Precise determination of the energy of the first excited state in ^{93}Nb

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The first excited state in ^{93}Nb is metastable, with a half-life of about 16 years. It decays to the ground state via an *M*4 transition. We are in the process of measuring the *K*-shell internal conversion coefficient (α_K) for this transition in order to test the validity of current methods of calculation. Compared to the transitions measured previously, the present one involves the lowest atomic number, the lowest transition energy, and the highest value of α_K.

The calculated α_K is sensitive to the transition energy E_t and its uncertainty is derived from the uncertainty of that energy. Therefore, it is important to know E_t as precisely as possible. Its presently adopted value is 30.77(20) keV, originating from an experiment preformed more than 40 years ago [1].

We are using x-ray/γ-ray spectroscopy to measure α_K. The same setup and technique are used to measure E_t at the same time. Nevertheless, this measurement is challenging for two main reasons: (*i*) because of the large value of α_K and the limited activity of the ^{93m}Nb source at hand, the gamma transition rate is very low. In order to overcome the limitations imposed by the counting statistics, the measurement has to be performed over a long period of time; and (*ii*) because the measurement takes a long time to complete, it has to be interrupted on a regular basis to determine the energy scale, monitor its stability, and make adjustments if necessary. We have acquired the spectrum of photons emitted from our ^{93m}Nb source for a total of 185 days.

The energy scale was determined using the sources of ^{241}Am and ^{109}Cd and finding centroids of the selected peaks in their spectra, with energies ranging from 11,870.8(21) eV (neptunium *Ll* x ray from the ^{241}Am source) [2] to 88,033.6(10) eV (^{109m}Ag γ ray following β decay of ^{109}Cd) [3]. Using this information, we determined the energy scale individually for every spectrum obtained in an uninterrupted measurement and then put all these spectra on a common energy scale by means of re-binning. We found no evidence of non-linearity and so all scale transformations were strictly linear. Because the slopes of individual energy scales were close to 10 eV per channel, we set the slope of the common energy scale to 10 eV per channel exactly. For the final analysis, individual re-binned spectra obtained under equivalent experimental conditions were combined into a single spectrum and the final energy scale was re-evaluated with increased scrutiny.

Four calibration points were used to establish an accurate energy scale in the region of interest. Two of these involved *K*α x rays of niobium (from the ^{93m}Nb source) and *K*α x rays of silver (from the ^{109}Cd source), whose weighted average energies are known with uncertainties of only ±0.27 eV and ±0.20 eV, respectively. Also, the corresponding peaks are well resolved from any other peaks, contain on the order of 10^8 events, and lie on a relatively low background, so that their centroids could be determined with uncertainty of only ±0.15 eV and ±0.07 eV, respectively.

The remaining two energy-calibration points were provided by the $K\alpha_1$ x ray of lanthanum and the ^{237}Np γ ray at 26.3 keV (both from the ^{241}Am source). Lanthanum was present in the ^{241}Am source as an impurity, in sufficient quantity to produce prominent *K* x-ray peaks in the spectrum by means of fluorescence. Peaks due to $K\alpha_1$ and $K\alpha_2$ x rays of lanthanum were well resolved from each other. However, a relatively small peak (accounting for less than 9% of the events) due to the ^{237}Np γ ray at 33.2

keV was not resolved from the lanthanum $K\alpha$ doublet, but it was properly taken into account by referring to an auxiliary measurement with a different ^{241}Am source that was not contaminated with lanthanum.

Energy of the measured ^{93m}Nb γ-ray peak was determined from its corresponding centroid and the scale based on the four calibration points referenced above. All relevant results from this analysis are given in Table I. The result we finally obtain for the ^{93m}Nb γ-ray energy (*i.e.*, the energy of the first excited state in ^{93}Nb) is

$$E_t = 30{,}760(5) \text{ eV}. \quad (1)$$

The quoted uncertainty includes statistical uncertainty of the corresponding peak centroid, as well as a minor contribution from uncertainty of the energy scale. Our result is in agreements with the currently accepted value, but its uncertainty is smaller by a factor of four.

Table 1. Calibration data and fit results used to determine the energy of the ^{93m}Nb γ ray. Symbols *E*, *I*, and *C* denote energy, intensity, and centroid, respectively. The centroids are given in channel units.

Quantity	Value	Source
$E(\text{Nb } K\alpha_1)$	16,615.16(33) eV	[2]
$E(\text{Nb } K\alpha_2)$	16,521.28(33) eV	[2]
$I(\text{Nb } K\alpha_2) / I(\text{Nb } K\alpha_1)$	0.5236 (26)	[4]
$E(\text{Nb } K\alpha)$	16,582.90(27) eV	deduced from above
$E(\text{Ag } K\alpha_1)$	22,162.917(30) eV	[2]
$E(\text{Ag } K\alpha_2)$	21,990.30(10) eV	[2]
$I(\text{Ag } K\alpha_2) / I(\text{Ag } K\alpha_1)$	0.5305 (27)	[4]
$E(\text{Ag } K\alpha)$	22,103.08(20) eV	deduced from above
$E(^{237}\text{Np } \gamma)$	26,344.6(2) eV	[5]
$E(\text{La } K\alpha_1)$	33,442.12(27) eV	[2]
$C(\text{Nb } K\alpha)$	1657.236(15)	fit
$C(\text{Ag } K\alpha)$	2209.771(7)	fit
$C(^{237}\text{Np } \gamma)$	2634.17(1)	fit
$C(\text{La } K\alpha_1)$	3344.33(3)	fit
$C(^{93m}\text{Nb } \gamma)$	3075.94(42)	fit
$E(^{93m}\text{Nb } \gamma)$	30,760(5) eV	deduced from above

Quality of the fit to the ^{93m}Nb γ-ray peak is illustrated in Fig. 1. This peak was fitted with a single Gaussian on a linear background, as shown. The centroid result was found to be stable against changes in the fitting region.

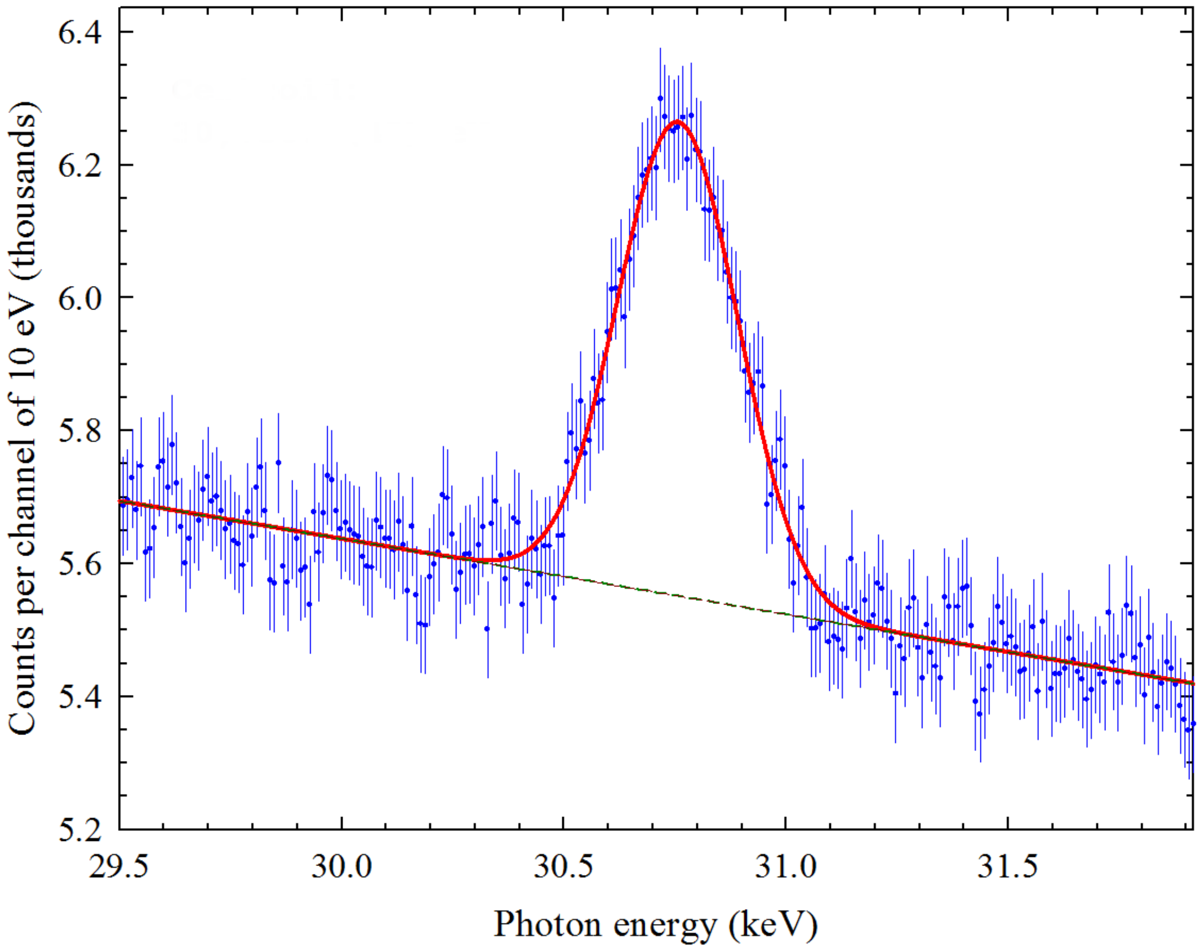

Fig. 1. Fit to the ^{93m}Nb γ-ray peak.

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