratio is a pure $E2$ transition [5]. For such a level, a half-life in the nanosecond range is reasonable if compared to systematics. The $B(E2)$ value for the 133 keV γ-transition has been calculated to be 0.11 e^2b^2 from the half-life determined in this work. For this transition, the $E2$ enhancement factor defined as the ratio of the experimental transition rate and the Weisskopf estimate has been found to be 18 for a value of $T_{1/2} = 12.1$ ns for the 615 keV level. This result indicates the collective nature of the 615 keV level.

The nanosecond half-life of the 615 keV level helps to explain the strong perturbation observed in H_2O and different molecular solutions, reported in reference [6]. These perturbations were found to be due to interactions between the nucleus and the excited atomic state ("after effects") where the presently measured half-life of the 615 keV level is comparable to the lifetime of the intermediate state ($T_{1/2} = 10.8$ ns). In this case, the atom may not reach its ground state before emitting the first β-delayed γ-ray, which results in a strong perturbation within the lifetime of the intermediate state. On the other hand, it is difficult to explain "after effects" in the angular correlation of the ^{181}Ta γ-γ cascade, if we consider a value in the microsecond range as reported earlier [5].

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