α decay of $_{97}^{249}Bk$ and levels in $_{95}^{245}Am$

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Alpha decay of $^{249}_{97}$Bk and levels in $^{245}_{95}$Am

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Abstract

Alpha decay of ^{249}Bk has been investigated by measuring its α and γ-ray spectra, both in singles and in coincidence modes. The α spectrum of a freshly purified ^{249}Bk sample was measured with a high-resolution, double-focussing magnetic spectrometer. Gamma singles, γ-γ coincidence, and γ-α coincidence spectra were also recorded. The absolute intensity of the 327.45-keV γ ray has been determined to be $(1.44\pm0.08)\times10^{-5}$% per ^{249}Bk decay. Assignments of previously known single-particle states were confirmed. A new rotational band was identified in the α singles spectrum and Am K x rays have been observed in its decay. This single-particle state, with an energy of 154 keV, has been assigned to the $3/2^{-}[521]$ Nilsson state. This is the lowest excitation energy for this orbital in any Am nucleus. More precise energies and intensities of the ^{249}Bk α groups and γ-ray transitions are provided.

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I. INTRODUCTION

The nucleus ^{249}Bk has a half-life of 330±4 d and decays mainly by β^- emission with a decay energy of 125±2 keV [1]. The ^{249}Bk β^- decay populates only the ground state of ^{249}Cf. However, the decay has also a small α branch of $(1.45\pm0.08)\times10^{-3}\%$. Because this α branch is small and because of the large amount of electrons, it has been difficult to study the associated α decay scheme with silicon and/or gas detectors. The α spectrum of ^{249}Bk was first measured by Ahmad [2] with a high-resolution magnetic spectrometer. Using the α singles data and α-γ coincidence measurements, a level scheme was proposed. Soon after, the α spectrum was measured by Baranov *et al.* [3–5] with a high-resolution magnetic spectrometer and by Milsted *et al.* [6] with a silicon detector. There were differences between the energies and intensities reported in Refs. [2] and [5]. In order to resolve these differences a new measurement of the ^{249}Bk α spectrum was undertaken.

Gamma singles spectrum of ^{249}Bk has previously not been measured. Two γ rays with energies of 327.2±0.5 and 307.5±1.0 keV were observed [2] in γ-α coincidence measurement. In the present work, γ-ray spectra of freshly purified ^{249}Bk sources have been measured in singles and coincidence mode. A new γ ray with an energy of 28.0 keV, previously seen in the ^{245}Pu β^- decay [7], has been identified in the γ-α coincidence spectrum. The present article describes these measurements and provides more precise energies and intensities of ^{249}Bk α groups and γ-ray transitions. The results of these measurements confirm the assignments of previously known single-particle states and provide evidence for the $3/2^-[521]$ Nilsson state at 154 keV.

II. SOURCE PREPARATION

For the present γ singles and coincidence spectra measurements, a 10-μg sample of freshly purified ^{249}Bk was obtained from Oak Ridge National Laboratory in May 2012. The berkelium sample was chemically purified at Oak Ridge one day before it was shipped to Argonne. A 1- μg source was prepared by placing the material on a 3-mg/cm^2 Kapton foil and covering it with scotch tape. The source was sandwiched between two 120-mg/cm^2 Be disks in order to minimize the production of bremsstrahlung. This source was used for γ singles spectrum. For γ-α coincidence measurement, 0.3 μg of ^{249}Bk was deposited on a one-mm thick quartz disk. This source contained $\sim 2.0\times 10^7$ ^{249}Bk β^- decays per second, $\sim$300 ^{249}Bk α decays per second, and 3 decays per second of the 327.45-keV γ ray from ^{249}Bk decay. Both sources contained ^{249}Cf from the decay of ^{249}Bk.

III. EXPERIMENTAL METHODS AND RESULTS

A. Alpha-particle spectroscopy

The α spectrum of ^{249}Bk was measured with a magnetic spectrometer at Argonne National Laboratory in the early 1970s. The spectrometer had a resolution [full width at half maximum (FWHM)] of 5 keV at a transmission of 0.1% of 4π for 6.0 MeV α particles and it has been described in Ref. [8]. For the spectrum presented in Fig. 1, the magnetic field was chosen to focus selectively ^{249}Bk α lines in the focal plane. The spectrum of Fig. 2, on the other hand, covered the main lines of both ^{249}Bk and ^{249}Cf. The ^{249}Bk α energies were measured with respect to that of the ^{249}Cf main α group present in the spectrum, which was taken as 5811 keV. Although the energy of the ^{249}Cf main α group is listed in the literature as 5812.8$\pm$1.6 keV [9], a new measurement gives a value of 5811.0$\pm$1.0 keV [10].

The energy calibration of the spectrometer was performed [8] with the following set of standards: ^{233}U (4824 keV), ^{238}Pu (5499 keV), ^{244}Cm (5805 keV), ^{242}Cm (6113 keV), ^{211}Bi (6279 and 6623 keV), and ^{214}Po (7687 keV). This calibration provided the parameters of the equation which were used to compute energies of unknown peaks. However, energies of other standard sources determined by this method were found to be few keV lower than the literature values because of variations in source thickness and source location. Therefore, for high precision, spectra of mixed sources containing the unknown and the standard were measured. The energy of the ^{249}Cf main peak was determined with respect to the energy of the ^{250}Cf α_0 peak which is known to be 6030.2$\pm$0.2 keV [9]. For this measurement, the spectrum of a source containing ^{249}Cf and ^{250}Cf was recorded with the magnetic spectrometer. The above calibration gave the energy of the ^{250}Cf α_0 group as 6025 keV, which is 5 keV lower than the literature value. A correction of +5 keV was applied to the computed energies of all peaks of this spectrum. This procedure is justified because, in the small energy range, the spectrometer is linear, and the energies of ^{249}Cf α groups obtained by this procedure agreed with the values measured with a passivated, implanted, planar silicon (PIPS) detector with the resolution (FWHM) of 9.0 keV. The energy of the ^{249}Bk main α group was obtained from the spectrum in Fig. 2 with respect to the ^{249}Cf 5811$\pm$1 keV peak. A correction of +6 keV was applied to the computed energies of all peaks. This procedure gave the energy of the ^{249}Bk main α group as 5414$\pm$2 keV. Energies of other ^{249}Bk α groups were determined with respect to the 5414-keV peak from the spectrum in Fig. 1. The energy of the main ^{249}Bk α group in Fig. 1 was computed to be 5411 keV, 3 keV lower than the precise value obtained from Fig. 2. Hence, the computed energies of all peaks in Fig. 1 were increased by 3 keV. The energies and intensities obtained from this spectrum, the corresponding excitation energies, and hindrance factors are given in Table I. The uncertainties of $\pm$2 keV in the absolute energies of α groups are due to the uncertainty in the energy of the reference and to that associated with the calibration of the spectrometer. The uncertainties in the relative energies are due to calibration only and these are smaller. Thus, the errors in the relative energies of α groups and, hence, the uncertainties in the level energies, are $\pm$1 keV. The hindrance factors were calculated with the spin-independent theory of Preston [11] using a radius parameter of 9.323 fm.

In Table I, the present results are compared with previous measurements. The new energies of ^{238}Pu (5499.03$\pm$0.20 keV) and ^{240}Pu (5168.13$\pm$0.15 keV) α groups [9] were used to revise the original values listed in Ref. [2]; this revision increases the original energies by 1.0 keV. The ^{249}Bk α energies reported from this experiment should be quite reliable since the ^{249}Bk source contained the Pu isotopes, herewith providing an internal calibration. Baranov *et al.* [3, 5]) report two different energies for the ^{249}Bk main α group in two different measurements. In Ref. [3], the energy of the main α group is listed as 5415.3$\pm$1.0 keV which was measured with respect to the energy of the ^{242}Cm α_0 group taken as 6111.30$\pm$0.25 keV. In a later measurement [5], however, the same authors report the energy of the same α group as 5421 keV using the energy of the ^{242}Cm α_0 group as 6112.9$\pm$0.08 keV. The first value was adjusted to 5416.8 keV in Ref. [4] because of the change in the energy of the standard used. Although the energy of the reference increases by only 1.6 keV between the two measurements [3, 5], the energy of the ^{249}Bk α group increases by 6 keV. The difference in the two measurements is quite large, considering the fact that the resolution (FWHM) is $\sim$ 4 keV. In Table I, their latest values [5] have been normalized to the 5416-keV value of the ^{249}Bk main α group obtained in the original measurement [3] because of ambiguities in the correction of the energies in Ref. [4]. The excellent agreement between the present energies and the corresponding values reported in Ref. [2] indicates that the present data represent the best values. Furthermore, the present intensities are in excellent agreement with the values of Ref. [2] and with the values reported for well-resolved α groups in Ref. [6]. However, they differ substantially from the intensities measured by Baranov *et al.* [5].

B. Alpha-gamma and gamma-gamma coincidence measurements

The γ-ray spectrum of a 0.3-μg ^{249}Bk source was measured in coincidence with α particles using a 20-cm^2$\times$15-mm low-energy photon spectrometer (LEPS). The α particles were detected with a 150-mm^2 PIPS detector. The source contained large amounts of α and γ activities from the decay of the ^{249}Cf daughter. In order to reduce the count rate due to the β^- particles hitting the PIPS detector, a set of Sm/Co permanent magnets was used which deflected ~90% of the electrons away from the detector. Nevertheless, the remaining β^- particles were intense enough to cause random summing with the α particles in the PIPS detector, resulting in a broadening of the peaks of interest. A one-mm thick Al and a one-mm plastic absorber were used to reduce the bremsstrahlung counts in the LEPS detector. The coincidence events were collected in event-by-event mode and were later sorted by placing gates on various regions of the α spectrum. The γ-ray spectrum gated by the ^{249}Bk α_{327} peak can be seen in Fig. 3. Contributions from the ^{249}Cf decay have been subtracted. All the γ rays deexciting the 327.45-keV level, observed in the singles spectrum, are present in the coincidence data of Fig. 3 with the same relative intensities as in the singles data. This coincidence spectrum establishes the sensitivity of the measurement as 0.10% per ^{249}Bk α decay for γ rays with energy $>$ 200 keV and as 0.05% per ^{249}Bk α decay for γ rays with energies ~100 keV. A γ-ray spectrum gated by α particles above the α_{327} group is presented in Fig. 4. This spectrum contains a 28.0$\pm$0.1 keV γ ray, and Am L x rays and K x rays. Most of the L x rays result from the conversion of transitions deexciting the rotational members of the ground-state band. The intensities of the 28.0-keV γ ray and Am K x rays associated with levels other than the 327.45-keV level are estimated to be ~0.10 % per ^{249}Bk α decay and ~ 0.20 % per ^{249}Bk α decay, respectively. These Am K x rays arise from the decay of the 154-keV band to the 28.0-keV band (see below).

For γ-γ coincidence measurements, the α detector was replaced by a 25% Ge detector and a 1-μg ^{249}Bk source was used. Coincidence events were collected in event-by-event mode for four days and spectra were generated later by placing gates on various γ and Am K x-ray peaks. In the γ-ray spectrum gated by Am K x rays, the 28.0-keV γ ray is present. In turn, Am K x rays were observed in the spectrum gated by the 28.0-keV γ ray. The fact that the 28.0-keV γ ray is in coincidence with Am K x rays indicates that the associated 28.0-keV level is populated from a level in ^{245}Am which lies $>$ 125.03 keV (Am K binding energy) above it.

C. Gamma-ray spectroscopy

The γ-ray singles spectrum of a 1-μg ^{249}Bk source was measured with a low-energy photon spectrometer (LEPS); it is presented in Fig. 5. A set of steel and Al absorbers was used to reduce the amount of bremsstrahlung in the spectrum. The spectrum contains strong peaks from ^{249}Cf decay (the 388.17-keV ^{249}Cf peak is $\sim$100 times stronger than the 327.45-keV ^{249}Bk one). Gamma-ray energies were determined with respect to the known energies [12] of the ^{249}Cf lines present in the spectrum. The internal ^{249}Cf transitions could not be used for detector efficiency calibration because some of the lines had contributions from ^{245}Am β^- decay. The detector efficiency was determined with a calibrated mixed source containing the ^{241}Am, ^{57,60}Co, ^{109}Cd, ^{139}Ce, ^{203}Hg, ^{113}Sn, ^{85}Sr, ^{137}Cs, and ^{88}Y nuclides. The energies and intensities measured in the present work are given in Table II along with previously measured values. The present γ-ray energies are in excellent agreement with previous values measured with a Bent Crystal Spectrometer [13] and the relative intensities agree with those measured in ^{245}Pu β^- decay [7]. The 28.0-keV γ ray and Am Kβ_2' x ray were identified in the γ-α coincidence spectrum only. In column 3 of Table II are given the absolute intensities of γ and K x rays with their respective uncertainties; uncertainties in the relative intensities are $\pm$5%.

The absolute intensity of the 327.45-keV γ ray was measured in the present experiment in the following way. Several spectra of the ^{249}Bk source were measured one week apart by placing the source on the 2-cm$^2\times$-10-mm LEPS detector in a fixed position. The area of the 327.45-keV peak was determined in the first spectrum and was corrected for the relative efficiency of the detector. Using the counting time (62.5 h), the 330-d half-life, and the absolute intensity I_γ (which is unknown; see below) the number of ^{249}Bk atoms in the source was determined. Subsequently, the number of ^{249}Bk atoms that decayed in 70 days was computed. Next, the number of ^{249}Cf atoms produced in 70 days was determined from the difference between the areas of the 388.2-keV peak obtained in the first spectrum and that measured 70 days later. This difference, when corrected for the relative efficiency, branching ratio (0.66), counting time (62.5 h), and half-life of 351 y for ^{249}Cf decay, gave the number of ^{249}Cf atoms produced. By equating the number of ^{249}Bk atoms decayed to the number of ^{249}Cf atoms produced, the absolute intensity of the 327.45-keV γ ray (I_γ) was determined to be $(1.44\pm0.08)\times10^{-5}$% per ^{249}Bk decay.

The α branching of ^{249}Bk was measured by Milsted *et al.* [6] by two different methods. In one experiment, the α activity of a sample with known number of ^{249}Bk atoms was measured as a function of time and this was fitted with an equation in which the α branching and the ^{249}Cf half-life were unknown parameters. By a least-squares-fit, the α branching and the ^{249}Cf half-life were determined to be $(1.45\pm0.08)\times10^{-3}$% per ^{249}Bk decay and 345±15 y, respectively. In another approach, the α spectrum of a thin freshly purified ^{249}Bk source was measured with a silicon detector and the ratio of ^{249}Cf counts to ^{249}Bk counts was determined. The increase in the ratio was followed for some time and data were fitted with an equation in which the α branching was an unknown parameter. This analysis gave a value of $(1.37\pm0.10)\times10^{-3}$% per ^{249}Bk decay for the α branching. A half-life of 314 d was used for the decay of ^{249}Bk in both methods. The second value of $(1.37\pm0.10)\times10^{-3}$% per ^{249}Bk decay is preferred here instead of the first value, recommended by the authors, because it does not involve detector solid angle and initial ^{249}Bk atoms in the analysis. Using this branching ratio, and the intensity of the 327.45-keV γ ray as $(1.44\pm0.08)\times10^{-5}$% per ^{249}Bk decay obtained earlier, the intensity of the 327.45-keV γ ray is determined to be (1.05 ± 0.09)% per ^{249}Bk α decay.

The absolute intensity of this transition can also be determined by balancing the α intensity to the 327.45-keV level and the total intensity of the deexciting transitions. Relative intensities of the γ rays and Am K x rays deexciting the 327.45-keV level were measured in this work. The intensity of Am K x rays due to the decay of the 154-keV band, estimated from the γ-α coincidence data discussed above, was subtracted from the Am K x rays intensity obtained from the singles spectrum. This Am K x-ray intensity was multiplied by the ratio of the theoretical total conversion coefficient [14] and the K conversion coefficient for the 327.45-keV transition. Equating the total intensity of the 327.45-, 308.26-, and 280.36-keV γ rays and associated conversion electron intensities to 2.7%, the absolute intensity of the 327.45-keV γ ray was obtained as (1.06±0.07)% per ^{249}Bk α decay. This value is in good agreement with that obtained by the direct measurement presented above and hence a weighted average of these two values has been used in Table II.

In the γ-ray spectrum of ^{249}Bk, higher intensities were recorded for the Cm K rays and the 252.8-keV γ ray relative to the intensities measured in the spectrum of a pure ^{249}Cf source, when proper normalization to the intensity of the 388.2-keV γ ray is carried out. This excess intensity is due to the ^{245}Am β^- decay as the latter populates the 252.8-keV level, but not the 388.2-keV state of ^{245}Cm. From this excess, the ratio of the intensities of the 252.8-keV and 327.45-keV γ rays was determined to be 4.7±0.4. Since the ^{249}Bk α decay rate is the same as the ^{245}Am β^- decay rate, because of the secular equilibrium, the absolute intensity of the 252.8-keV γ ray in ^{245}Am β^- decay can be determined using 1.06% per ^{249}Bk α decay for the intensity of the 327.45-keV γ ray. This gives an intensity of (5.2±0.5)% per ^{245}Am β^- decay for the 252.8-keV γ ray, in agreement with the value of (6.1±0.6)% per ^{245}Am β^- decay measured by Bunker *et al.* [15].

IV. DISCUSSION

A. Level scheme

The level structure of ^{245}Am has previously been deduced on the basis of data from the α decay of ^{249}Bk [2] and β^- decay of ^{245}Pu [7]. The present data confirm the proposed assignments. The levels observed here and their Nilsson state assignments can be found in Fig. 6. The level structure is discussed below in light of the present measurements. The ground-state spin of ^{249}Bk has been measured [16] as 7/2 and its measured magnetic moment is in good agreement with the value calculated for the $7/2^+$[733] proton configuration. In addition, the ground-state spin and magnetic moment of ^{253}Es, which decays by a favored α transition to the ^{249}Bk ground state, has also been measured [17] and the observations confirm the $7/2^+$[633] assignment. The 327.45-keV level in ^{245}Am is populated by a favored α transition indicating that it has the same configuration as the ^{249}Bk ground state, namely $7/2^+$[633]. This state decays to the ground state and to the 19.2-keV level by M1 transitions, measured directly in Ref. [7] and deduced from the Am K x rays intensity in the present work. This fixes the parity of these two levels as positive. The β^- decay of ^{245}Pu, which has a $9/2^-[734]$ ground-state configuration [18, 19], populates the $7/2^+[633]$ state at 327.45 keV in ^{245}Am, but not the ground state and the 28.0-keV level. This observation indicates that the spin of the ^{245}Am ground state and the 28.0-keV level is 5/2 or lower. The β^- decay of ^{245}Am populates the $7/2^+[624]$ ground state and the $5/2^+[622]$ level in ^{245}Cm, suggesting a spin value of 5/2 or 7/2 for the ^{245}Am ground state. Thus, the above decay data fix the spin-parity of the ^{245}Am ground state as $5/2^+$ and the $5/2^+[642]$ configuration is assigned. The α transition to the 19.2-keV level has a very low hindrance factor. This occurs only for a decay to a state strongly mixed with the favored one. Thus, the 19.2-keV level should have $K^\pi=5/2^+$ and $I^\pi=7/2^+$. The levels at 47.07, 87.65, and 134.5 keV fit well as the 9/2, 11/2 and 13/2 members of the ground-state band. The low hindrance factors to the members of this ground-state band were quantitatively reproduced in Ref. [2] by calculating the admixture of the $7/2^+[633]$ state in these levels due to Coriolis mixing.

In Refs. [1, 7], levels at 28.0, 70.4, 124.6, and 190.8 keV were deduced from the transitions deexciting higher-lying states in ^{245}Am and these were assigned to the 5/2, 7/2, 9/2, and 11/2 members of the $5/2^-[523]$ band. A 28.0-keV γ ray was observed in ^{245}Pu β^- decay and it has also been observed in the present γ-α and γ-γ coincidence spectra. The measured intensity of the 28.0-keV γ ray and the α population of the levels which generate the 28.0-keV transition indicate a low conversion coefficient, and, hence, an E1 multipolarity. Thus, the 28.0-keV level should have either $5/2^-$ or $3/2^-$ spin-parity. The fact that the 887-keV level, fed in the β^- decay of ^{245}Pu, decays to the 28.0-keV level favors a $5/2^-$ assignment. Thus, a $5/2^-[523]$ assignment is proposed for the the 28.0-keV level. This assignment is further supported by the reasonable value of 6.1 keV for the rotational constant of the band. An α transition to the 28.0-keV level is not observed directly because it is too close to the 19.2-keV level, which is very strongly populated. However, α groups feeding 71- and 124-keV levels are observed. The large hindrance factors suggest spin flip transitions and, hence, support the $5/2^-[523]$ assignment made in Ref. [7].

New α groups were observed in the ^{249}Bk α spectrum which populate levels at 154, 187, 232, and 293 keV. These levels fit well as members of a K=3/2 band with a rotational constant of 6.5 keV. Am K x rays were observed in coincidence with the 28.0-keV γ ray, indicating that the members of the 154-keV band decay to the $5/2^-$ level. The measured intensities of the Am K rays and of the α population to the 154-keV band suggest an M1 multipolarity for these transitions and, thus, negative parity for the 154-keV band. No γ ray was observed deexciting the 154-keV band in coincidence with either ^{249}Bk α particles or the 28.0-keV γ ray, indicating large internal conversion for these transitions. The only single-particle state available in this energy region is the $3/2^-$[521] Nilsson state and, therefore, this assignment to the 154-keV band is adopted. This assignment is further supported by the similarity between the hindrance factors to these levels and those to the known $3/2^-$ band in ^{249}Bk (see Table III).

The energies of single-particle orbitals measured in ^{245}Am are compared in Fig. 7 with those measured in the other odd-mass Am isotopes [2, 20, 21]. According to the calculations of Ref. [22], variations in the energy difference between the $5/2^-$[523] and $5/2^+$[624] orbitals could be due to changes in the β_2 and/or β_4 deformations. However, the systematic lowering of the $3/2^-$[521] level can not be explained by a deformation change. Most likely, the lower energies of the $3/2^-$[521] and $7/2^+$[633] orbitals are caused by phonon admixtures. Calculations by Gareev *et al.* [23] for ^{241}Am using a potential with phonon admixtures give the energies of the $5/2^-$[523], $5/2^+$[624], $3/2^-$[521], and $7/2^+$[633] orbitals as 0, 50, 200, and 350 keV, respectively, in excellent agreement with the energies measured in this work for ^{245}Am.

B. Summary

The α-particle spectra, presented here, were measured with the Argonne double-focussing magnetic alpha spectrometer. Precise energies and intensities of ^{249}Bk α groups and γ rays have been measured. Four rotational bands, seen earlier in neighboring odd-mass Am nuclei, have now also been identified in ^{245}Am. Strong Coriolis mixing between the $5/2^+$[624] and $7/2^+$[633] orbitals has been observed and this produces a large intensity to the 7/2 member of the ground-state band. The absolute intensity of the 327.45-keV γ ray has been measured as $(1.44\pm0.08)\times10^{-5}$% per ^{249}Bk decay. This quantity can be used in the future for quantitative determination of ^{249}Bk samples.

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FIG. 1: A ^{249}Bk α spectrum measured with the Argonne double-focussing magnetic spectrometer. The energy scale is 2.43 keV per channel.

FIG. 2: Alpha spectrum of ^{249}Bk and ^{249}Cf measured with the Argonne double-focussing magnetic spectrometer. The energy scale is 2.59 keV per channel. ^{249}Cf peaks are labelled by the energies of levels populated by the α groups in ^{245}Am.

FIG. 3: γ-ray spectrum of a 0.3 μg ^{249}Bk source measured with a 20-cm$^2\times$15-mm LEPS spectrometer through a set of one-mm quartz, one-mm plastic, and one-mm thick Al absorbers in coincidence with the ^{249}Bk α_{327} group. Alpha particles were detected with a 150-mm^2 PIPS detector at a solid angle of 2%. The counting time was 11 days. The peak at 333.4 keV belongs to the decay of ^{249}Cf.

FIG. 4: γ-ray spectrum measured with a 20-cm$^2\times$15-mm LEPS spectrometer gated by α particles above the ^{249}Bk α_{327} group. The spectrum was generated from the same data set that was used for Fig. 3. Peaks next to the Am K x-ray peaks are from ^{249}Cf decay. Only a quarter of the Am K x rays are due to transitions from the decay of the 154-keV band; the rest belongs to the decay of the 327.45-keV level (see text for further details).

FIG. 5: γ-ray spectrum of a 1-μg ^{249}Bk source measured with a 2-cm$^2\times$10-mm LEPS spectrometer. The source was sandwiched between two 120-mg/cm^2 Be disks and was placed directly on top of the detector. A set of 0.4 g/cm^2 steel and 0.23 g/cm^2 Al absorbers was used to reduce the bremsstrahlung radiation. The measurement was started 3 days after chemical separation; the counting time was 62.5 hours. The ^{249}Cf γ-ray contribution has been removed by subtracting the normalized spectrum of a pure ^{249}Cf source. The inset provides the Am K x-ray region of the same spectrum.

FIG. 6: Alpha-decay scheme of ^{249}Bk deduced in the present work. On the left side of the levels, the single-particle state quantum numbers [N$n_z\Lambda$]K,I$^\pi$ are given. On the right side, level energies in keV, α energies in keV, α intensities in %, and hindrance factors are presented. The α decay to the 28.0-keV level was not observed because it was masked by the strong 5414-keV peak,

FIG. 7: A comparison between experimental single-particle energies in odd-mass Am isotopes; the data for ^{239}Am are taken from Ref. [2], for ^{241}Am from Ref. [20], and for ^{243}Am from Ref. [21]. The information on ^{245}Am is from the present work.

TABLE I: ^{249}Bk α-decay data obtained in the present work and previous measurements. Hindrance factors were calculated with the spin-independent theory of Preston [11] using a radius parameter of 9.323 fm.

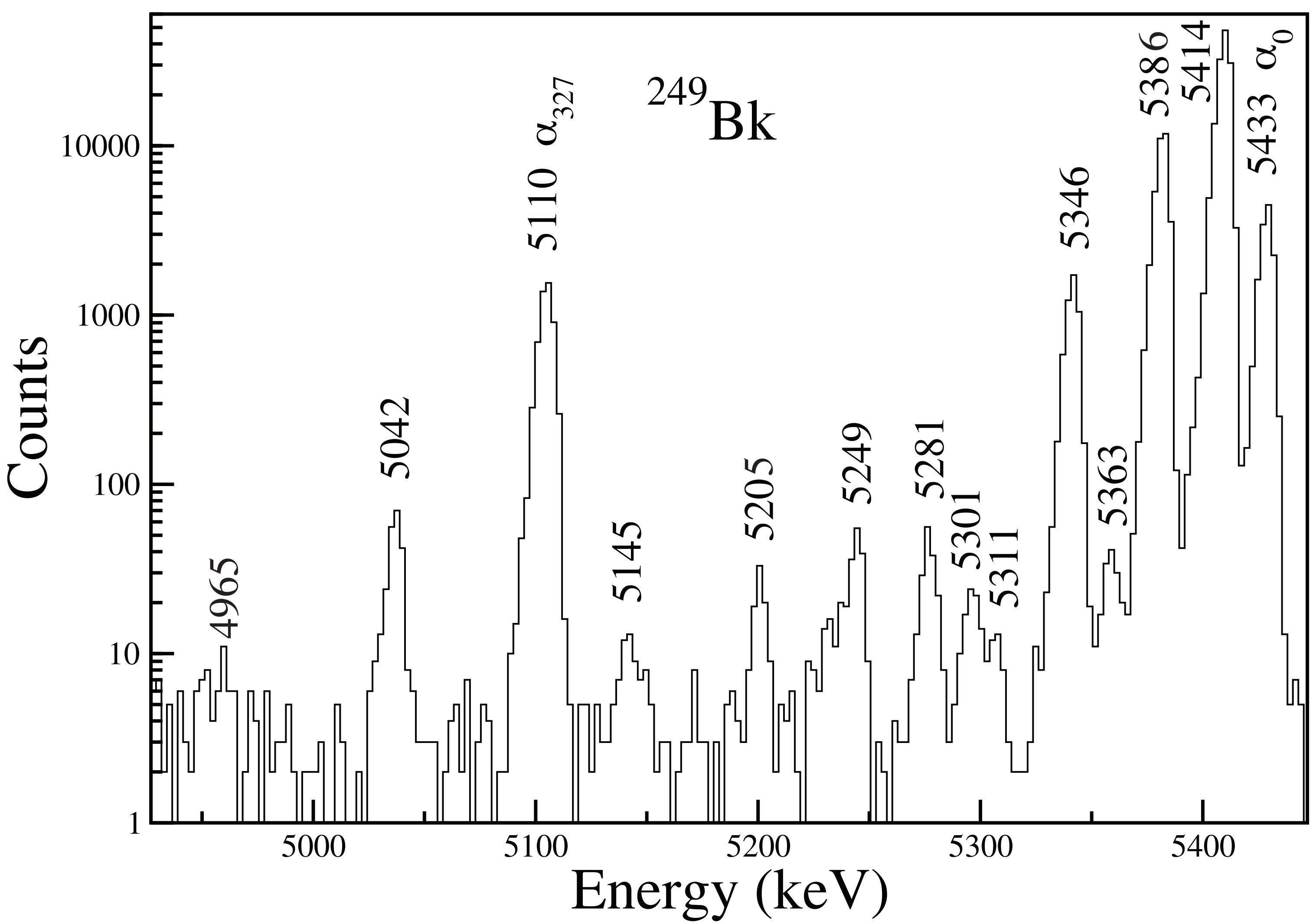
Level	α energy (keV)			α intensity (%)				Hindrance
energy (keV)	(Present)	(Ahmad) Ref. [2]	(Baranov) Ref. [5]	(Present)	(Ahmad) Ref. [2]	(Baranov) Ref. [5]	(Milsted) Ref. [6]	Factor
0	5433(2)	5432(2)	5432(1)	6.57(10)	6.7(3)	4.8	8.4	106
19	5414(2)	5413(2)	5416(1)	69.7(3)	69.2(15)	74.8	68.0	7.6
48	5386(2)	5385(2)	5388(1)	17.9(2)	18.4(5)	16.0	18.3	20.1
71	5363(2)			0.077(8)				3400
88	5346(2)	5346(2)	5347(1)	2.60(5)	2.6(2)	1.5	2.5	79
124	5311(2)			0.03(1)				4100
134	5301(2)			0.046(7)				2300
154	5281(2)			0.09(1)				890
187	5249(2)	5248(2)		0.09(1)	∼0.1		∼0.1	551
232	5205(2)			0.048(7)				544
293	5145(2)			0.018(5)				590
328	5110(2)	5110(2)	5109(1)	2.70(5)	2.7(2)	1.8	2.7	2.35
397	5042(2)	5047(5)	5040(1)	0.12(1)	0.10(4)	0.04	∼0.07	18.6
476	4965(4)			∼0.01				∼64

TABLE II: ^{249}Bk γ rays measured with a 2-cm^2×10-mm LEPS spectrometer.

Energy (keV) present	Energy (keV) Börner *et al.* [13]	Intensity present	Intensity Daniels *et al.* [7]	Transition Initial (keV) →Final (keV)
28.0±0.1		∼0.10		28.0→0.0
102.04±0.04		0.35±0.03		Am Kα_2
106.48±0.04		0.53±0.04		Am Kα_1
119.26±0.04				Am Kβ_3
		0.22±0.02		
120.31±0.04				Am Kβ_1
123.8±0.3		0.08±0.01		Am Kβ_2'
280.36±0.04	280.385±0.013	0.10±0.01	0.07±0.01	327.45→47.1
308.26±0.04	308.222±0.008	0.24±0.02	0.24±0.02	327.45→19.2
327.45±0.04	327.428±0.008	1.06±0.06	1.06±0.07 (norm)	327.45→0.0

TABLE III: Hindrance factors to the members of the $3/2^-$[521] band.

Spin	HF, ^{249}Bk	HF, ^{245}Am	Ratio
3/2	181	890	0.20
5/2	160	551	0.29
7/2	95	544	0.17
9/2	145	590	0.25


249Bk
Counts
Energy (keV)
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5110 α327
5145
5205
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5301
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5200
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5400

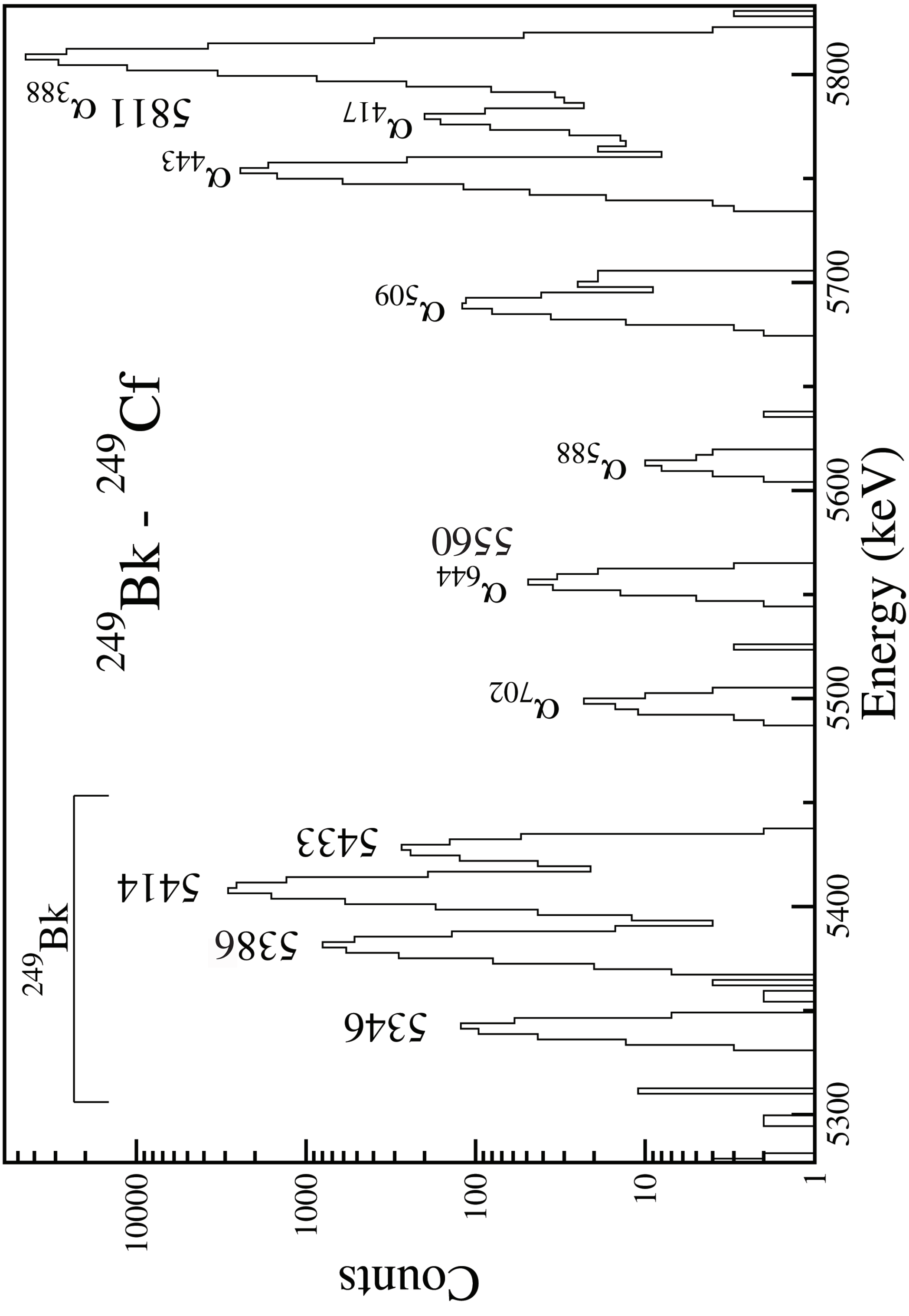


Figure 2 CC10348 22Apr2013

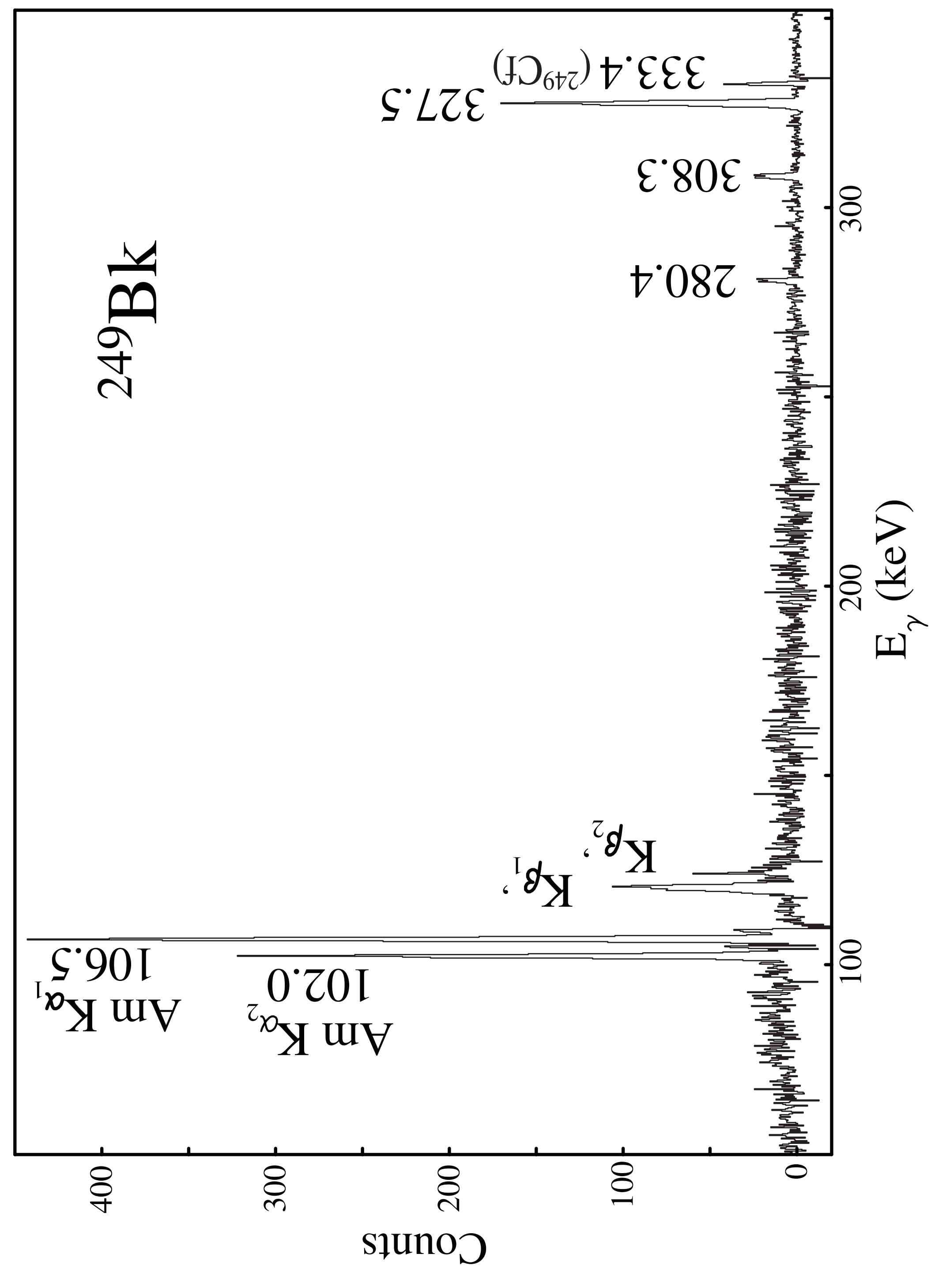


Figure 3 CC10348 22Apr2013

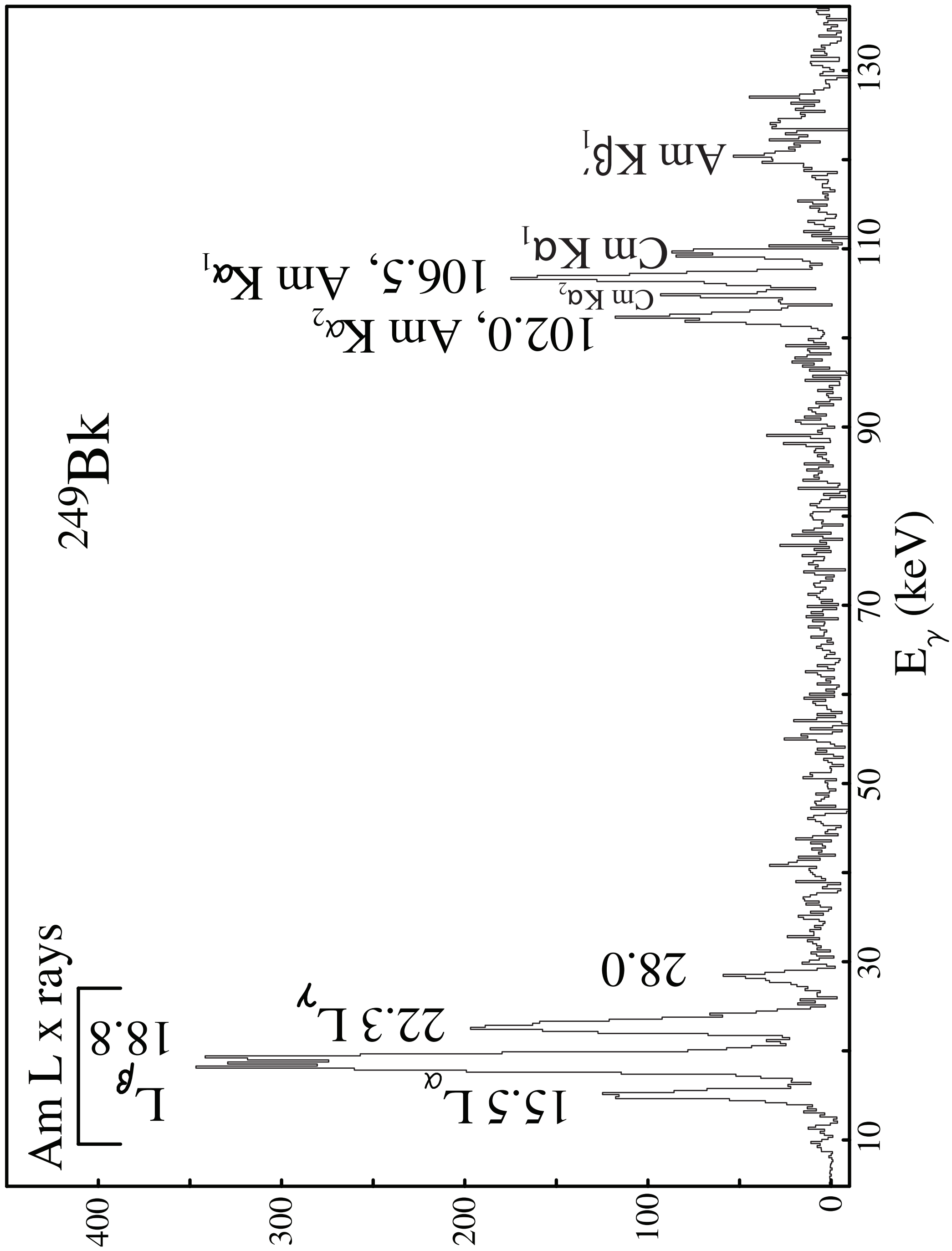


Figure 4 CC10348 22Apr2013

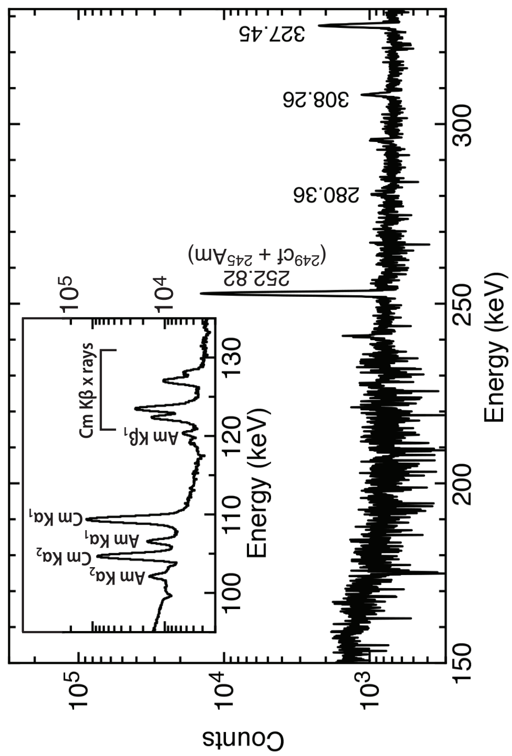
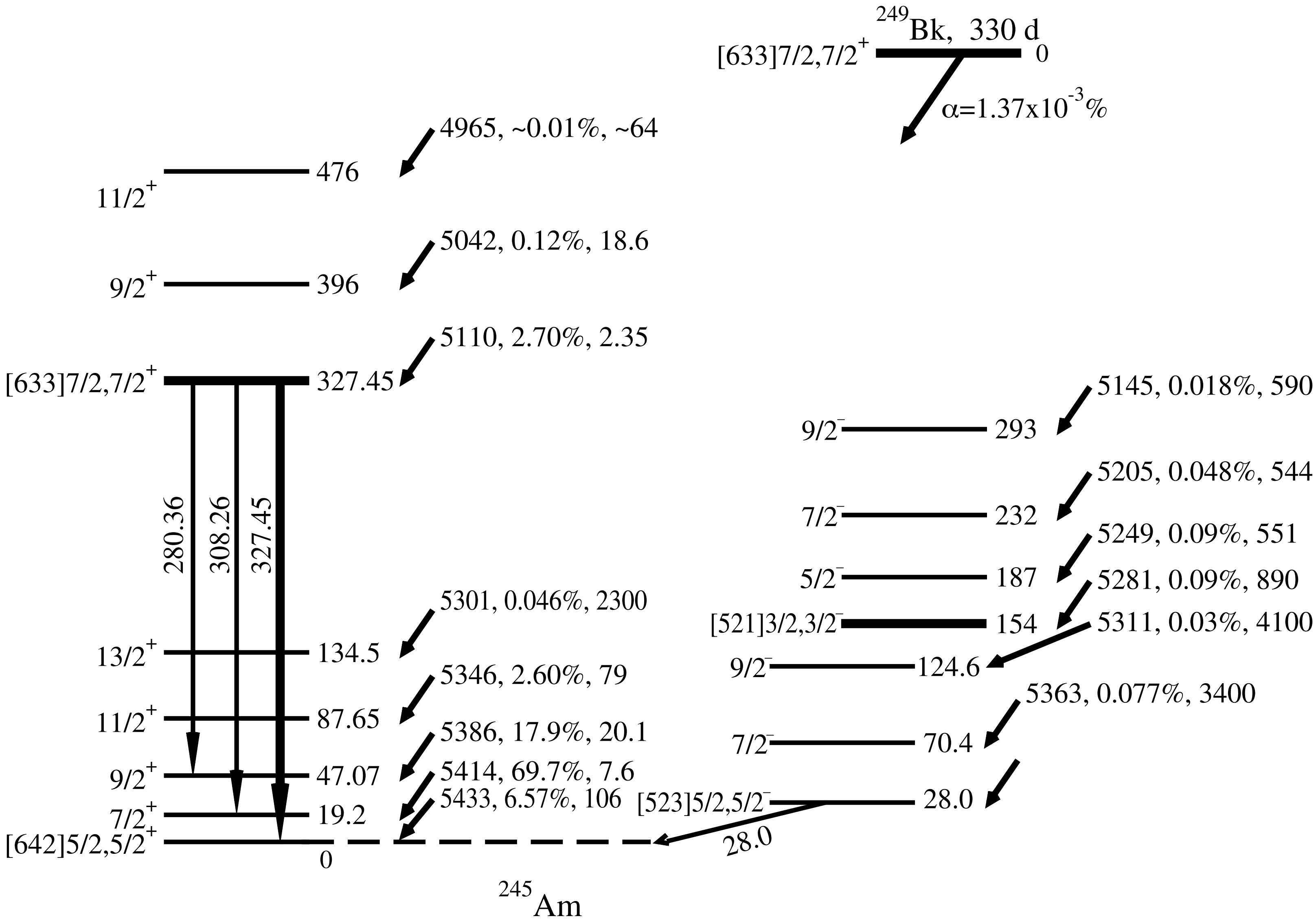
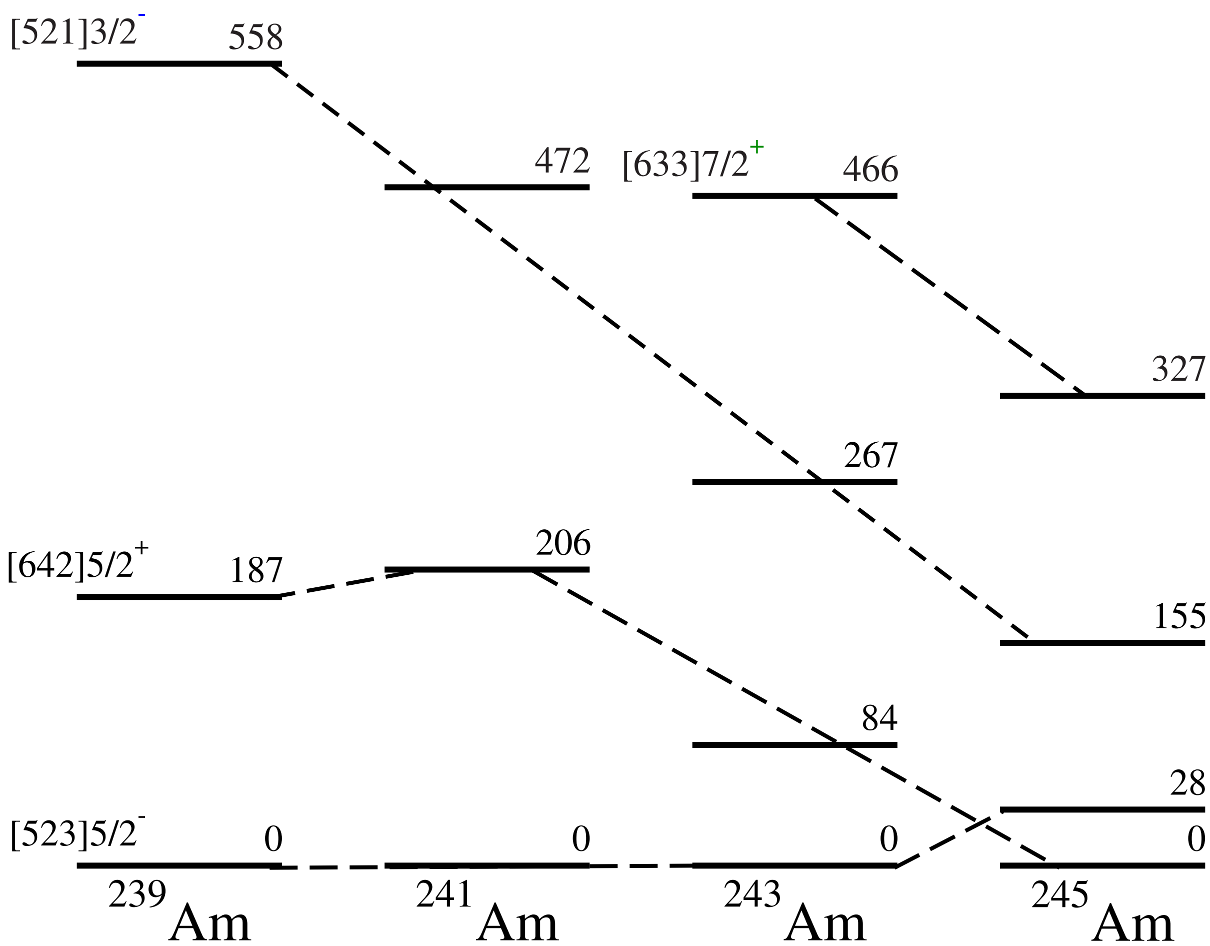


Figure 5 CC10348 22Apr2013

Figure 6 CC10348 22Apr2013

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241Am
243Am
245Am