

Nuclear Data Evaluation for ^{217}Po

Sherif S. Nafee, Amir K. Al-Ramady, Salem S. Shaheen

Abstract—Evaluated nuclear decay data for the ^{217}Po nuclide is presented in the present work. These data include recommended values for the half-life $T_{1/2}$, α -, β - and γ -ray emission energies and probabilities. Decay data from ^{221}Rn α and ^{217}Bi β -decays are presented. $Q(\alpha)$ has been updated based on the recent published work of the Atomic Mass Evaluation AME2012. In addition, the $\log ft$ values were calculated using the Logft program from the ENSDF evaluation package. Moreover, the total internal conversion electrons and the K-shell to L-shell and L-shell to M-shell and to N-shell conversion electrons ratios K/L, L/M and L/N have been calculated using Brice program. Meanwhile, recommendation values or the multi-polarities have been assigned based on recently measurement yield a better intensity balance at the 254 keV and 264 keV gamma transitions.

Keywords—Atomic Mass Evaluation, Nuclear Data Evaluation, Total Electron Conversion Electrons.

I. INTRODUCTION

THE decay scheme for ^{217}Po has been so far known from the α -decay of ^{221}Rn with 95 % and from the β -decay of ^{217}Bi with 5 %. The latest nuclear decay data evaluation was carried out for the ^{217}Po by [1]. This paper presents the results of the ^{217}Po nuclear decay data evaluation, which has been performed in the frame of the KASCT Research Contract no. 11-MAT2037-03, using the procedures adopted by the DDEP working group. The references cut-off date was 2015, January 31st. The adopted beta decay energy value of $Q(\beta^-)$, the alpha decay energy value of $Q(\alpha)$ and the half-life $T_{1/2}$ were 1440 keV, 6600 (3) keV and 1.46 (5) mS [1]-[3], respectively.

The evaluated adopted gamma levels for ^{217}Po by [1] indicated that there were two recorded gamma transitions. The energies, spin and parities J^π were, adopted to be 254.2 and 264.7 keV, and $7/2^+$ and $9/2^+$, respectively. Whereas, the J^π for the ground state of Po is $11/2^+$.

II. PROCEDURE FOR DECAY DATA EVALUATION

A. ^{217}Bi β^- Decay

The most recently completed decay data for the β^- decay are [4] and [5]. In the first experiment, ^{217}Bi was produced by projectile fragmentation using ^{238}U of energy = 1 GeV/nucleon beam provided by the UNILAC-SIS accelerator facilities at GSI with an intensity of 1.5×10^9 ions/spill and a repetition of

3 s and an extraction time of 1 s [4]. The reaction products were separated and identified in the magnetic spectrometer Fragment Separator (FRS).

The separation of ^{217}Bi nuclei is based on means of the $B\rho$ - ΔE - $B\rho$ scheme. At the focal plane, the recoils were slowed down in an Al wedge-shaped degrader and implanted in a composite DSSSD detector system comprising of 3 layers, each with 3 DSSSD pads with 16×16 pixels, and dimensions of 5×5 cm² and 1 mm thick. The DSSSD detectors were surrounded by the RISING γ -ray spectrometer comprised of 105 HPGe crystals arranged clusters of seven elements. The detection efficiency of was 15% at 662 keV [6].

This array enabled the measurement of γ -ray transitions in time coincidence with implantations or radioactive particles, during a correlation time window of up to 100 μs [7], [8]. Measured E_γ , I_γ , $\gamma\gamma$ - coin, β - γ - coin in coincidence with implanted recoils.

In [5], two separate experiments were carried out at the PS Booster ISOLDE facility in CERN in which the neutron rich nuclei of mass $A = 217$ were investigated.

In the first experiment, a thick target of $^{232}\text{ThC}_2$ combined with a hot-plasma ion source [7] was bombarded with pulsed beam of 1 GeV protons with an intensity of 3×10^{13} particles per pulse. The PS Booster accelerator operated in a sequence of 14.4 seconds long super cycle consisting of 12 equidistant pulses of which a fixed number was sent to the ISOLDE target. Whereas, in the second experiment, the Resonant Ionization Laser Ion Source (RILIS) [5] is used to investigate the activity produced by spallation of a UC_x target of ^{238}U and by a 1.4 GeV proton beam with the same intensity as in the first experiment.

B. ^{221}Rn - α Decay

The magnetic α -spectrograph of the Joint Institute for Nuclear Research JINR [8] was used to study the spectrum of α -particles. In 2004, a 20 μCi ^{225}Ra source was used from Hussonnios to study its α -decay. After the ^{225}Ra removal by the ion-exchange separation, the ^{225}Ra was evaporated onto a Ta- foil and placed in front of a transport tape to collect the alpha-recoil ^{221}Rn nuclei used in our experiments. The alpha detector used in these measurements was an ion-implanted Si wafer 200 mm² in area and 100mm thick with 17 keV resolution. The gamma detector was a 20% efficient coaxial Ge detector with a Be window sensitive to low energy gammas with 1 keV resolution (FWHM) at 100keV. The source was placed between the alpha and gamma detectors in 180° very close geometry. Moreover, same experiment of [5] was used to measure the excited states for ^{217}Po from the α -decay of ^{221}Rn which diffuses from the separator by means of α - γ -coincidences.

S. S. Nafee is with King Abdulaziz University, Faculty of Science, Physics Department, Jeddah 20589, Saudi Arabia (phone: +966-5658-131-80; e-mail: snafee@kau.edu.sa).

A. K. Al-Ramady is with King Abdulaziz University, Deanship for Post Graduate Studies, Jeddah 20589, Saudi Arabia (e-mail: ameerkamel@hotmail.com).

S. A. Shaheen is with King Abdulaziz University, Faculty of Science, Physics Department, Jeddah 20589, Saudi Arabia (e-mail: sshaheen@live.com).

III. RESULTS AND DISCUSSIONS

A. ^{217}Bi β^- Decay

The statistical analysis of γ -ray data and the deduced level schemes were calculated using the computer codes available at Brookhaven Lab's website: www.nndc.bnl.gov. The direct feeding(s) to excited states in β^- and ϵ decays have generally been computed by the evaluator from $I(\gamma+\epsilon)$ intensity balances at each level; the associated $\log ft$ values were calculated using LOGFT online stand-alone package available at Brookhaven Lab's website: www.nndc.bnl.gov. In addition, the theoretical conversion coefficients were deduced from BrIcc code: v2.3 (29-March-2013) [9] with "Frozen Orbitals" approximation, and with implicit uncertainty of 1.4%. Q values were adopted from the atomic mass evaluation AME 2012 [10] to be 3000 keV.

The β^- -delayed γ spectra of ^{217}Bi , showing several new γ -ray transitions in the decay daughter ^{217}Po in addition to the previously reported ones as shown in Fig. 1. The spectra were obtained from β - α correlations.

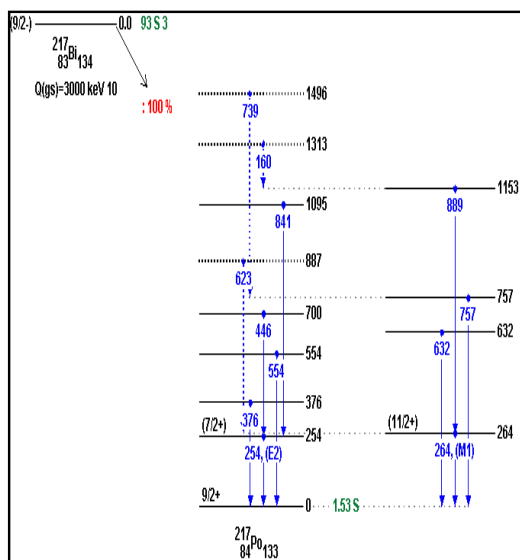


Fig. 1 The ^{217}Bi - β decay to ^{217}Po . Gamma transition energies are in blue color, the black lines are for the level energies of the daughter nucleus ^{217}Po , whereas, the green color is for the half-lives of the ground state of ^{217}Bi and ^{217}Po

The multiplicities that were assigned to the γ -transitions (254 and 264) keV based on the β - α correlations in [4], as will be discussed later. The level energies of the ^{242}Pu were deduced by a least-square fit to the adopted γ -ray energies using the computer program GTOL from the ENSDF evaluation package. The level energies E_x , γ -ray energies E_γ , relative γ intensities (normalized to the most intense γ peak) I_γ , and the possible assigned multiplicities are listed in Table I. The total internal conversion coefficients ICCs were calculated from BrIcc program and the $\log ft$ values calculated from the online $\log ft$ stand-alone package are listed in Table I as well.

B. ^{221}Rn - α Decay

Studying the ^{221}Rn α -decay during 8 consecutive seconds gave us a good estimation for the half-life of ^{217}Po to be 1.53 ± 0.03 s [5]. Three α -transitions were observed with energies listed in Table II. The decay hindrance factor HF calculated by equation (1) using the ALPHAD program which is available from Brookhaven Lab's website, are listed in Table II as well as the normalized emission probabilities.

$$HF_i = \frac{T_{1/2}^{Exp}(\alpha_i)}{T_{1/2}^{Theory}} = \frac{T_{1/2}^{Exp} / BR_i}{T_{1/2}^{Theory}} \quad (1)$$

Weighted average of α -branching ratios determined by [2] (22%) and by [3] (18%) was used in the present evaluation using AVETOOLS from ENSDF package. $\alpha/\beta = 22(2)/78(2)$ was obtained by [3] by comparing intensities of ^{221}Rn , ^{221}Fr , ^{217}Po and ^{217}At α -groups that were present in the mass-separated source in equilibrium with its daughters. Whereas, $\alpha/\beta = 18(2)/82(2)$ was deduced by [2].

The measured $\text{Ice}(K) < 0.2$ as in [2] and $(\alpha(K)_{\text{exp}} < 0.1)$ Suggested E1 or E2 multipolarity. Since $\alpha(K)(E1) = 0.0377$, $\alpha(K)(E2) = 0.0984$ and it was reported in [3], [11] that M1 transition is hardly seen because of it is too high internal conversion $\alpha(K)(M1) = 0.648$. Therefore, the E2 multipolarity was assigned for the 254 keV level, which yields a better intensity balance. Meanwhile, $0.46 < \text{Ice}(K) < 0.76$ was measured in [3], [11] too. Therefore M1 multipolarity in which $\alpha(K)(M1) = 0.579$ yields a better intensity balance at the 264 keV level. The decay scheme for the ^{221}Rn α -decay in the present evaluation is presented in Fig. 2.

TABLE I
THE LEVEL ENERGIES, GAMMA-RAY ENERGIES, RELATIVE GAMMA INTENSITIES (NORMALIZED TO THE MOST INTENSE GAMMA PEAK), POSSIBLE ASSIGNED MULTIPOLARITIES, AND THE LOGFT VALUES

E_x (keV)	E_γ (keV)	I_γ %	Possible Multipolarity	$\log ft$
254(10)	254	29(4)	[E2]	6.44(0.07)
264(10)	264	100(11)	[M1]	5.9(0.05)
376(10)	376	16(3)		6.7(0.09)
554(10)	554	17(3)		6.67(0.08)
632(10)	632	10(3)		6.9(0.14)
700(14)	446	3(1)		7.42(0.15)
757(10)	757	16(4)		6.7(0.11)
887(14)	632	4(2)		7.3(0.22)
1095(14)	841	4(2)		7.3(0.22)
1153(14)	889	7(2)		7.06(0.13)
1313(17)	160	17(8)		6.67(0.21)
1496(14)	739			

TABLE II
 α -TRANSITION ENERGIES AND THEIR INTENSITIES WITH THE ASSOCIATED γ -TRANSITION ENERGIES AS WELL AS THE CALCULATED HINDRANCE FACTORS USING ALPHAD PROGRAM

E_α (keV)	E_γ (keV)	I_γ %	HF
6037(2)	0	81	13
5788(2)	254.2	11	6.8
5778(2)	264.68	8	8.3

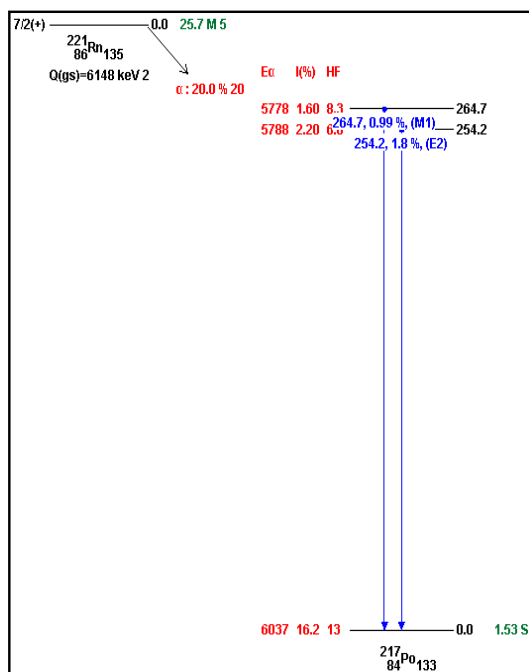


Fig. 2 The ^{221}Rn - α decay to ^{217}Po Gamma transition energies are in blue color, the black lines are for the level energies of the daughter nucleus ^{217}Po , and the green color is for the half-lives of the ground states of ^{221}Rn and ^{217}Po . Whereas, the hindrance factors for the three alpha energies (6037, 5788 and 5778) keV of intensities (16.2, 2.2 and 1.6) % are (13, 6.8 and 8.3), respectively and indicated in red colors

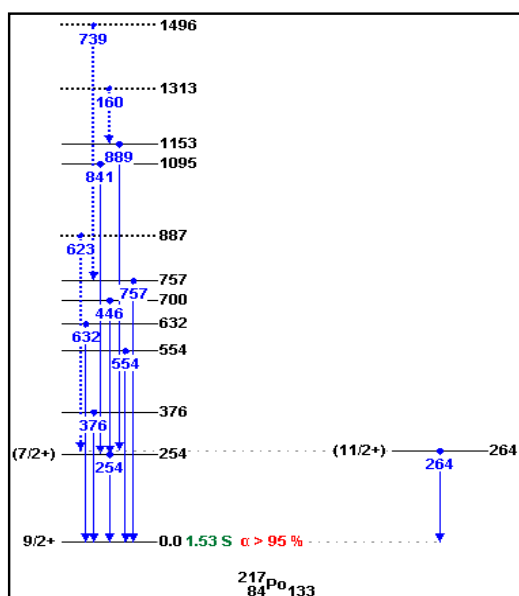


Fig. 3 The newly adopted gamma levels for ^{217}Po . Gamma transition energies are in blue color and the black lines are for the level energies, respectively

In comparison to the previous evaluation by [1], the current adopted gamma levels for the ^{217}Po shows that the J^π of the ground state is $9/2^+$. In addition the J^π for the 254 and 264

keV are $7/2^+$ and $11/2^+$, respectively. Moreover, ten newly gamma lines were recorded. The adopted energy levels and the gamma transitions are shown in Fig. 3. The adopted gamma lines and the internal conversion coefficients $\alpha_k, \alpha_L, \alpha_M, \alpha_N$, calculated by BrICC are listed in Table III. Moreover, the K-shell to L-shell and L-shell to M-shell and to N-shell conversion electrons ratios K/L, L/M and L/N have been calculated, respectively, for the 254 and 264 gamma lines and listed in Table IV.

TABLE III
THE ADOPTED GAMMA-RAY ENERGIES, THE INTERNATIONAL CONVERSION COEFFICIENTS $\alpha_k, \alpha_L, \alpha_M, \alpha_N$ AND THE TOTAL CONVERSION COEFFICIENTS ICCS VALUES WITH THEIR ASSOCIATED UNCERTAINTIES

E_γ (keV)	α_k	α_L	α_M	α_N	ICCs
254	0.0976(17)	0.0844(18)	0.0221(5)	0.0056(13)	0.211(4)
264	0.58(7)	0.102(12)	0.024(3)	0.0062(7)	0.72(9)

TABLE IV
THE K-SHELL TO L-SHELL, L-SHELL TO M-SHELL AND L-SHELL TO N-SHELL CONVERSION ELECTRON RATIOS FOR THE 254 AND 264 GAMMA LINES IN ^{217}Po

E_γ (keV)	K/L	L/M	L/N	ICCs
254	1.16(4)	3.82(12)	14.9(5)	0.211(4)
264	5.7(10)	4.2(7)	16.0(3)	0.72(9)

IV. CONCLUSION

A new ^{217}Po nuclear decay data evaluation has been performed and the current recommended data have been proposed for the decay energy (Q), half-life of the ground state, internal conversion coefficients, energies and probabilities of beta and gamma-ray transitions, energies and emission probabilities of gamma-rays, X-rays, conversion and Auger electrons. New γ -transitions have been deduced from the ^{217}Bi - β decay and added to the decay scheme. The relative emission probabilities of the conversion electrons, deduced using the evaluated gamma-ray emission probabilities and adopted ICCs, are in good agreement with the published experimental values. Adopted gamma level file has been evaluated and completed.

ACKNOWLEDGMENT

The authors would like to thank the authorities of King Abdulaziz City for Science and Technology (KASCT), Long-Term Comprehensive National Plan for Science, Technology and Innovations, and King Abdulaziz University (KAU), Saudi Arabia, for funding this project, contract number "11-MAT2037-03". Also, we express our deepest appreciations to Dr. J. Tuli, National Nuclear Data Center (NNDC), Brookhaven National Laboratory (BNL) Upton, NY, USA, for supervising this work and valuable discussions throughout the evaluation process.

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