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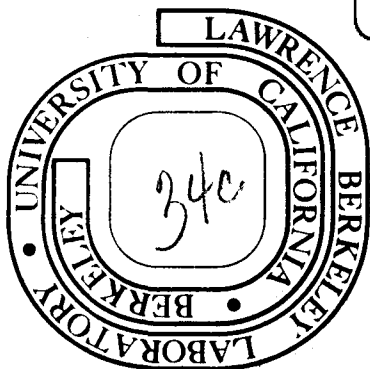
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THE ELECTRON-CAPTURE DECAY OF $^{206}\text{Po}^*$ L. J. Jardine[†] and A. A. Shihab-Eldin[‡]University of California
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RADIOACTIVITY ^{206}Po [from $^{209}\text{Bi}(p,4n)$];
measured E_γ , I_γ , γ - γ coinc; deduced EC branching,
log ft. ^{206}Bi deduced levels, J, π , γ -multi-
polarity. Ge(Li) detectors, Ge(Li)-Ge(Li) coinc.

ABSTRACT

The energies and intensities of seventy-seven γ -ray transitions assigned to the electron-capture decay of ^{206}Po have been measured. Multipolarities of transitions were determined from internal conversion coefficients calculated from our relative γ -ray intensities and the relative conversion electron intensities of Fujika, Kanbe and Hisatake. Gamma-ray singles, γ - γ coincidence, and previous conversion electron measurements were used to construct a more complete decay scheme for ^{206}Po . Data obtained from in-beam reaction studies, ^{210}At alpha decay studies and the present electron-capture decay scheme were used to identify states in ^{206}Bi of a one proton particle - three neutron hole character. In addition a qualitative discussion of the level structure of ^{206}Bi generated from (zero-order) couplings of $1h_{9/2}$ and $2f_{7/2}$ protons with the low-lying states of ^{205}Pb is given, and this is compared with reasonable success to the experimental spectrum. The dominant electron-capture decay rates are explained in terms of an allowed single-particle mechanism.

I. INTRODUCTION

The ^{206}Bi nucleus can be described in terms of the shell model as one proton particle and three neutron holes removed from the doubly closed shell of ^{208}Pb . The low-lying level structure of ^{206}Bi is expected to be generated from couplings of $1h_{9/2}$ and $2f_{7/2}$ protons with the low-lying three neutron hole states in ^{205}Pb . Allowed electron-capture decay from the 0^+ ground state of ^{206}Po is expected to directly populate only the 1^+ states of ^{206}Bi . Subsequent electromagnetic transition cascades to the 6^+ ground state of ^{206}Bi should populate states in the spin range of 0 - 7, thus identifying a major portion of the 1p-3h states in ^{206}Bi .

Earlier investigations of the electron-capture decay of ^{206}Po were carried out by Arbman¹ and Stoner² before high-resolution Ge(Li) detectors were available. More recent in-beam reaction studies^{3, 4} have provided some properties of the high-spin states of ^{206}Bi . Direct measurements of the alpha spectra of ^{210}At have also been made.⁵ To learn more about the level structure of ^{206}Bi , restudies of electromagnetic transitions from the electron-capture decay of ^{206}Po and from the alpha decay of ^{210}At were undertaken. Reports^{6, 7} of the alpha decay of ^{210}At have been given elsewhere. During the course of the electron-capture study,⁸ preliminary reports⁹ on the internal-conversion electrons from the ^{206}Po decay were made available to us. These high-resolution magnetic spectrometer measurements prompted us to abandon Si(Li) conversion-electron measurements and to concentrate on γ -ray singles and γ - γ coincidence measurements in order to further establish the decay scheme.

In this paper we report the γ -ray transitions following the electron-capture decay of ^{206}Po using Ge(Li) spectrometers. A new decay scheme for ^{206}Po is constructed from present and all previous data.¹⁻⁹ The levels of ^{206}Bi are discussed in terms of a zero-order one proton particle-three neutron hole coupling model.

II. EXPERIMENTAL

A. Source Preparation

Sources of 8.8-day ^{206}Po were obtained by the reaction $^{209}\text{Bi}(p, 4n)^{206}\text{Po}$ at bombarding energies of 37 - 42 MeV with bismuth metal targets of thicknesses 25 - 115 mg/cm². These targets initially contained appreciable amounts of (5.7 hr.) ^{207}Po and (2.9 yr.) ^{208}Po due to the broad excitation functions for the (p, xn) reactions, so they were allowed to stand for several days until the ^{207}Po had decayed. The following modified chemical separation procedure¹⁰ was used to remove the ^{207}Bi , in addition to the ^{206}Bi which grew in from the decay of ^{206}Po .

The target was dissolved in 6N HNO_3 . The excess HNO_3 was destroyed by repeated additions of HCl followed by a slow evaporation of the solution to a small volume using a heat lamp. A 1 ml solution of the activity was made $\approx 0.3\text{M}$ in KI and 3M in HCl and then was transferred to a separatory funnel containing 5 ml of iso-propyl ether. The polonium was extracted into the ether phase while the bismuth (and lead) remained in the aqueous phase. (A bismuth carrier was added when initial sources were "repurified" a second or third time after appreciable amounts of

^{206}Bi had grown in.) The ^{206}Po was removed from the ether phase by washing with 3N HCl. Sources for γ -ray counting were prepared by evaporation onto thin aluminum or teflon backings.

B. Gamma Ray Spectra

Gamma-ray singles spectra were obtained with a 35-cm³ coaxial Ge(Li) detector (system resolution 2.6 keV (FWHM) at 1332 keV) coupled with a 4096-channel data acquisition system previously described.^{11, 12} A 10-cm³ planer Ge(Li) detector (system resolution 1.4 keV (FWHM) at 122 keV) was also used in some measurements. A typical γ -ray spectrum in the energy range of 30 - 1800 keV is shown in figure 1. Since ^{206}Bi , the daughter of ^{206}Po , was itself unstable to electron-capture decay, the γ -ray spectra became progressively more complex after the initial preparation of a ^{206}Po source. Thus, major ^{206}Bi γ -rays are also identified in figure 1.

The spectra were analyzed with the computer code¹³ SAMPO. Energy calibrations were obtained from the data compiled by Jardine.¹⁴ Uncertainties due to relative efficiency calibrations¹⁵ were estimated to be $\pm 5\%$. The energies and relative intensities of γ -ray transitions assigned to the decay of ^{206}Po are given in Table 1 which also includes the energies of the transitions determined from the internal conversion-electron measurements of ref. 9. Our results are in rather good agreement with those of ref. 9 for transitions observed in both types of measurements. Gamma rays of energies $\lesssim 280$ keV are especially difficult to observe because of the intense Compton background coupled with the relative weakness and complexity of these transitions. Thus the high-

resolution conversion-electron energy measurements of ref. 9 generally provide the most complete data below this energy.

We have also shown in Table 1 multipolarities for many γ -rays which were deduced from a comparison of experimental subshell ratios and/or experimental conversion coefficients⁹ with the theoretical values of Hager and Seltzer.¹⁶ Conversion coefficients were calculated from the relative electron intensities of ref. 9 and our relative γ -ray intensities; they were normalized to the theoretical value for the 861.4-keV E2 transition. A renormalization of the relative intensities in Table 1 can be made using the absolute intensity for the 286.2 keV γ -ray calculated from the level scheme. It is calculated to be 22.8 ± 2.0 photons per 100 decays of ^{206}Po .

C. Gamma-Gamma Coincidence Measurements

Three parameter γ - γ coincidence measurements were made with two coaxial Ge(Li) detectors of about 35 cm^3 (active volume) each. The axes of the two detectors were positioned at 90° with respect to the source and were separated by a graded shield of lead-cadmium-copper to minimize scattering between the detectors. A fast-coincidence electronic arrangement (leading-edge timing) previously described^{11,12} was used. The width of the prompt time distribution was determined from the 286 - 1032 keV γ -ray cascade to be about 35 nsec (FWHM). Three parameter data (E_1 , E_2 , Δt) were stored serially on magnetic tape and were later sorted on the LBL CDC-7600 computer system. The sorting routine employed permitted subtraction of random events and events associated with the neighboring Compton distributions from each energy

gate. Approximately fifty such sorts were performed at a resolving time of about 70 nsec. Several typical coincidence spectra are shown in figures 2 and 3. A summary of coincidence relations deduced from these measurements is given in Table 2.

III. DECAY SCHEME

Coincidence measurements and sum-difference relationships among γ -ray energies have been used to construct the scheme shown in figure 4. Electron-capture branching ratios were determined from the total transition intensity (calculated from our γ -ray intensity data and the multipolarities given in Table 1) depopulating each level. No decay to the ground state was assumed. Based on the ^{206}Po electron-capture branching¹⁷ of 94.6% and a Q-value of 1820 ± 40 keV,¹⁸ $\log ft$ values were calculated¹⁹ employing the methods discussed by Konopinski and Rose.²⁰ Spin and parity assignments are based upon $\log ft$ values of electron-capture branches, γ -ray multipolarities and previously reported data.¹⁻⁹ For completeness and for use in later discussions, levels populated by the alpha decay of ^{210}At ^{5,6} have also been included in figure 4.

The decay scheme of figure 4 is substantially different than the previous one proposed by Arbman¹ because of the discovery⁹ of an intense (93% of EC decays) 10.84-keV M1 transition depopulating a new 3^+ state at 70.8 keV; this has been recently discussed in detail by ref. 9. In the ^{206}Po decay, states of spin and parity 1^+ are directly populated, presumably by an allowed Gamow-Teller decay; states with spins ≤ 7 are identified by subsequent γ -ray cascades to the 6^+ ground state.

IV. SPIN, PARITY, AND CONFIGURATION ASSIGNMENTS

No theoretical calculations of the level structure of ^{206}Bi have been made. However, its low-lying level structure might a priori be characterized by one (proton) particle-three (neutron) hole states arising from couplings of the (odd) 83rd proton with the (odd) 123rd neutron. To estimate qualitatively the number and type of such states, we show in figure 5 the experimental^{21,22} states of ^{209}Bi and ^{205}Pb . The first three states of ^{209}Bi are due²¹ to the proton single-particle orbitals $1h_{9/2}$, $2f_{7/2}$, and $1i_{13/2}$. The four states of ^{205}Pb at 0, 2.3, 270 and 1014 keV are due²² predominantly to an odd neutron (or three-neutron holes) in the $2f_{5/2}$, $3p_{1/2}$, $3p_{3/2}$, and $1i_{13/2}$ single-particle orbitals, respectively. The remaining ^{205}Pb states shown are presumably of a more complex nature. If one now considers couplings of the $1h_{9/2}$ and $2f_{7/2}$ protons with the three neutron hole states of ^{205}Pb , the band structure shown in column 4 of figure 5 results. For clarity, the degeneracy of multiplets formed from these couplings has not been removed; however, all possible spins contained in each multiplet are explicitly identified. For example, the ground state and other low-lying states of ^{206}Bi are presumably formed from the couplings of a $1h_{9/2}$ proton with an odd $2f_{5/2}$ neutron. The shell model configurations for such even parity states will be of the form $(\pi(h_{9/2})\nu(f_{5/2})^{-1}(p_{1/2})^{-2})_{J=2,3,4,5,6,7^+}$. Similarly, two states belonging to the $(\pi(h_{9/2})\nu(p_{1/2})^{-1}(f_{5/2})^{-2})_{4,5^+}$ configurations are expected in the immediate proximity followed at a slightly higher energy by four states with the $(\pi(h_{9/2})\nu(p_{3/2})^{-1}(p_{1/2})^{-2})_{3,4,5,6^+}$ configurations. Finally, all known experimental states of ^{206}Bi are shown (with a shifted energy for the

ground state) in the last column of figure 5.

A. Levels at 0, 59.9, 70.8, 82.8, 140 and 409.2 keV

The ground state of ^{206}Bi has a measured spin²³ of 6 and can be assigned an even parity because of its shell-model configuration and electron-capture decay properties to states in ^{206}Pb . The alpha decay of ^{210}At populates⁵ the ground state and a state at 60 keV. Arguments for the placement of a pure E2 transition de-exciting a state at 59.9 keV have been given by Arbman;¹ this state has a measured²⁴ half-life of 7.8 ± 0.2 μsec . A spin of 4 for the 59.9-keV state is most consistent with the decay data and the lack of strong population of this state in in-beam reaction studies.^{3,4}

A state at 70.8 keV is well defined by the decay scheme of figure 4. A 3^+ assignment for the spin and parity of this state can be made on the basis of the intense⁹ 10.84-keV M1 transition depopulating this state to the 4^+ state at 59.9 keV and the 807.3-, 1007.1-, and 1032.3-keV M1 transitions populating this state from the 2^+ states at 878.1, 1078.0, and 1103.1 keV, respectively. The absence of alpha decay to this state, assuming such an assignment, is in agreement with detailed theoretical alpha-rate calculations.⁷

A state at 83 ± 1 keV that is de-excited by a γ -ray transition to the ground state has been identified⁶ in the alpha decay of ^{210}At . Theoretical alpha-rate calculations of ref. 7 suggested an assignment of 5^+ . An 82.80-keV M1 transition observed by ref. 9 has been placed in figure 4 as de-exciting this state, employing the fact that the 117.5-keV transition (which feeds the 82.8-keV state) is in coincidence with the

511.4 and 677.8 keV transitions. This is shown in figures 2c and 3d. The weak intensity of the 82.8-keV γ -ray, compared to the K X-rays, prevented the observation of this transition in the γ -ray singles measurements. The intensity balance of the decay scheme is also consistent with this placement.

A 7^+ state at 140 keV was observed in in-beam experiments^{3,4} and the alpha decay^{5,6} of ^{210}At . It decays by a 140 ± 1 -keV M1 transition to the ground state. The 140.5-keV M1 transition observed in the electron-capture decay of ^{206}Po has not been placed as de-exciting this level. A 7^+ state should not be populated with such an intensity, if at all, in the electron-capture decay. Further, the γ - γ coincidence data (figures 2c and 3d) are only consistent with the placement of the 140.5-keV γ -ray as depopulating the 200.4-keV level.

Coincidence relations of Table 2 define a state at 409.2 keV. A 2^+ assignment can be made for this state from the M1 multipolarities of the 338.4-keV transition to the 3^+ state at 70.8 keV and the 980.1-keV transition from the 1^+ state at 1389.5 keV.

As indicated by the dashed lines in figure 5, these even parity states discussed above with spins between 2 and 7 are tentatively assigned the dominant configuration $\pi(h_{9/2})\nu(f_{5/2})^{-1}(p_{1/2})^{-2}$. Relative alpha-decay rate calculations⁷ assuming this configuration for these six states also gave results that are in essential agreement with experimental measurements. Even better agreement for the 4^+ and 5^+ states at 59.9 and 82.8 keV, respectively, was obtained when small admixtures from the $\pi(h_{9/2})\nu(p_{3/2})^{-1}(p_{1/2})^{-2}$ and $\pi(h_{9/2})\nu(p_{1/2})^{-1}(f_{5/2})^{-2}$ configurations were included in the description of these states.

B. Levels at 167 and 200.4 keV

Coincidence relationships define a state at 200.4 keV. The three M1 transitions depopulating this state to the 4^+ , 3^+ , and 5^+ states at 59.9, 70.8, and 82.8 keV, respectively, establish the spin and parity as 4^+ .

There is no definite evidence from our γ -ray measurements that the 5^+ state at 167 ± 1 keV identified^{5,6} in the alpha decay of ^{210}At is also populated in the ^{206}Po electron-capture decay. Reference 6 observed two transitions of 106 ± 1 and 167 ± 2 keV (with the relative photon ratio of $2.7 \pm 0.5/1.0$) depopulating this state, but neither was observed in our measurements.

If these two states are identified with the shell-model $(\pi(h_{9/2})\nu(p_{1/2})^{-1}(f_{5/2})^{-2})$ configuration as indicated in figure 5, then the 167-keV state must be the 5^+ member of this configuration. Theoretical (relative) alpha decay rates and electromagnetic transition rates employing these assignments were in agreement with experimental results, provided appreciable admixtures of the $(\pi(h_{9/2})\nu(f_{5/2})^{-1}(p_{1/2})^{-2})$ and $(\pi(h_{9/2})\nu(p_{3/2})^{-1}(p_{1/2})^{-2})$ configurations were also included in the wavefunctions.^{6,7}

C. Levels at 352.7, (400), and 523.3 keV

The states at 352.7 and 523.3 keV are well defined by coincidence and sum-difference relationships. The M1 transitions of 292.8 and 282.0 keV from the 352.7-keV state to the 4^+ and 3^+ states at 59.9 and 70.8 keV, respectively, limit the spin of this state to 4 or 3 only. A weak argument, like lack of M1 transitions feeding this state from higher-lying 2^+ states, can be used to make a tentative assignment of 4^+ more favorable, but speculative.

The transitions not observed would be of E2 multipolarity in comparison with the faster M1 transitions which are observed to populate lower-lying 3^+ states. A spin and parity assignment of 3^+ for the state at 523.3 keV can be made on the basis of the M1 character of the 463.4-keV transition de-exciting this state to the 4^+ state at 59.9 keV and by population of this state by an M1 transition of 554.7 keV from the 2^+ state at 1078.0 keV.

A tentative state at 400 ± 3 keV has been identified⁵ in the alpha decay of ^{210}At . There is no additional data about its γ -decay properties. However, the energy of this state does not agree with the energy of the 2^+ state at 409.2 ± 0.2 keV. Further, theoretical alpha rate calculations⁷ do not predict such an intensity for the population of the configuration $(\pi(h_{9/2})^{\nu}(f_{5/2})^{-1}(p_{1/2})^{-2})_{2^+}$. Thus it is believed that these are two separate states. One might argue that the state at 400 keV is a 5^+ state which is populated by an admixture of the favored alpha decay configuration. If this is so, one can make tentative assignments for the dominant configurations of these states as $(\pi(h_{9/2})^{\nu}(p_{3/2})^{-1}(p_{1/2})^{-2})_{3,4,5,6^+}$. This would imply that a yet unobserved 6^+ state also exists in this energy region. Such a state is not expected to be populated by the electron-capture decay of ^{206}Po . We have indicated these tentative assignments in figure 5.

D. Levels at 734.0, 878.1, 897.2, 1072.1, 1078.0, 1080.0 and 1103.1 keV

The level at 734.0 keV is defined by numerous sum-difference relations and by the coincidence relations of the 282.0- and 381.2-keV transitions shown in Table 2. The M1 transitions of 533.6 and 328.8 keV to the 4^+ and 2^+ states at 200.4 and 409.2 keV define the spin and parity

as 3^+ .

States at 878.1, 1078.0, and 1103.1 keV are very well defined by coincidence relations shown in Table 2. A definite spin and parity assignment of 2^+ for each of these three states can be made since each state is populated by an M1 transition from the 1^+ state at 1389.5 keV and each decays by an E2 transition to the 4^+ state at 59.9 keV. The lack of β -decay feeding to these states is also consistent with second-forbidden transitions²⁵ implied by the 2^+ assignment.

Coincidence relationships among γ -rays establish a state at 897.2 keV. An assignment of 3^+ for the state can be made because of the 180.79-keV M1 transition populating it from the 2^+ state at 1078.0 keV and the 837.3-keV M1 transition depopulating it to the 4^+ state at 59.9 keV.

The states at 1072.1 and 1080.0 keV are established only by a limited number of sum-difference relationships indicated by the decay scheme of figure 4. If the transitions are placed correctly, the multiplicities limit the spin to 3 or 4 and the parity as even. No γ -ray transitions could be placed populating these states implying that a weak electron-capture feeding to these states apparently exists. However, decay to states of these spins would be third forbidden, or greater. Such decays are not expected to compete with the allowed decay branches to the 1^+ states. Thus it is almost certain that weak, unplaced or unobserved transitions populate these two states and are the cause of these apparent feedings. In figure 4 we show dashed feedings for these states with the indicated limits representing the intensities of such transitions.

E. Levels at 931.8, 1389.5, 1523.8, 1568.1 and 1600.4 keV

States at 931.8 and 1389.5 keV are firmly established from coincidence relations of Table 2. The state at 931.8 keV can be given a spin and parity assignment of 1^+ because of the 861.1-keV E2 transition to the 3^+ state and the 522.5-keV M1 transition to the 2^+ state at 409.2 keV. In addition, the $\log ft$ value of 8.0 for decay to this state is also consistent with a spin of 1 as all known second forbidden (non-unique) transitions²⁵ have values of $\log ft \geq 11.0$. The state at 1389.5 keV receives about 77% of the total electron-capture decay. The 1318.7 keV E2 transition to the 3^+ state at 70.8 keV and the 511.4 keV M1 transition to the 2^+ state at 818.1 keV make a spin and parity assignment of 1^+ definite. This is supported by the $\log ft$ value of 6.7 which is consistent²⁵ only with an allowed beta decay (i.e., $0^+ \rightarrow 1^+$) as no parity change is involved in the electron-capture decay.

States at 1523.8 and 1600.4 keV are established by the coincidence of the 338.4-keV transition with the 1114.6- and 1191.2-keV γ -rays, respectively, as shown in figure 2. The E2 transition to the 3^+ state at 70.8 keV and the M1 transition to the 2^+ state at 409.2 keV established the spin and parity of the 1532.8-keV state as 1^+ ; the $\log ft$ value is also consistent with an allowed transition. The $\log ft$ value of 8.0 for decay to the state at 1600.4 keV is the strongest argument for a 1^+ assignment as the multiplicities of the 1191.2- and 222.0-keV transitions can only limit the spin assignments to 1, 2 or 3.

Coincidence data for the 1497.2- and 1044.8-keV transitions are consistent with a state at 1568.1 keV. The parity is established as

even by the 1497.2-keV E2 transition to the 3^+ state at 70.8 keV. Again the $\log ft$ value of 8.4 indicates an allowed transition thereby strongly arguing for a spin and parity assignment of 1^+ .

V. CONCLUSIONS

The rather low Q-value for the electron-capture decay of ^{206}Po helps to make an interpretation of the levels of ^{206}Bi easier as only five states receive any measureable direct electron-capture decay in the present level scheme. Electron-capture decays to these 1^+ states from the even-even 0^+ ground state of ^{206}Po proceed via an allowed beta transition. Subsequent γ -ray decay of these 1^+ states populates states of spin 2, 3, 4, and 5 until the 6^+ ground state is reached.

In figure 5 we have shown five possible (degenerate) multiplets formed from couplings of the odd proton and the odd neutron (or three-neutron holes) that give rise to 1^+ states in the energy range of interest. (It may only be fortuitous that five 1^+ states are presently experimentally identified.) The 1^+ state at 1389.5 keV receives most of the electron-capture decay and is believed to arise from the coupling of a $2f_{7/2}$ proton to the three-neutron holes with a configuration of the ground state of ^{205}Pb . This is indicated in figure 5. Such a configuration of ^{206}Bi can be written explicitly as $(\pi(f_{7/2})\nu(f_{5/2})^{-1}(p_{1/2})^{-2})_1^+$. The 0^+ ground state of ^{206}Po is of a two proton-four neutron hole character with the probable dominant configuration $(\pi(h_{9/2})^2\nu(f_{5/2})^{-2}(p_{1/2})^{-2})_0^+$. An allowed single-particle electron-capture decay of the type $\pi 2f_{7/2} \xrightarrow{\text{EC}} \nu 2f_{5/2}$ can be used to explain the electron-capture decay

to the 1^+ state at 1389.5 keV if the ground state wave function of ^{206}Po has a second component of the form $(\pi(f_{7/2})^2\nu(f_{5/2})^{-2}(p_{1/2})^{-2})_0^+$. This same type of argument has been used^{26,27} to explain the electron-capture decay of ^{207}Po and ^{205}Po to the $7/2^-$ single-particle states in ^{207}Bi and ^{205}Bi , respectively. Reference 9 has previously suggested this type of mechanism for ^{206}Po and we also believe that this is the main mechanism for the electron-capture decay. Decay to the other 1^+ states in ^{206}Bi (with somewhat higher $\log ft$ values) probably proceeds via the same single-particle mechanism through admixtures of the $(\pi(f_{7/2})\nu(f_{5/2})^{-1}(p_{1/2})^{-2})_1^+$ configuration present in the wavefunctions of these states.

States assigned to the $(\pi(h_{9/2})\nu(f_{5/2})^{-1}(p_{1/2})^{-2})_{2,3,4,5,6,7^+}$, $(\pi(h_{9/2})\nu(p_{1/2})^{-1}(f_{5/2})^{-2})_{4,5^+}$, and $(\pi(h_{9/2})\nu(p_{3/2})^{-1}(p_{1/2})^{-2})_{3,4,5,6^+}$ configuration have been previously discussed in Section IV, and are shown in figure 5.

Calculations of electromagnetic transition probabilities and alpha decay rates using these assumed configurations for states of ^{206}Bi populated in the alpha decay of ^{210}At have previously been made.^{6,7} The results indicated that agreement of the theoretical calculations with existing experimental data could be obtained if some configuration mixing among these three configurations was allowed for the 4^+ and 5^+ states.

Finally the states in the energy range of 734.0 to 1103.1 keV are presumably of a rather complex structure and we presently can not ascribe a specific configuration to these states using only qualitative arguments. However, two states observed^{3,4} in recent in-beam experiments in this energy range merit some additional remarks. A 10^- isomer of 1 msec half-life at 1043 keV has been assigned^{28,29} a $(\pi(h_{9/2})\nu(i_{13/2})^{-1}(p_{1/2})^{-2})$ configuration. This is also consistent with the

qualitative predictions of figure 5. Decay of this isomeric state to an 8^+ state at 814 keV has been observed. This 8^+ state, as suggested from figure 5, might arise from a coupling of a $1h_{9/2}$ proton with a $7/2^-$ state of ^{205}Pb . The dominant configuration of the $7/2^-$ state of ^{205}Pb is expected to be of the type $(\nu(f_{5/2})^{-2}(p_{1/2})^{-1})_{7/2^-}$, with perhaps the following internal coupling $(\nu((f_{5/2})^{-1}(p_{1/2})^{-1})_{2^+}(f_{5/2})^{-1})_{7/2^-}$. Thus the 8^+ state of ^{206}Bi might have a major component of the type $(\pi(h_{9/2})(\nu(f_{5/2})^{-2}(p_{1/2})^{-1})_{7/2^-})_{8^+}$. Perhaps these latter two states provide further evidence that the level structure of ^{206}Bi can be interpreted in terms of one particle-three hole configurations, at least up to 1389 keV.

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FOOTNOTES AND REFERENCES

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Table 1. Gamma-rays observed in the decay of ^{206}Po

γ -ray ^a energy (keV)	γ -ray energy (keV)	Relative ^b γ -ray intensity	Multipolarity ^c
10.836 ± 0.022			M1
32.532 ± 0.019			M1 + E2
53.610 ± 0.043			
59.908 ± 0.018	60.0 ± 0.3	4.6 ± 1.5	E2
82.802 ± 0.022			M1
109.484 ± 0.033			
117.536 ± 0.028	117.6 ± 0.2	0.40 ± 0.05	M1
124.669 ± 0.043			(M1)
129.644 ± 0.020	129.6 ± 0.3	0.10 ± 0.03	M1
140.486 ± 0.028	140.4 ± 0.6	0.40 ± 0.10	M1
144.166 ± 0.028	144.5 ± 0.6	0.15 ± 0.07	M1
146.180 ± 0.026	146.8 ± 0.6	0.31 ± 0.14	M1
152.308 ± 0.052			(M1)
162.621 ± 0.030			
170.501 ± 0.021	170.6 ± 0.2	0.85 ± 0.34	M1
171.340 ± 0.024	171.5 ± 0.3	0.22 ± 0.12	M1
177.035 ± 0.036			
179.453 ± 0.020	179.1 ± 0.4	0.13 ± 0.08	M1
180.791 ± 0.019	180.6 ± 0.2	0.34 ± 0.15	M1
205.936 ± 0.050	205.5 ± 1.0 ^d	0.16 ± 0.06	(E2)
210.672 ± 0.051	210.8 ± 0.2	0.15 ± 0.03	(M1 + E2)
224.853 ± 0.042	226.0 ± 1.0 ^d	0.065 ± 0.014	(M1 + E2)
	258.9 ± 0.2	0.094 ± 0.013	
	270.1 ± 0.2	0.11 ± 0.02	
281.923 ± 0.023	282.0 ± 0.1	2.57 ± 0.16	M1
286.410 ± 0.026	286.4 ± 0.1	70.8 ± 3.9	M1
292.799 ± 0.030	292.8 ± 0.2	0.13 ± 0.02	M1
311.558 ± 0.030	311.6 ± 0.1	12.6 ± 0.8	M1
322.809 ± 0.033	322.9 ± 0.2	0.31 ± 0.03	M1
324.728 ± 0.040	324.8 ± 0.2	0.24 ± 0.03	M1
338.441 ± 0.034	338.4 ± 0.1	57.2 ± 3.0	M1
343.968 ± 0.041			(M1)

(continued)

Table 1 (continued)

γ -ray energy (keV)	γ -ray energy (keV)	Relative γ -ray intensity	Multipolarity
354.866 \pm 0.037	354.9 \pm 0.1	1.06 \pm 0.05	M1
	363.0 \pm 1.0 ^d	0.10 \pm 0.04	
369.077 \pm 0.080	369.2 \pm 0.1	0.60 \pm 0.03	M1
381.220 \pm 0.041	381.2 \pm 0.1	0.57 \pm 0.06	M1
452.472 \pm 0.048	452.6 \pm 0.2 ^e	0.97 \pm 0.07	M1
457.765 \pm 0.049	457.9 \pm 0.2	0.46 \pm 0.03	M1
463.381 \pm 0.048	463.4 \pm 0.1	5.35 \pm 0.30	M1
468.983 \pm 0.052	469.0 \pm 0.1	0.78 \pm 0.04	M1
511.359 \pm 0.052	511.4 \pm 0.2	71.5 \pm 3.8	M1
522.469 \pm 0.052	522.5 \pm 0.1	47.3 \pm 2.5	M1
533.557 \pm 0.063	533.6 \pm 0.2	0.34 \pm 0.03	M1(+E2)
544.393 \pm 0.070	544.4 \pm 0.2	0.23 \pm 0.02	M1(+E2)
554.636 \pm 0.056	554.7 \pm 0.1	4.63 \pm 0.24	M1
579.778 \pm 0.060	579.8 \pm 0.1	3.11 \pm 0.16	M1
	591.9 \pm 0.3	0.19 \pm 0.02	
645.583 \pm 0.067	645.5 \pm 0.1	0.99 \pm 0.06	M1
664.077 \pm 0.077	663.0 \pm 0.3	0.13 \pm 0.02	M1(+E2)
668.750 \pm 0.071	668.8 \pm 0.1	2.57 \pm 0.13	M1
677.709 \pm 0.073	677.8 \pm 0.1	4.37 \pm 0.22	E2
693.812 \pm 0.075	693.9 \pm 0.2	0.64 \pm 0.04	M1(+E2)
	696.7 \pm 0.3 ^f	0.12 \pm 0.08	
719.699 \pm 0.077	719.5 \pm 0.3	0.15 \pm 0.03	M1
722.034 \pm 0.075	722.0 \pm 0.4	0.22 \pm 0.06	M1
	723.5 \pm 1.2 ^g	0.06 \pm 0.05	
727.343 \pm 0.078	727.5 \pm 0.2	0.28 \pm 0.03	M1(+E2)
	731.2 \pm 1.0 ^g	0.046 \pm 0.023	
	742.4 \pm 0.5 ^f	0.086 \pm 0.022	
807.385 \pm 0.082	807.3 \pm 0.1	67.9 \pm 3.5	M1
818.231 \pm 0.084	818.4 \pm 0.2	3.33 \pm 0.17	E2
826.442 \pm 0.094	826.4 \pm 0.2	0.21 \pm 0.03	M1
837.235 \pm 0.087	837.3 \pm 0.2	0.34 \pm 0.03	M1
860.933 \pm 0.089	861.1 \pm 0.2	10.2 \pm 0.6	E2
866.225 \pm 0.095			

(continued)

Table 1 (continued)

γ -ray energy (keV)	γ -ray energy (keV)	Relative γ -ray intensity	Multipolarity
	878.0 ± 0.2	0.21 ± 0.02	
902.531 ± 0.091	902.9 ± 0.3	0.75 ± 0.04	E2
947.241 ± 0.096	947.1 ± 0.3	0.11 ± 0.02	M1(+E2)
980.288 ± 0.096	980.1 ± 0.2	21.0 ± 1.1	M1(+E2)
1007.146 ± 0.097	1007.1 ± 0.2	9.00 ± 0.50	M1
1008.87 ± 0.10	1009.2 ± 0.4	0.62 ± 0.05	M1(+E2)
1012.23 ± 0.12	1012.2 ± 0.2	0.62 ± 0.04	M1
1017.93 ± 0.13	1018.1 ± 0.5^e	0.70 ± 0.06	E2
	1020.1 ± 0.3	0.47 ± 0.03	
1032.26 ± 0.10	1032.3 ± 0.2	(100)	M1
1043.17 ± 0.13	1043.2 ± 0.2	0.67 ± 0.06	E2
	1044.8 ± 0.3	0.37 ± 0.06	
	1069.7 ± 0.4	0.05 ± 0.01	
1105.25 ± 0.14	1107.1 ± 0.4^g	0.06 ± 0.02	
	1109.5 ± 0.3^g	0.08 ± 0.02	
1114.49 ± 0.14	1114.6 ± 0.2	0.92 ± 0.05	M1
1190.92 ± 0.14	1191.2 ± 0.2	1.42 ± 0.07	E2
1193.89 ± 0.16	1194.2 ± 0.3^e	0.14 ± 0.09	M1
	1207.9 ± 0.4^g	0.05 ± 0.04	
1318.68 ± 0.13	1318.7 ± 0.2	1.88 ± 0.10	E2
1452.74 ± 0.15	1452.9 ± 0.2	0.20 ± 0.02	E2
1496.70 ± 0.18	1497.2 ± 0.3^e	0.89 ± 0.05	E2
1566.40 ± 0.18	1566 ± 1^g	0.010 ± 0.010	
1571.02 ± 0.16			

Table 1 (continued)

Footnotes

- a) Energies were provided by Ref. 9.
 - b) Absolute γ -ray intensities (derived from the level scheme) may be obtained by renormalizing the relative intensities, since the 286.4-keV transition has an absolute intensity of 22.8 ± 2.0 photons per 100 decays of ^{206}Po .
 - c) Multipolarity deduced from internal conversion electron measurements of Ref. 9 as discussed in text.
 - d) Peak may be complex.
 - e) Intensity was corrected for a ^{206}Bi component.
 - f) Intensity was corrected for a double or single escape peak component.
 - g) Assignment to ^{206}Po decay from present data is very uncertain.
-

Table 2. Gamma-gamma coincidence results

E_{γ} (gate) (keV)	Gamma rays in coincidence with gate (keV)
170.5 + 171.3	KX ^a , 281.9, 286.4, 311.6, 554.7, 579.8
281.9	KX, 170.5, 286.4, (311.6), ^b 381.3, 554.7, 579.8
286.4	KX, 170.5, (171.3), 281.9, 322.9, (324.9), 338.5, 369.2, (381.3), 463.4, (522.6), 579.8, (694.0), 903.0, 1032.2, 1043.2
311.6	KX, (146.2), (170.5), (180.8), 281.9, 338.5, 452.6, 463.4, 522.6, (544.4), 554.7, 668.8, (826.4), (837.3), (861.1), 1007.0, 1018.1
322.9	(554.7), (579.8)
338.5	KX, 286.4, 311.6, (324.9), 457.9, 469.0, (511.4), 522.6, 668.8, 694.0, 980.1, 1114.6, 1191.2
354.9	KX, (281.9), 463.4, 511.4
369.2	KX, 286.4, (381.3)
452.6	KX, (286.4), (311.6), (554.7), (579.8)
463.4	KX, 286.4, 311.6, 354.9, 511.4, 554.7, 579.8, (1044.8)
469.0	KX, 338.5, 511.4
511.4	KX, 117.5, 140.5, 338.5, 354.9, 463.4, 469.0, 677.8, 807.3, 818.4
522.6	KX, 338.6, 457.9
554.7	KX, 170.5, 281.9, 311.6, (338?) ^c , 452.6, 463.4
579.8	KX, 170.5, (281.9), 286.4, (322.9), 452.6, 463.4
668.8	KX, 311.6, 338.5
677.8	KX, (83), 117.5, 140.5, 511.4
807.3	KX, 511.4, (583.0), 645.5
818.4	KX, 511.4
903.0	KX, (140.5), 286.4
980.1	KX, 338.5
861.1	KX
1007.1 + 1009.2	KX, 311.4
1018.1 + 1020.1	KX, 311.4

(continued)

Table 2 (continued)

E_{γ} (gate) (keV)	Gamma rays in coincidence with gate (keV)
1032.2	KX, 286.4
1043.2 + 1044.8	KX, 286.4, (463.4)
1107.1 + 1109.4	KX, (286.4)
1114.6	KX, 338.5
1191.2	KX, 338.5
1194.2	KX, 338.5
1318.7	KX
1497.3	KX

a) KX is used to mean K_{α} and K_{β} X-rays of polonium.

b) Energies in parentheses represent possible or weak coincidences.

c) This coincidence would imply that a transition of 114.1 keV ($523.3 \xrightarrow{M1} 409.2$) exists; however such a transition has not been observed.

FIGURE CAPTIONS

- Fig. 1. Typical γ -ray spectrum of ^{206}Po . Transitions due to the decay of ^{206}Bi and background are labeled separately.
- Fig. 2. Gamma-ray spectra in coincidence with the 463.4-, 554.7-, and 677.8-keV transitions. These helped establish levels at 523.3, 1078.0, and 878.1 keV, in addition to the placement of the 117.5- and 140.5-keV γ -rays.
- Fig. 3. Gamma-ray spectra in coincidence with the 286.4-, 311.6-, 338.4-, and 511.4-keV transitions.
- Fig. 4. Level scheme of ^{206}Bi . Relative photon intensities (with errors in italics) from the ^{206}Po decay are shown above the transitions. Relative alpha intensities from the ^{210}At decay and calculated 19 alpha hindrance factors are also shown. The absolute intensity of the 286.2 keV γ -ray was calculated from the level scheme to be 22.8 ± 2.0 photons per 100 decays of ^{206}Po .
- Fig. 5. Comparison of the experimental $^{1-9}$ ^{206}Bi level scheme with the predictions of a simple coupling model. The experimental 21,22 states of ^{209}Bi and ^{205}Pb are used to estimate the energies and range of spins from multiplets formed from couplings of the odd proton and the three-neutron holes (1p-3h states) in ^{206}Bi .

Log counts/channel (arbitrary units)

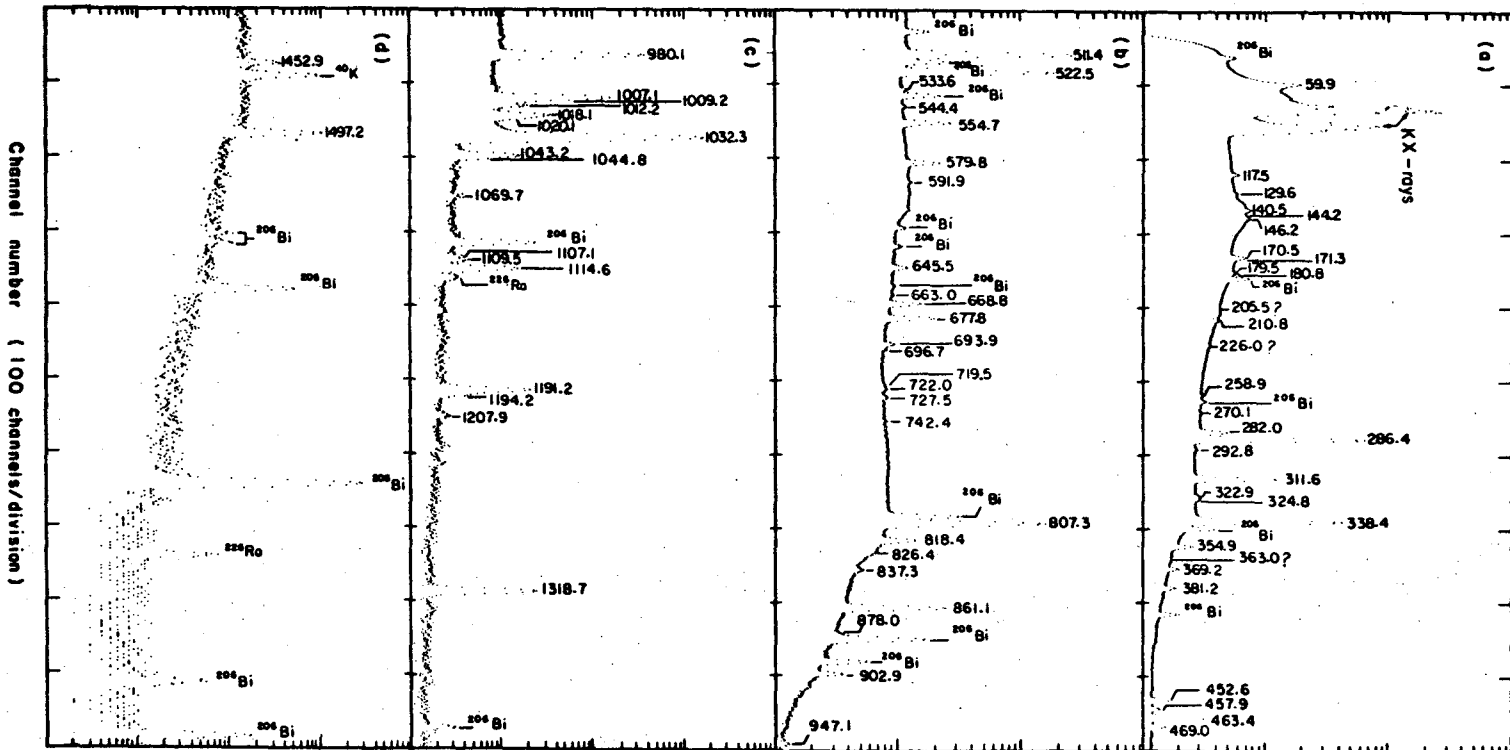
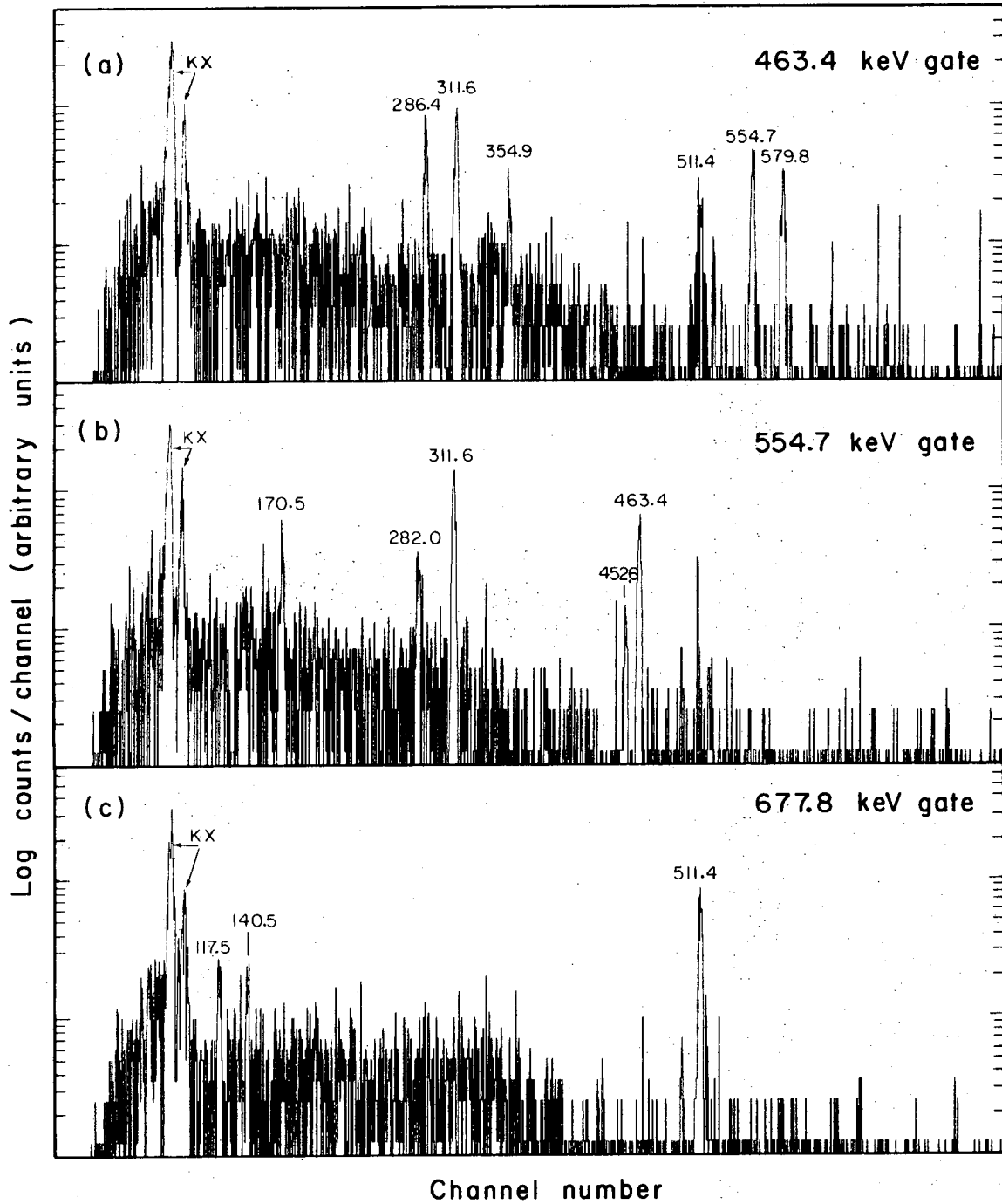


Fig. 1

LBL 7412-8348



XBL7412-8369

Fig. 2.

Log counts/channel (arbitrary units)

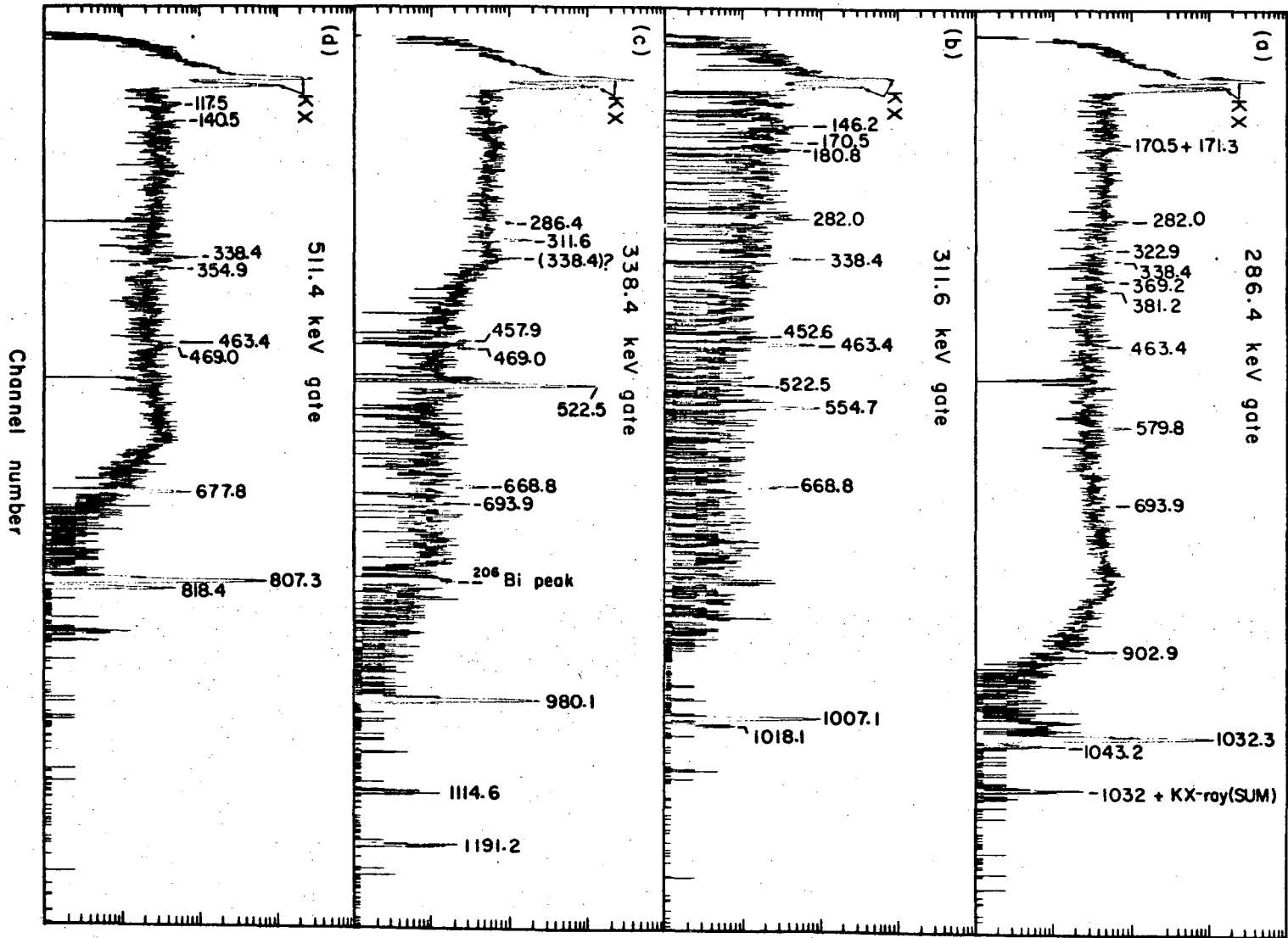


Fig. 3.

XBL7412-8370

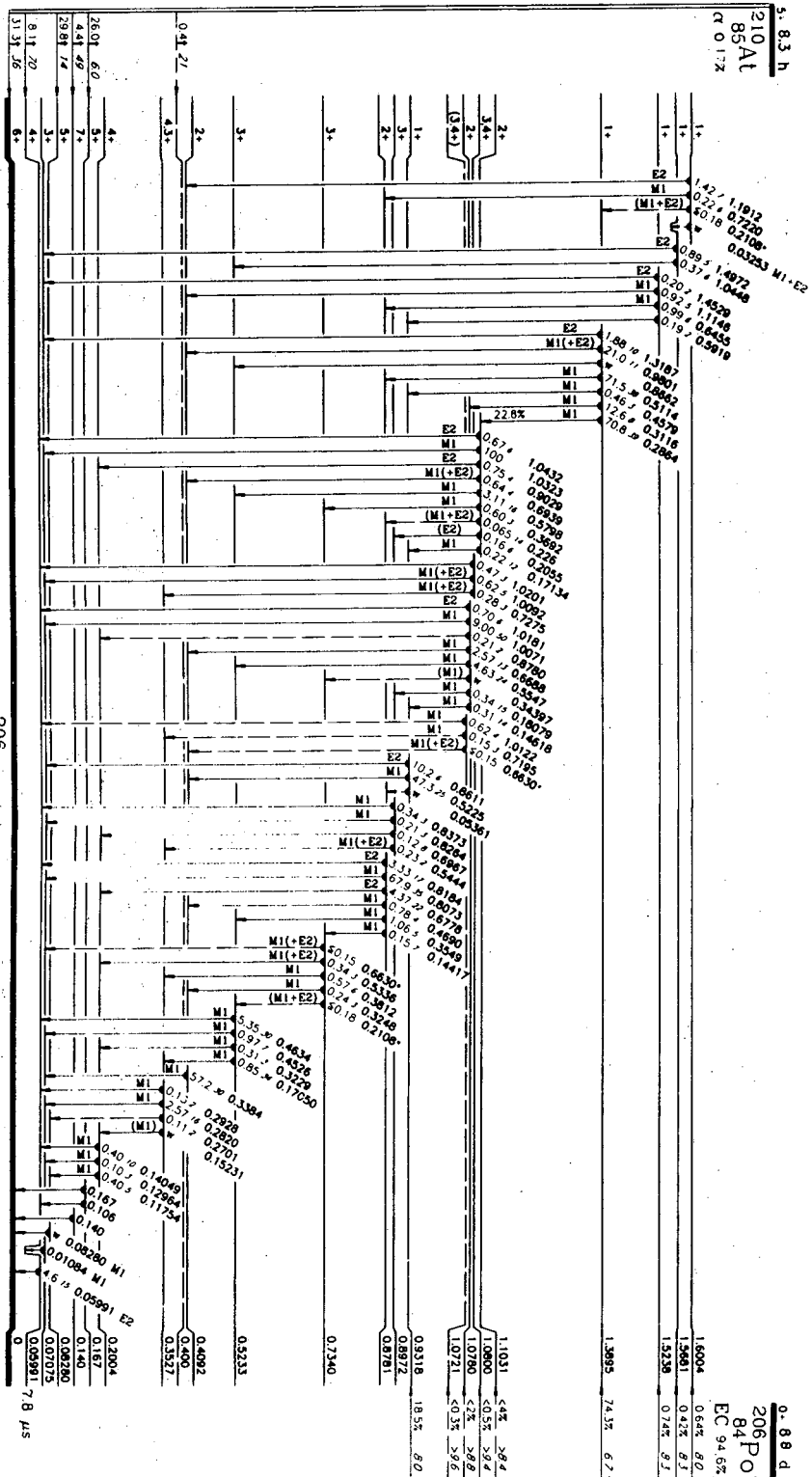
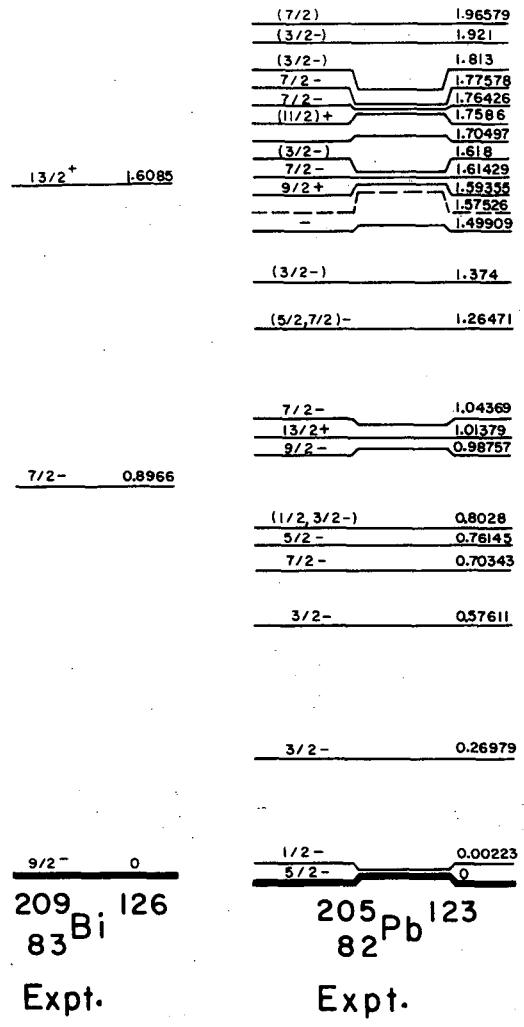


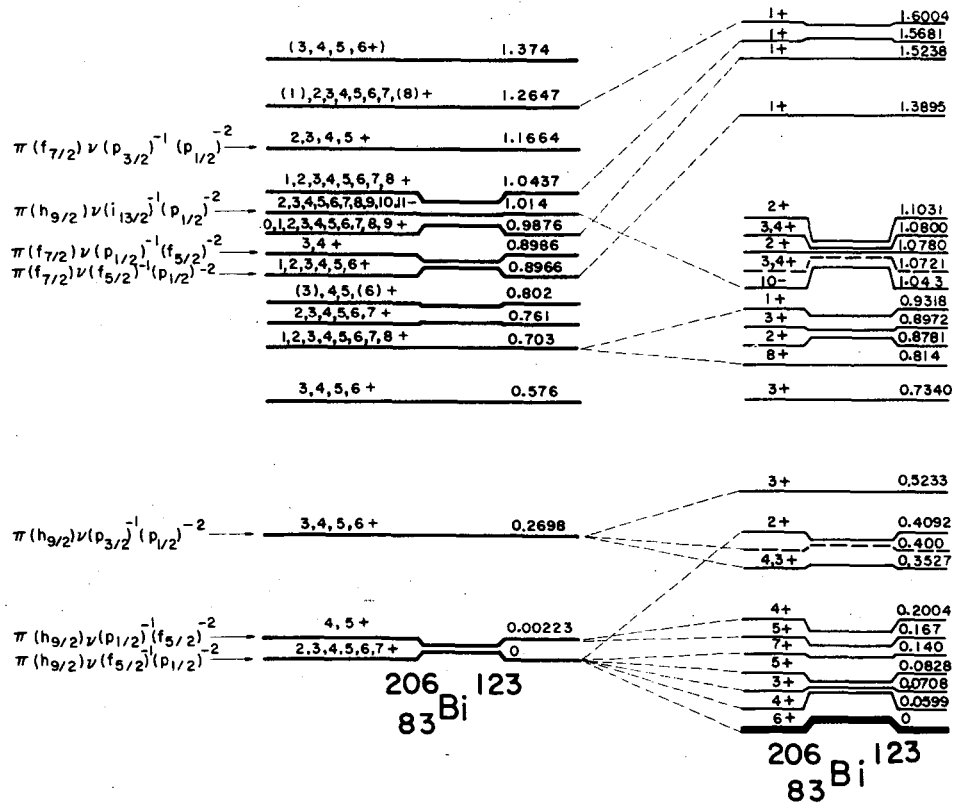
Fig. 4

206B1
83B1

XBL 7412-7847



Configuration



1p-3h degenerate model

XBL 7412 - 8385

Fig. 5

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