Title
DECAY OF 2I0At TO LEVELS IN 2I0Po

Authors
Jardine, L.J.
Prussin, S.G.
Hollander, J.M.

Publication Date
1971-11-01

Submitted to Nuclear Physics

LBL-278
Preprint

DECAY OF ^{210}At TO LEVELS IN ^{210}Po

L. J. Jardine, S. G. Prussin, and
J. M. Hollander

November 1971

AEC Contract No. W-7405-eng-48

DISCLAIMER

DECAY OF ^{210}At TO LEVELS IN ^{210}Po*

L. J. Jardine and S. G. Prussin

Lawrence Berkeley Laboratory and Department of Nuclear Engineering
University of California
Berkeley, California 94720

and

J. M. Hollander

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

November 1971

Abstract

The electron-capture decay of ^{210}At has been reinvestigated and present data define twenty-three levels in ^{210}Po. The multipolarity of thirty-six transitions have been measured and combined with data from recent reaction studies to assign spins and parities to these levels. Evidence is presented which locates the 3^- collective level in ^{210}Po at 2400 keV above the ground state. The electron-capture transition rates to odd parity levels are discussed with reference to the particle-hole excitations in ^{208}Pb. Transition probabilities for gamma decay of members of the $\pi(h_{9/2}\, f_{7/2})$ multiplet are compared to predictions from recent theoretical calculations.

RADIOACTIVITY ^{210}At [from ^{209}Bi(α,3n)]; measured E_γ, I_γ, I_{ce}, Icc, γγ, γγ delayed coin. ^{210}Po deduced levels, J, π, level $t_{1/2}$, EC branching, log ft.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

1. Introduction

Previous studies of the electron-capture decay of ^{210}At [1,2,3,4] have provided some detail on the energies and decay characteristics of levels of spin 4, 5, and 6 in ^{210}Po. While the experimental level energies were in general agreement with theoretical shell model spectra calculated from a simple two proton model, it was pointed out[1,2] that the low values of log ft for electron-capture transitions to the odd-parity levels around 3 MeV were inconsistent with this model and might be indicative of admixtures from neutron excitation out of the ^{208}Pb core. Since the earlier work of Mukherjee and Cohen[5] and Bardwick and Tickle[6], a number of experimental studies[35] have established the characteristics of the low-lying levels in ^{208}Pb which arise from excitation of neutrons and protons out of this core. As a result it has become evident that the mixing of such states with those arising from the two proton configurations $(h_{9/2}\ i_{13/2})$ and $(f_{7/2}\ i_{13/2})$ should be a dominant characteristic of the ^{210}Po level spectrum above 3 MeV. Whereas single proton-stripping reactions on ^{209}Bi probe the $(h_{9/2}\ \ell_j)$ components of a given level, electron-capture should strongly excite only the neutron-neutron and proton-proton particle-hole components.

Not only has there been a need for better experimental definition of levels involving particle-hole configurations, but also the data reported by Prussin and Hollander[1]) were limited in several aspects. The lack of coincidence measurements placed some uncertainty on the inclusion of several levels in the decay scheme which involved reasonably intense gamma-rays. Of greater importance, no evidence for levels of spins other than 4, 5, or 6 was obtained.

None of the two-proton shell model states are expected to be fed directly by electron-capture with any appreciable strength, but such states should be populated in the gamma decay of higher-lying levels.

For these reasons we have performed a detailed reinvestigation of the electron-capture decay of ^{210}At. Besides observing a number of new, very weak transitions, we have measured the multipolarities of 36 of the stronger transitions. The results of multiparameter γ-γ coincidence measurements have been used with the recent data from nuclear reaction studies[7,8,9]) to define twenty-three levels in ^{210}Po. Evdience is presented for a 3^- collective level at 2400 keV, and more detailed information on the higher-lying odd-parity states has been obtained. The latter are discussed in terms of the proton and neutron particle-hole components giving rise to unhindered β-decay transitions. The transition probabilities in the gamma decay of lower-lying levels are compared with those obtained from recent theoretical calculations.

2. Experimental

2.1. SOURCES

The astatine samples used in this study were produced by the $^{209}Bi(\alpha,3n)^{210}At$ reaction at bombarding energies of 36.5-39 MeV, with bismuth metal targets of thickness 52-73 mg/cm^2. No detectable ^{209}At from the $(\alpha,4n)$ reaction was observed. Chemical purficiation of the astatine was achieved by volatilization as previously described[10,11,12]). The only γ-emitting impurities were ^{211}At and its daughters. Sources for electron measurements were prepared by evaporation of ^{210}At solutions onto either gold-coated or aluminum-coated mylar. The sources were covered with a thin (3-10 μg/cm^2) layer of aluminum to prevent migration of the astatine in the vacuum chamber of the electron detector.

2.2. GAMMA-RAY SPECTRA

Gamma-ray singles spectra in the energy range 100 to 2500 keV were obtained with a 35 cm^3 coaxial Ge(Li) detector (system resolution of 2.6 keV (FWHM) at 1332 keV) and a 10 cm^3 planar Ge(Li) detector (system resolution of 2.2 keV (FWHM) at 1332 keV). For the energy range 16 to 130 keV, spectra were obtained with a 0.785 cm^2 × 5 mm Si(Li) detector system (resolution of 0.8 keV (FWHM) at 60 keV). All measurements were taken with conventional high-rate pulse electronics[13,14]) coupled to a 4096-channel analog to digital converter of the successive approximation type[15]). A PDP-7 computer system[16,17,18]) was used for "on-line" analysis. The gamma-ray spectra obtained in these measurements are shown in figs. 1 and 2 and the energies and intensities of all transitions are given in Table 1. The uncertainties due to relative efficiency calibration of the various detectors were estimated to be ±5% in the energy range 60-500 keV and ±3% in the range 500-2800 keV[19]. All photopeak intensities were obtained with the computer code SAMPO[20]. For energy calibration the data compiled by Jardine[21] were used.

In addition to previously reported transitions, we have been able to observe fourteen new transitions of very low intensity. The transition at 790.6±0.7 keV reported by Prussin and Hollander[1] can be reassigned to the decay of ^{209}At (E_γ = 790.2±0.1 keV)[22,43]. Our data (see sec. 2.3.1) place some doubt on the existence of a 125.2 keV transition reported by Hoff and Hollander[2], but not observed in the photon spectrum of Prussin and Hollander[1]. Otherwise our data agree well with previous measurements.

2.3. CONVERSION ELECTRON SPECTRA

The detector system consisted of a thick (0.785 cm^2 × 5 mm) lithium-drifted silicon detector operated at liquid nitrogen temperature. The electronics system was similar to that used in the gamma-ray measurements. This system gave a resolution of 2.2 keV (FWHM) for the K-conversion electron line of the 1063-keV transition in the decay of ^{207}Bi and permitted observation of well-defined electron lines at energies up to about 1600 keV. The relative electron efficiency function for this detector was obtained with sources having known conversion coefficients[43]. The estimated error in the efficiency determination is ±8% over the energy range 100-1500 keV.

The conversion-electron spectrum obtained for ^{210}At decay is shown in figs. 3 and 4. We have used these data along with the gamma-ray intensities reported here to determine conversion coefficients normalized to the theoretical value of α_K(E2) for the 1181.4 keV ($2^+ \rightarrow 0^+$) ground state transition. These are given in Table 2 along with multipolarity assignments deduced by comparison with the theoretical values of Hager and Seltzer[23,24]. The K-conversion coefficients are also shown in fig. 5 with the theoretical curves constructed from the data of ref. [23]. A number of the results are worthy of some comment in the light of previously reported data.

2.3.1. <u>125-keV transition</u>. The present data do not improve the limit $I_{\gamma 125} \leqslant 0.32$, which was derived from a compton-suppressed gamma-ray spectrum[1]. However, our observation of a weak gamma-ray transition at 201.8±0.2 keV suggests that at least one of the lines assigned as the L-conversion lines of a 125 keV transition by Hoff and Hollander[2] should be reassigned as the K-conversion line of this new transition. The measured value of α_L for the 201.8 keV transition is also consistent with the multipolarity assignment of M1 obtained from our measurement of the K-conversion coefficient of this transition.

2.3.2. <u>83.45-keV transition</u>. Hoff and Hollander[2] have observed an 83.45 keV E2 transition in ^{210}At decay. Because of low intensity and poor resolution this transition was not observed in our measurements or in the previous study by Prussin and Hollander[1]. However, in a recent study of the ^{208}Pb(α,2nγ) reaction by Bergström <u>et al.</u>[9], an 83.7-keV γ-ray has been identified as the transition between the 8^+ and 6^+ members of the $\pi(h_{9/2})^2$ ground state band in ^{210}Po. Their data place the location of the 8^+ level at 1557 keV. A level at 1557±5 keV was also observed in recent studies of the ^{209}Bi(α,t) and ^{209}Bi(^{3}He,d) reactions[7,8]. In the present study, we have obtained evidence for weak population of this level by γ-rays following decay of ^{210}At.

2.4. GAMMA-GAMMA COINCIDENCE MEASUREMENTS

Three parameter gamma-gamma coincidence measurements were taken with two Ge(Li) detectors of about 35 cm^3 each (active volume) and a fast-coincidence electronic arrangement similar to that described by Jaklevic _et al._[25]). The axes of the two detectors were positioned at 90° with respect to the source and were separated by a graded shield (lead-cadmium-copper) to minimize scattering between the detectors. The width of the prompt time-distribution as determined by the 1181.4-1483.3 keV gamma-ray cascade was about 40 nsec. The three parameter data (E_1, E_2, Δt) were stored serially on magnetic tape and later sorted on the LBL-CDC-6600 computer system. Spectra in coincidence with the various gates were corrected for chance coincidences and for contributions from the compton background within the gates. For each gate two sorts were obtained corresponding to prompt and delayed coincidence events (the latter were delayed in time by about 60 nsec from the centroid of the prompt time distribution). Several important coincidence spectra are shown in figs. 6 and 7 and a complete set of all spectra is given in ref. [43]). These results are discussed in connection with the ^{210}At decay scheme in sec. 3.

3. The Decay Scheme

Coincidence measurements and sum-difference relationships among gamma-ray energies have been used to construct the level scheme shown in fig. 8. Spin and parity assignments are based upon previously reported data, our conversion electron measurements and the results of recent reaction studies[7,8,9]) summarized in fig. 9. For convenience the levels are discussed below in related groups.

3.1. LEVELS AT 1181.4, 1426.7, 1473.4, AND 1556.8 keV

Spin and parity assignments for the first three levels in ^{210}Po have been well established[1,2,3,7,8,26]). We note that our delayed coincidence measurement of the 1436.3-245.3 keV gamma-ray cascade (40±6 ns) confirms the half-life of the 6^+ level (38±5 ns) at 1473.4 keV reported by Funk et al.[26]).

The 8^+ level at 1556.8 keV, whose existence was first inferred by Yamazaki and Ewan[27]), is now well established[7,8,9]). As discussed in sec. 2.3.2., we assign the 83.45 keV transition[2]) to the decay of this level. Our energy differences and intensity balance support this interpretation. The half-life of the level has been measured as 110±8 ns[28]) and 115±10 ns[9]).

3.2. EVEN-PARITY LEVELS AT 2187.7, 2290.0, 2326.0, 2382.4, 2403.2, AND 2438.3 keV

The levels at 2382.4 and 2403.2 keV were established by Prussin and Hollander[1]) and we have been able to observe several new weak transitions involving these levels. A 4^+ assignment to the 2382.4 keV state is established in our work through E1 transitions from 5^- states at 2910.0 and 3026.2 keV and by decay via the 1201.2 (E2) and 955.8 (M1) keV transitions which connect this level to the 2^+ and 4^+ levels at 1181.4 and 1426.7 keV. This assignment is consistent with results from the reaction studies as shown in fig. 9. The spin and parity assignments of 5^+ to the level at 2403.2 keV are similarly established.

The data of ref. [1]) established a tentative level at either 2278 or 2325 keV which decayed via the 852.7 keV transition to either the 4^+ or 6^+ levels at 1426.7 or 1473.3 keV. Our γ-γ coincidence data show that the 852.7 keV transition is in delayed coincidence with the 245.3 and 1181.4 keV transitions and also that it is in prompt coincidence with the 584.0 keV transition. These results along with the probable absence of a transition at 125.2 keV (see sec. 2.3.1.) indicate the existence of a level at 2326 keV. A level at this energy has been observed in reaction studies[7,8,9]) and a spin and parity assignment of 6^+ is indicated from these data. The measured M1 multipolarity of the 852.7 keV transition and the E1 multipolarity of the 584.0 keV transition (from the 5^- level at 2910.0 keV) are consistent with this assignment.

We note here tentative evidence for the existence of a weak transition of 77.2 keV connecting the 5^+ level at 2403.2 keV to the 2326.0 keV level. Our re-examination of the conversion electron spectrum of ^{210}At (from the original photographic plates of Hoff and Hollander[2]) indicates that the K L_{II} L_{II} Auger line at 60.2 keV is too intense relative to neighboring Auger lines by a factor of about 1.7 compared to the Auger lines from ^{211}At decay. The excess intensity may be ascribed to the L_I line of a 77.2-keV transition. From the absence of L_{II} and L_{III} lines, one may infer an M1 character. We discuss later (sec. 5) how this and other low energy intraband transitions might compete favorably with higher energy interband transitions.

The levels at 2187.7 and 2438.3 keV have been observed in reaction studies[7,8,9]) and spin and parity assignments of 8^+ and 7^+ have been given, respectively. These levels are weakly populated through radioactive decay of ^{210}At. While our data alone are insufficient to define the spins, the measured multipolarities of transitions involving these levels are consistent with these assignments. We have shown a possible transition (M1) of 112.3 keV connecting the 7^+ level at 2438.3 keV to the 6^+ level at 2326.0 keV. Hoff and Hollander[2]) reported an unassigned electron line at 85.27 keV which can be interpreted as the L_1 conversion line of this transition.

Finally we have shown in fig. 8 a tentative level at 2290.0 keV, which is defined by a single transition to the ground state of ^{210}Po and by decay of the 4^+ level at 2382.4 keV. The latter transition (92.0 keV) was identified by Hoff and Hollander[2]) as a probable E2 transition. Both (TB)[7]) and Lanford[8]) report a level at about 2285 keV with a spin and parity assignment of 1^+ or 2^+. If our identification is correct and corresponds to the same level observed in the reaction studies, a 2^+ or 3^+ assignment is inferred.

3.3. ODD PARITY LEVEL AT 2386.8 keV

The sum-difference relations between gamma-ray energies and tentative coincidence data on the 639.4-1205.4 keV gamma-ray cascade have led to the placement of a level at 2386.8 keV which decays to the ground state and first-excited (2^+) state of ^{210}Po and possibly to the 4^+ level at 1426.7 keV. The level is weakly populated by at least three transitions from higher-lying odd-parity levels (see sec. 3.5). The measured E2 multipolarity of the 639.4-keV transition connecting this level to the 5^- level at 3026.2 keV establishes the parity as <u>odd</u> and limits probable spins to 3-7. The 1205.4-keV transition from this level to the 2^+ first-excited state is limited to a multipolarity of E1, with up to about 15% M2 admixture, from the intensity limit of its (unobserved)

K-conversion electron line. These data in conjunction with the direct transition from this level to the ground state define the spin as 3, and it is most likely the 3^- collective state analogous to that observed in ^{208}Pb at 2614 keV. This assignment gains some support from the fact that no odd-parity states of single-particle character are expected at this low energy and the state apparently is not strongly excited by stripping reactions.

The energy of the 3^- level in ^{210}Po is somewhat depressed from that observed in ^{208}Pb (2614 keV). This shift may result in part from configuration mixing via the 3^- component of the $\pi(h_{9/2}\ i_{13/2})$ configuration. Hamamoto has calculated the energies of the 3^- octupole vibration in a number of even mass lead isotopes[30]) and in ^{210}Po [31]). The calculated energies were generally higher than those observed experimentally[29]) but did reflect the large reduction in ^{210}Pb relative to the energy in ^{208}Pb because of the strong coupling of the octupole vibration to the 3^- component of the neutron configuration $\nu(2g_{9/2}\ 1j_{15/2})$. In ^{210}Po, two 3^- levels, arising from mixing of the octupole vibration with the 3^- member of the two proton $\pi(h_{9/2}\ i_{13/2})$ multiplet, are predicted[31]) to occur at 2.52 and 2.88 MeV, the lower one being predominantly vibrational in character.

3.4. ODD-PARITY LEVELS AT 2910.0, 3016.8, 3026.2, 3075.1, 3111.4, AND 3124.7 keV

Levels in this region are expected to arise from the two proton configuration $\pi(h_{9/2}\ i_{13/2})$ and evidence from this and previous studies has also established the importance of contributions from excited states of the ^{208}Pb core.

The two odd-parity levels at 2910.0 and 3026.2 keV are well known and our data on the first of these is in agreement with the previously assigned spin of 5. The spin of the level at 3026.2 keV is now established from our limit on α_K of the 1552.7 keV transition to the 6^+ level at 1473.3 keV which requires that its multipolarity be predominately E1. Together with the measured E1 multipolarity of the 1599 keV transition, this firmly establishes the spin of the 3026.2 keV level as 5. This assignment had been suggested by Schima et al.[4]) as a result of (NaI) angular distribution measurements on the 1599-245 keV gamma-ray cascade, but was questioned by Prussin and Hollander who favored a spin assignment of 4 because of the large difference in the branching ratio (I_{1599}/I_{1552}) as compared with the ratio (I_{1483}/I_{1436}) for the analogous decay of the level at 2910 keV. Present evidence suggests that these two levels arise predominantly from configuration mixing of the two proton configuration $\pi(h_{9/2}\, i_{13/2})_{5^-}$ with the neutron excitation $\nu(g_{9/2}\, p_{1/2}^{-1})_{5^-}$. Both levels have been observed in the reaction studies of (TB)[7]) and Lanford[8]) who report weak population of the 2910.0 keV level compared to other high spin members of the $\pi(h_{9/2}\, i_{13/2})_{J^-}$ multiplet. As discussed below (see sec. 4.1) their data are qualitatively in agreement with respect to the amplitudes of the two-proton configuration assigned to each level by analysis of the β-decay transition probabilities in the decay of ^{210}At.

The remaining levels in this group are tentatively identified through weak gamma-ray transitions observed in our work and we have combined these data with the results from reaction studies to arrive at suggested spin and parity assignments. Due to small level spacings and poor statistics, substantial differences exist between the spin assignments of (TB)[7]) and Lanford[8]). Assignments for these levels shown in fig. 8 and on the composite scheme of fig. 9 represent our summary of all reaction and decay data.

The level shown at 3075.1 keV may be identified with that observed in the reaction studies which has been assigned a spin and parity of 4^-. (We have observed only a single gamma-ray transition defining this level). The level at 3124.7 keV has been seen by both (TB)[7]) and Lanford[8]) but was not identified in the (α,2n) studies of Bergström et al.[9]). Our gamma-ray data establish the parity as odd and limit the likely spin assignments to the range 4, 5, 6. With the assumption that this level is due primarily to the two proton configuration $\pi(h_{9/2}\ i_{13/2})$, and having located the spin 4 and 5 members elsewhere, we tentatively identify this level as the 6^- level defined by Lanford. This assumption seems reasonable through the following arguments. First the only likely core excitation leading to levels in this energy range is the neutron configuration $\nu(g_{9/2}\ p_{1/2}^{-1})$. Secondly as discussed in sec. 4, electron-capture of ^{210}At should occur with much higher probability to core-excited states in ^{210}Po than to levels of the simple two proton configuration of the 83rd and 84th protons of ^{210}Po. (Note here the low log ft values for transitions to the 5^- levels in this region).

We have tentatively included a level at 3016.8 keV in agreement with the results of the reaction studies of (TB)[7]) and Lanford[8]). In our work the level is defined only by a single gamma-ray transition to the 6^+ level at 1473.3 keV and thus its spin is limited to the range 4-8. We favor a likely assignment of 7^-, 8^- to this level.

The remaining level in this region at 3111.4 keV was unresolved in the reaction studies and its decay to the 3^- level at 2386.8 keV by an M1 transition defines the parity as odd and limits spin to the range 2-4. The weak population of this level in β-decay rules out its assignment as the 4^- member of the neutron excitation $\nu(g_{9/2}\, p_{1/2}^{-1})$. The M1 decay to this level from the $(4)^-$ level at 3428.2 keV then suggests a tentative spin and parity assignment of $(3)^-$ (see sec. 3.5).

The levels of the $\pi(h_{9/2}\, i_{13/2})$ multiplet with spins 8, 9, 10, and 11 have been identified from reaction studies and we have included these in the composite level scheme in fig. 9. The location of levels with spins 10 and 11 at energies of 3183 and 2849 keV, respectively, seems well defined. However, the definite assignment of spins 8 and 9 to the levels at 3138 and ~ 3009 keV, respectively, is open to question as the data of (TB)[7]) and Lanford[8]) are not in agreement.

Of the ten levels arising from the $\pi(h_{9/2}\, i_{13/2})$ proton multiplet, only the 2^- member remains unassigned. Both (TB)[7]) and Lanford[8]) have argued for an unresolved doublet at about 2845 keV composed of the 11^- and (possibly) 2^- members of this multiplet. With the tentative location of the 3^- member at 3111.4 keV, it would appear that the 2^- level might belong in the quartet of states in the energy range 3000-3030 keV. While the reaction studies require greater strength at 2945 keV than can be accounted for by the 11^- level alone, this may reflect a relatively reduced strength for the lower spin members of the multiplet due to configuration mixing. The calculations of Kim and Rasmussen[32]) locate the levels of the $\pi(f_{7/2}\, i_{13/2})_{J^-}$ proton multiplet at about 0.8-1.0 MeV above the corresponding levels of the $\pi(h_{9/2}\, i_{13/2})_{J^-}$ multiplet. Mixing among these states would leave the 2^- and 11^- members of the $\pi(h_{9/2}\, i_{13/2})$ multiplet pure and would give them somewhat greater intensity in the (α,t) or $(^3He,d)$ studies relative to the remaining levels.

3.5. LEVELS IN THE RANGE 3428-3780 keV

These levels are all populated rather strongly in the electron-capture decay of ^{210}At and it is likely that they arise from neutron and proton excitation of the ^{208}Pb core.

The spin and parity of the level at 3428.2 keV is limited to $(4,5,6)^-$ by observation of M1 transitions from this level to the 5^- level at 2910.0 and 3026.2 keV. The probable assignment of $(4)^-$ has been inferred by the M1 + E2 assignment of the 316.8 keV transition from this level to the $(3)^-$ level at 3111.4 keV. We note that so long as the latter level is limited to a spin of 2 or 3, the presence of an M1 component in the 316.8 keV transition requires both that the spin of the 3111.4 keV level be 3 and the spin of the level at 3482.2 keV be 4. The spin and parity of the level at 3727.2 keV is then defined as $(5)^-$ by the measured M1 decay to levels of spin 4, 5, and 6. Similar arguments have been invoked to limit the assignment of spin and parity of the level at 3525.2 keV to $(5,6)^-$. The remaining levels at 3699.4, 3711.2, and 3779.5 keV are probably limited to spins 4, 5, and 6 and the 3779.5 keV level seems to be of odd parity.

4. Electron-Capture Decay Rates and Particle-Hole Core Excitation in ^{210}Po

Log ft values have been obtained by using the method discussed by Konopinski and Rose[33]) for allowed transitions. The electron-capture feeding was obtained from our γ-ray intensity data corrected for internal conversion. The Q-value for the electron-capture decay was taken as Q_{EC} = 3877±26 keV[34]).

Newby and Konopinski[36]) discussed the importance of particle-hole core excitations in the level spectrum of ^{210}Po. Experimental evidence for such effects was first pointed out by Hoff and Hollander[2]) through analysis of the electron-capture decay rates of ^{210}At to the odd-parity levels in ^{210}Po above 3 MeV. Specifically, they pointed out that the decay to levels of the two-proton configurations $\pi(h^2_{9/2})$, $\pi(h_{9/2}\ f_{7/2})$ or $\pi(h_{9/2}\ i_{13/2})$ should all be highly forbidden due to the large change in orbital angular momentum required for conversion of an $h_{9/2}$ proton into a $p_{1/2}$ neutron. Experimentally, highly-hindered electron-capture transitions are evident for the allowed decay to all even-parity levels below 2.9 MeV. Above this energy, however, unhindered transitions of the first-forbidden type to the odd-parity levels at 2910 and 3026 keV were attributed to contributions in these states from neutron excitation of the ^{208}Pb core.

Recently a fairly complete picture of core-excited states in ^{208}Pb has been obtained in the energy range below about 4.1 MeV through numerous reaction studies[35]). The observed ^{208}Pb levels are shown to the right in fig. 10. The lowest levels due to core excitation (3198 and 3475 keV) are predominantly the two components of the <u>neutron</u> excitation $\nu(g_{9/2}\ p^{-1}_{1/2})_{5^-,4^-}$ respectively. Although a number of the levels in the energy range 3700-4100 keV have unknown parentage, at least four levels arise predominantly from the neutron excitations $\nu(g_{9/2}\ f^{-1}_{5/2})_{J^-}$ and the proton excitations $\pi(h_{9/2}\ s^{-1}_{1/2})_{5^-,4^-}$. Configuration mixing between components of these excitations is evident from the wave functions for these states calculated by True et al.[37]).

In the case of ^{210}Po these core excitations should occur in the vicinity of the odd-parity levels arising from the two-proton configurations $\pi(h_{9/2}\ i_{13/2})_{J^-}$ and $\pi(f_{7/2}\ i_{13/2})_{J^-}$[32,36,38]). Although the effect of the additional 83rd and 84th protons on the zero-order energies of the particle-hole core excitations is unknown, energy shifts are expected to be small and strong configuration mixing is expected. Electron-capture decay of ^{210}At to odd parity levels of ^{210}Po that contain components of the neutron particle-hole excitation $\nu(g_{9/2}\ p^{-1}_{1/2})$ and/or the proton particle-hole excitation $\pi(h^3_{9/2}\ s^{-1}_{1/2})$ will be relatively unhindered. In the first case, unhindered 1st forbidden decay is due to conversion of an $1h_{9/2}$ proton into a $2g_{9/2}$ neutron. In the second case a $3s_{1/2}$ core proton in ^{210}At is converted into a $3p_{1/2}$ neutron in ^{210}Po. Hence the β-decay transition probabilities to levels in ^{210}Po above about 3 MeV should be a measure of the total amplitudes in these states of the neutron particle-hole component $|\nu(g_{9/2}\ p^{-1}_{1/2})\rangle$ and the proton particle-hole component $|\pi(h^3_{9/2}\ s^{-1}_{1/2})\rangle$. This is of particular importance to the characterization of the more highly-excited levels, since the complimentary information on amplitudes of two-proton components is derived from the reaction data of (α,t) and (^{3}He,d) studies.

4.1. ELECTRON-CAPTURE DECAY TO LEVELS AT 2910.0 AND 3026.2 keV

Both of these levels are populated by relatively unhindered electron-capture transitions, and they are identified with the two states arising from configuration mixing of the first two-proton 5^- state in ^{210}Po (predominantly $\pi(h_{9/2}\, i_{13/2})_{5^-}$) and the first 5^- ^{208}Pb neutron core state. (The two-proton wave function undoubtedly contains a small component of the configuration $\pi(f_{7/2}\, i_{13/2})_{5^-}$, but this does not affect the following argument. The wave function for the first 5^- state in ^{208}Pb has been calculated by True, Ma, and Pinkston (TMP)[37] as

$$\psi_{5^-} = -0.923|\nu(g_{9/2}\, p^{-1}_{1/2})\rangle + 0.200|\pi(h_{9/2}\, s^{-1}_{1/2})\rangle$$

$$+ 0.147|\nu(i_{11/2}\, p^{-1}_{1/2})\rangle + 0.144|\pi(h_{9/2}\, d^{-1}_{3/2})\rangle$$

$$- 0.122|\pi(f_{7/2}\, d^{-1}_{3/2})\rangle + 0.0199|\nu(g_{9/2}\, f^{-1}_{5/2})\rangle$$

and the amplitudes of the two largest components are in agreement with the experimental data of McClatchie, Glashausser, and Hendrie[39] and Bardwick and Tickle[6].)

To estimate the relative amplitudes of core and two proton components in these states using our experimental log ft values, we followed the analysis of first-forbidden β-decay in the ^{208}Pb region given by Damgaard and Winther[40], and Damgaard, Broglia, and Riedel[41]. The analysis was carried out only for β^- decay, but it is reasonable to expect that the same formulation is applicable for examination of relative ft values for electron-capture transitions involving the same particle configurations. In the present case we have made the further simplifying assumptions that the ground-state wave functions of ^{210}At is $|\pi(h^3_{9/2})\nu(p^{-1}_{1/2})\rangle_{5^+}$ and that the wave functions for the two 5^- levels in ^{210}Po can be approximated by the two-component vectors

$$\psi_{5^-}(2910) = a_1|\pi(h_{9/2}\ i_{13/2})\rangle_{5^-} + b_1|\nu(g_{9/2}\ p^{-1}_{1/2})\rangle_{5^-}$$

$$\psi_{5^-}(3026) = a_2|\pi(h_{9/2}\ i_{13/2})\rangle_{5^-} + b_2|\nu(g_{9/2}\ p^{-1}_{1/2})\rangle_{5^-}$$

where the full strength of the two-proton and neutron-core excitation components are included. Electron-capture decay to these states was assumed to proceed only through the single component $\nu(g_{9/2}\ p^{-1}_{1/2})$. Using our experimental ratio $(ft)_{2910}/(ft)_{3026}$,

$$\frac{(ft)_{2910}}{(ft)_{3026}} = \frac{|a_1|^2}{|a_2|^2} \simeq 0.40$$

the two-component vectors are calculated to be

$$\psi_{5^-}(2910) \approx 0.534|\pi(h_{9/2}\ i_{13/2})\rangle_{5^-} + 0.846|\nu(g_{9/2}\ p^{-1}_{1/2})\rangle_{5^-}$$

$$\psi_{5^-}(3026) \approx 0.846|\pi(h_{9/2}\ i_{13/2})\rangle_{5^-} \mp 0.534|\nu(g_{9/2}\ p^{-1}_{1/2})\rangle_{5^-}$$

These results can be compared directly to the relative two-proton amplitudes obtained with the same assumptions as above from the ^{209}Bi(α,t) and ^{209}Bi$(^3$He,d) reaction studies of TB[7]) and Lanford[8]). In both studies the

5^- level at 2910 keV was excited and was well resolved from other members of the $\pi(h_{9/2}\, i_{13/2})$ multiplet. Since the 11^- member of this multiplet is expected to arise only from this two-proton configuration, the ratios $I_{5^-}(2910)/I_{11^-}(2945)$ (corrected for the (2J + 1) dependence of the reaction cross sections) directly yield experimental values for the amplitude $|a_1|^2$. The ratios of the two proton components in these states are estimated[7,8]) from these data as

$$\left(\frac{|a_1|^2}{|a_2|^2}\right)_{(TB)} = 0.41 \qquad \text{and} \qquad \left(\frac{|a_1|^2}{|a_2|^2}\right)_{(Lanford)} = 0.82 \pm 0.20$$

The agreement between these values and that derived from analysis of the electron-capture transition rates is good, in spite of the many simplifying assumptions required in the calculation , and is suggestive of the correct interpretation of the character of these levels. Unfortunately the lack of experimental data and the complexity of the wave functions for other odd-parity states involving core excitations precludes extension of this analysis at present. The fact that only the two lowest energy core excitations are expected to contribute significantly to unhindered β-decay does however permit the qualitative discussions given in the following paragraphs.

4.2. ELECTRON-CAPTURE DECAY TO LEVELS AT 3075.1 AND 3428.2 keV

The extent to which the $\nu(g_{9/2}\, p^{-1}_{1/2})_{4^-}$ core configuration mixes with the state arising from the $|\pi(h_{9/2}\, i_{13/2})_{4^-}$ configuration should be reduced relative to that observed in the 5^- levels because of the larger difference in zeroth-order energies of these states. Unhindered electron-capture decay is then expected only to the relatively pure core state and it is reasonable to associate this state with the $(4)^-$ level at 3428.2 keV (log ft = 6.9). Decay to the (4^-) level at 3075.1 keV is highly hindered (log ft = 8.9) and this state probably arises predominately from the two proton configuration. The reaction studies also indicate that the greater part of the strength of the $\pi(h_{9/2}\ i_{13/2})_{4^-}$ configuration is located in the lower of these two levels since the higher one was not excited to a measurable extent.

4.3. DECAY TO LEVELS AT 3525.2, 3699.4, 3711.2, 3727.2, AND 3779.5 keV

The electron-capture decay to these levels is also relatively unhindered which reflects strong admixtures of particle-hole core components in the wave function of these states. Of the possible core components that are expected here, the most probable admixture that can give rise to these fast transitions is the proton excitations $|\pi(h_{9/2}\ s_{1/2})\rangle_{4^-,5^-}$. The decay of the $3s_{1/2}$ proton in ^{210}At to the $3p_{1/2}$ neutron in ^{210}Po might be expected to occur with a somewhat greater absolute rate than for the similar decay of an $1h_{9/2}$ proton into a $2g_{9/2}$ neutron because of better overlap of the wave functions of the initial and final states. Thus the low log ft values assigned to transitions to the two highest energy levels of this group may be due to strong admixtures of this proton core excitation. The inverse of these decay processes, observed in the decay of ^{208}Tl to the core states of ^{208}Pb, proceed with similar (but somewhat lower) log ft values.

5. Gamma-Ray Transition Rates Involving Levels of the $\pi(h_{9/2}\ f_{7/2})$ and $\pi(h_{9/2})^2$ Configurations

The data available from reaction studies and the electron-capture decay of ^{210}At now give a fairly detailed description of the lower-lying levels in ^{210}Po. All levels of the $\pi(h_{9/2})^2$ ground-state multiplet are well characterized and the major transitions in decay of the levels of the $\pi(h_{9/2}\ f_{7/2})$ multiplet, other than those of the low-spin members, are now known. Comparison of the level sequences calculated by (KR)[32] and (MT)[38] with the the experimental spectrum indicates general agreement with energies and level spacings (see fig. 10). With the decay properties of these levels known, the experimental data may serve as a guide to future calculations. In particular the M1 branching ratios in the decay of the odd spin members of the $\pi(h_{9/2}\ f_{7/2})$ band to the low-lying even-parity levels may serve as a sensitive test of admixtures in the $\pi(h_{9/2})^2$ band.

We have calculated the total gamma-ray transition probabilities for decay of a number of levels of the $\pi(h_{9/2}\ f_{7/2})$ multiplet using the eigenfunctions of (KR)[32] and (MT)[38] and our experimental level energies. In Table 3 we list for reference the theoretical transition probabilities obtained with these wave functions using the Schmidt or free space values for the factors g_j, g_ℓ and g_s. The results were found to be extremely sensitive to various assumed values of g_j, g_ℓ and g_s and the possibility of using a set of effective values is currently being investigated. While quantitative agreement with experimental transition probabilities was generally poor, all calculations gave several qualitative predictions that could be compared directly with our experimental findings;

(a) The intensities of the transitions $8_2 \rightarrow 6_1$ (714.4 keV), $6_2 \rightarrow 8_1$ (769.2 keV), $6_2 \rightarrow 4_1$ (899.3 keV), and $2_2 \rightarrow 2_1$ (1188.6 keV) are predicted to be small compared to other competing transitions. These gamma rays were not detected in our measurements.

(b) Low-energy intraband transitions between members of the $\pi(h_{9/2}\ f_{7/2})$ multiplet are predicted to compete favorably with the more energetic transitions to levels of the $\pi(h_{9/2})^2$ multiplet. Our placement of the 77.2, 92.1, and 112.2 keV transitions as interband transitions is supported by these results and experimental multipolarities are consistent with the theoretical predictions.

The authors wish to acknowledge the generous assistance given by Drs. C. M. Lederer and G. L. Struble, and helpful discussions with J. O. Rasmussen. We are indebted to Drs. W. F. Lanford and R. Tickle for providing unpublished data and to Drs. C. W. Ma and W. W. True for providing us with their theoretical wave functions. One of us (L.J.J.) wishes to acknowledge financial support from the Lawrence Berkeley Laboratory and from the Atomic Energy Commission in the form of a Nuclear Science and Engineering Fellowship.

References

1) S. G. Prussin and J. M. Hollander, Nucl. Phys. A110 (1968) 176

2) R. W. Hoff and J. M. Hollander, Phys. Rev. 109 (1958) 447

3) J. W. Mihelich, A. W. Schardt, and E. Segré, Phys. Rev. 95 (1954) 1508

4) F. Schima, E. G. Funk, Jr., and J. W. Mihelich, Phys. Rev. 132 (1963) 2650

5) P. Mukherjee and B. L. Cohen, Phys. Rev. 127 (1962) 1284

6) J. Bardwick and R. Tickle, Phys. Rev. 161 (1967) 1217

7) R. Tickle and J. Bardwick, Phys. Letters 36B (1971) 32; private communication, September 1971

8) W. F. Lanford, private communications, March, September 1971

9) I. Bergström, J. Blomqvist, B. Fant, and K. Wikström, Research Institute for Physics, Stockholm, Annual Report (1970) 80; Physica Scripta 3 (1971) 103

10) E. H. Appleman, Ph.D. Thesis, UCRL-9025 (1960)

11) E. H. Appleman, National Academy of Sciences, National Research Council Report No. NAS-NS 3012 (1960)

12) A. W. Stoner, Ph.D. Thesis, UCRL-3471 (1956)

13) F. S. Goulding, UCRL-17559 (1967), unpublished

14) F. S. Goulding, D. A. Landis, and R. H. Pehl, UCRL-17560 (1967), unpublished

15) L. B. Robinson, F. Gin, and F. S. Goulding, UCRL-17419 (1967), unpublished

16) L. B. Robinson and J. D. Meng, UCRL-17220 (1967), unpublished

17) J. O. Radeloff, L. B. Robinson, and J. D. Meng, UCRL-18883 (1969), unpublished

18) F. M. Bernthal, Ph.D. Thesis, UCRL-18651 (1969), unpublished

19) L. J. Jardine, Nucl. Instr. Methods 96 (1971) 259

20) J. R. Routti and S. G. Prussin, Nucl. Instr. Methods 72 (1969) 125

21) L. J. Jardine, UCRL-20476 (1971), unpublished

22) L. J. Jardine and S. G. Prussin (to be published)

23) R. S. Hager and E. C. Seltzer, Nucl. Data A4 (1968) 1

24) C. M. Lederer, UCRL-19980 (1970), unpublished

25) J. M. Jaklevic, F. M. Bernthal, J. O. Radeloff, and D. A. Landis, Nucl. Instr. Methods 69 (1969) 109

26) E. G. Funk, Jr., H. J. Prask, F. Schima, J. McNulty, and J. W. Mihelich, Phys. Rev. 129 (1963) 757

27) T. Yamazaki and G. T. Ewan, Phys. Letters 24B (1967) 278

28) M. Ishihara, Y. Gono, K. Ishii, M. Sakai, and T. Yamazaki, Phys. Rev. Letters 21 (1968) 1814

29) C. Ellegaard, P. D. Barnes, E. R. Flynn, and C. J. Igo, Nucl. Phys. A162 (1971) 1

30) I. Hamamoto, Nucl. Phys. A155 (1970) 362

31) I. Hamamoto, private communication, May 1971

32) Y. E. Kim and J. O. Rasmussen, Nucl. Phys. 47 (1963) 184; 61 (1965) 173

33) E. J. Konopinski and M. E. Rose, Alpha-, Beta-, and Gamma-Ray Spectroscopy, Vol. 2, ed. K. Siegbahn (North-Holland, Amsterdam) (1965) 1357

34) A. H. Wapstra and N. B. Gove (June 1970), Concepts of Nuclear Physics by B. L. Cohen (McGraw-Hill, New York) (1971) 418

35) M. B. Lewis, Nucl. Data Sheets B5 (1971) 264

36) N. Newby, Jr. and E. J. Konopinski, Phys. Rev. 115 (1959) 434

37) W. W. True, C. W. Ma, and W. T. Pinkston, Phys. Rev. C3 (1971) 2421

38) C. W. Ma and W. W. True, private communication, September 1971

39) E. A. McClatchie, C. Glashausser, and D. L. Hendrie, Phys. Rev. C1 (1970) 1828

40) J. Damgaard and A. Winther, Nucl. Phys. 54 (1964) 615

41) J. Damgaard, R. Broglia, and C. Riedel, Nucl. Phys. A135 (1969) 310

42) R. A. Meyer, private communication, September 1971

43) L. J. Jardine, Ph.D. Thesis, LBL-246 (1971), unpublished

Table 1. Gamma-rays observed from decay of ^{210}At.

Gamma-Ray Energy (keV)	Absolute[a] Gamma-Ray Intensity (percent of ^{210}At decays)	Absolute Transition Intensities[b] (percent of ^{210}At decays)
46.6 (2)		(34.5 (15))[i]
77.2[c]		(≈ .15)[h]
83.45[c]		(≳ 0.60 (3))[i]
92.1[c]		(≈ 0.01)[h]
112.2[c]		(≈ .27)[h]
116.2 (1)	.65 (6)	5.6 (5)
201.8 (2)	.15 (2)	.39 (4)
245.3 (1)	80.0 (40)	99.0 (50)
250.5 (2)	.21 (4)	.39 (6)
298.8 (2)	.11 (2)	.17 (2)
316.8 (2)	.17 (1)	.24 (7)
334.3 (2)[e]	.05 (1)	.07 (2)
402.0 (2)	.78 (2)	.97 (4)
498.9 (2)	.15 (1)	.17 (1)
506.8 (2)	.69 (2)	
518.3 (2)	.15 (1)	
527.6 (1)	1.15 (4)	
584.0 (2)	.34 (2)	
602.5 (2)	.12 (2)	
615.3 (2)	.36 (2)	

(continued)

Table 1 (continued)

Gamma-Ray Energy (keV)	Absolute[a] Gamma-Ray Intensity (percent of ^{210}At decays)
623.0 (2)	.43 (2)
630.9 (2)	.31 (2)
639.4 (2)	.26 (2)
643.8 (2)	.46 (2)
701.0 (2)	.47 (2)
721.6 (3)	.10 (4)
724.7 (2)	.21 (3)
798.6 (3)	.06 (2)
817.2 (2)	1.72 (5)
852.7 (2)	1.39 (5)
869.4 (2)	.13 (2)
881.1 (2)	.22 (2)
909.2 (3)	.09 (3)
929.9 (2)	.76 (3)
955.8 (1)	1.81 (6)
(960.1) (5)[f]	(< 0.04)[f]
964.9 (2)	.16 (4)
976.5 (2)	.81 (4)
1041.6 (2)	.30 (4)
1045.9 (3)	.16 (3)

(continued)

Table 1 (continued)

Gamma-Ray Energy (keV)	Absolute[a] Gamma-Ray Intensity (percent of ^{210}At decays)
1087.2 (3)	.22 (3)[d]
1181.4 (1)	100.0 (25)
1201.2 (2)	.16 (2)
1205.4 (2)	.80 (3)
1289.0 (2)	.52 (2)
1324.1 (2)	.47 (2)
1436.7 (1)	29.2 (13)
1483.3 (1)	46.8 (20)
1543.5 (3)	.03 (1)
1552.7 (2)	.17 (1)
1599.5 (1)	13.5 (6)
1648.4 (2)	.072 (8)
1684.6 (5)	.026 (4)
1955.0 (2)	.41 (2)
2001.7 (2)	.11 (1)
2051.9 (3)	.071 (3)
2226.0 (3)	.046 (3)

(continued)

Table 1 (continued)

Gamma-Ray Energy (keV)	Absolute[a] Gamma-Ray Intensity (percent of ^{210}At decays)
2237.9 (5)	.018 (2)
2246.6[g] (5)	.026 (4)
2254.0 (2)	1.53 (5)
2266.8[e] (3)	.029 (5)
2272.7 (3)	.35 (1)
2284.5 (3)	.019 (2)
2290.0 (3)	.012 (3)
2306.2 (3)	.037 (2)
2352.8 (2)	.14 (1)
2386.8 (3)	.008 (2)

[a]Absolute intensity values were derived by normalizing results to the intensity of the 1181.4 keV transition, which is known from the level scheme to be 100.0(25)%.

[b]Transition intensities (< 500 keV) were derived from measured gamma-ray intensities by correcting for internal conversion using the theoretical values of Hager and Seltzer[23,24]).

[c]Not observed in this work. These transitions were obtained by assignment of conversion electrons reported by Hoff and Hollander[2]).

[d]This intensity was obtained by correcting for contribution from the single escape peak of the 1599.5 keV gamma-ray.

[e]Assigned to ^{210}At decay but unplaced in present level scheme.

[f]This transition was not observed in the singles spectrum due to the intense compton background but was observed in the coincidence spectra of the 639.4 keV transition. The intensity limit was extracted from the coincidence spectra.

(continued)

Table 1 (continued)

[g]Assignment to ^{210}At decay is uncertain.

[h]The intensity was estimated from the relative electron intensities reported by Hoff and Hollander[2]).

[i]The intensity was estimated from an intensity balance of the decay scheme.

Table 2. Experimental and theoretical internal conversion coefficients: ^{210}At.

Transition Energy keV	Experimental[c] conversion coefficient (10^{-3})	Theoretical[a] conversion coefficient E1(10^{-3})	E2(10^{-3})	M1(10^{-3})	Assigned Multipolarity
46.6	$(\alpha_{L1} + \alpha_{L2})/\alpha_{L3}$ = 1010(80)	1980	1060	132800	E2
116.2	α_L = 1220 (140)	504	2580	1100	M1
	α_M = 299 (35)	11.9	687	259	
201.8	α_K = 1240 (110)	65.3	165	1290	M1
	α_L = 220 (22)	11.9	221	227	
	α_M = 50 (10)	2.8	58.2	53.5	
245.3	α_K = 110 (13)	41	107	747	E2
	α_L = 102 (18)	7.28	98.6	131	
	$(\alpha_{L1} + \alpha_{L2})/\alpha_{L3}$ = 2320(240)	6600	2500	160000	
250.5	α_K = 700 (140)	39	102	705	M1
298.8	α_K = 440 (44)	26	68.2	434	M1
	α_L = 81 (9)	4.5	45.4	76.1	
316.8	α_K = 314 (65)	22.7	59.8	370	M1(+E2)
	α_L = 62 (8)	3.91	36.4	64.8	

(continued)

Table 2 (continued)

Transition Energy keV	Experimental[c] conversion coefficient (10^{-3})	Theoretical[a] conversion coefficient E1(10^{-3})	E2(10^{-3})	M1(10^{-3})	Assigned Multipolarity
402.0	α_K = 212 (15)	13.4	35.4	195	
	α_L = 37 (4)	2.26	15.5	33.9	M1
	α_M = 9.6 (10)	0.0527	0.395	7.97	
498.9	α_K = 110 (10)	8.52	22.4	109	M1
506.8	α_K = 9.2 (1.2)	8.25	21.7	105	E1
518.3	α_K = 107 (11)	7.88	20.7	99.0	M1
527.6	α_K = 8.3 (8)	7.60	20.0	94.4	E1
584.0	α_K = 7.0 (11)	6.20	16.3	72.3	E1
602.5	α_K = 80 (12)	5.83	15.3	66.6	M1
615.3	α_K = 59 (5)	5.59	14.7	63.0	M1
623.0	α_K = 6.4 (11)	5.46	14.3	61.0	E1

(continued)

Table 2 (continued)

Transition Energy keV	Experimental[c] conversion coefficient (10^{-3})	Theoretical[a] conversion coefficient			Assigned Multipolarity
		E1(10^{-3})	E2(10^{-3})	M1(10^{-3})	
630.9	α_K = 57 (5)	5.32	14.0	59.1	M1
	α_L = 12.5 (16)	0.903	4.10	10.8	
639.4	α_K = 12.5 (17)	5.19	13.6	57.0	E2
643.8	α_K = 4.7 (8)	5.12	13.5	56.0	E1
701.0	α_K = 39 (4)	4.35	11.4	44.9	M1(+ E2)
	α_L = 6.5 (11)	0.694	2.87	7.69	
724.7	α_K = 40 (4)	4.08	10.7	41.2	M1
817.2	α_K = 30 (2)	3.26	8.52	30.2	M1
	α_L = 5.5 (5)	0.514	1.93	5.13	
852.7	α_K = 24 (2)	3.01	7.87	27.0	M1
869.4	($\alpha_K \leqslant$ 17 (4))[b]	2.91	7.59	25.7	(M1 + E2)[b]
881.1	α_K = 18.4 (25)	2.84	7.4	24.8	M1 + E2

(continued)

Table 2 (continued)

Transition Energy keV	Experimental[c] conversion coefficient (10^{-3})	Theoretical[a] conversion coefficient			Assigned Multipolarity
		E1(10^{-3})	E2(10^{-3})	M1(10^{-3})	
909.2	($\alpha_K < 23$)[b]	2.68	6.98	22.9	(E2 ?)[b]
929.9	$\alpha_K = 20$ (2)	2.57	6.69	21.6	M1
	$\alpha_L = 4.1$ (5)	0.403	1.41	3.68	
955.8	$\alpha_K = 19$ (2)	2.45	6.36	20.1	M1
	$\alpha_L = 3.3$ (4)	0.383	1.32	3.42	
976.5	$\alpha_K = 19$ (2)	2.36	6.11	19.1	M1
1181.4	$\alpha_K = 4.31$ (0)[c]	1.69	4.31	11.7	Assumed pure E2
	$\alpha_L = 0.80$ (7)	0.26	0.821	1.98	E2
1201.2	($\alpha_K < 12.5$)	1.64	4.19	11.2	(E2)[b]
1205.4	($\alpha_K < 2.5$)	1.63	4.16	11.1	(E1 + < 15% M2)[b]
1289.0					(E3 or E1 + < 32% M2)
1436.7	$\alpha_K = 1.13$ (10)	1.21	3.03	7.12	E1
	$\alpha_L = 0.18$ (2)	0.184	0.542	1.20	

(continued)

Table 2 (continued)

Transition Energy keV	Experimental[c] conversion coefficient (10^{-3})	Theoretical[a] conversion coefficient E1(10^{-3})	E2(10^{-3})	M1(10^{-3})	Assigned Multipolarity
1483.3	α_K = 1.06 (10)	1.14	2.86	6.56	E1
	α_L = 0.17 (2)	0.174	0.508	1.10	
1552.7					(E1 + < 21% M2)[b]
1599.5	α_K = 0.93 (10)	1.01	2.50	5.41	E1

[a]Theoretical values were obtained by computer interpolation[24]) from the tables of Hager and Seltzer[23]).

[b]Only a limit could be set on the conversion electron intensity, as discussed in text, so that the assigned multipolarity is tentative.

[c]These (relative) conversion coefficients were measured relative to the 1181.4 keV ($2^+ \rightarrow 0^+$) transition which was assumed to be a pure E2 transition.

Table 3. Comparison of transition probabilities for M1 and E2 transitions in the decay of the $\pi(h_{9/2} f_{7/2})$ multiplet in ^{210}Po. (The theoretical transition probabilities were calculated with the wave functions of Ma and True (MT)[41]) and Kim and Rasmussen (KR)[32]).

Transition[a] $(J_i \rightarrow J_f)$	E_γ (keV)	Relative γ-ray Branching Intensities (exp)	Multi-polarity (exp)	Theoretical Transition Probabilities[d] $T(\lambda) \times 10^{-8}$ sec^{-1} MT		KR	
				M1	E2	M1	E2
$7_1 \rightarrow 8_1$	881.1	100	M1 + E2	2669	51.0	822	60.1
$7_1 \rightarrow 8_2$	250.5	96	M1	1652	0.053	1672	0.044
$7_1 \rightarrow 6_1$	964.9	73	---	585	36.9	643	33.3
$7_1 \rightarrow 6_2$	112.2	~14[b]	M1	183	1.58×10^{-6}	248	7.86×10^{-5}
$5_1 \rightarrow 6_1$	929.9	94	M1	2631	4.7	939	3.01
$5_1 \rightarrow 6_2$	77.2	4[b]	(M1)	127	2.63×10^{-5}	132	2.04×10^{-5}
$5_1 \rightarrow 4_1$	976.5	100	M1	517	66.9	751	66.2
$8_2 \rightarrow 8_1$	630.9	100	M1	5966	21.5	1909	16.3
$8_2 \rightarrow 6_1$	(714.4)	<13[c]	---	0	1.59×10^{-7}	0	0.0475
$6_2 \rightarrow 8_1$	(769.2)	< 4[c]	---	0	1.05	0	33.2
$6_2 \rightarrow 6_1$	852.7	100	M1	2782	109	870	65.5
$6_2 \rightarrow 4_1$	(899.3)	<14[c]	---	0	26.5	0	6.1

(continued)

Table 3 (continued)

Transition[a] ($J_i \rightarrow J_f$)	E_γ (keV)	Relative γ-ray Branching Intensities (exp)	Multi-polarity (exp)	Theoretical Transition Probabilities[d] $T(\lambda) \times 10^{-8}$ sec^{-1}			
				MT		KR	
				M1	E2	M1	E2
$4_2 \rightarrow 6_1$	909.2	5	---	0	46.1	0	107
$4_2 \rightarrow 4_1$	955.8	100	M1	3246	158	235	50.3
$4_2 \rightarrow 2_1$	1201.2	9	(E2)	0	433	0	98.0
$4_2 \rightarrow 2_2$	92.1	~0.05[b]	(E2)	---	0.025	---	0.022
$2_2 \rightarrow 4_1$	(863.3)	---	---	0	75.7	0	78.0
$2_2 \rightarrow 2_1$	(1108.6)	---	---	4940	231	11.1	1.44
$2_2 \rightarrow 0_1$	2290.0	100	---	0	17300	0	4400

[a] J_i and J_f refer to the spins of the initial and final states respectively. The subscripts 1 and 2 refer to the first and second levels (increasing energy) of a given spin.

[b] Estimated from conversion-electron line intensities in the spectrographic plates obtained by Hoff and Hollander[2]).

[c] Estimated from preliminary data taken with a compton suppressed Ge(Li) spectrometer[42]).

[d] Values of 1.5e for the effective charge and 0.165 for the oscillator parameter ν were used in the calculation of T(E2). Schmidt values were used for the factors g_j, g_ℓ and g_s.

Figure Captions

Fig. 1. Gamma-ray spectrum of ^{210}At in the energy range 16-130 keV.

Fig. 2. Gamma-ray spectrum of ^{210}At in the energy range 100-2500 keV.

Fig. 3. Conversion-electron spectrum of ^{210}At in the energy range 20-320 keV.

Fig. 4. Conversion-electron spectrum of ^{210}At in the energy range 70-1500 keV.

Fig. 5. Comparison of experimental K-conversion coefficients with theoretical values of Hager and Seltzer[23,24]).

Fig. 6. Gamma-ray spectra in prompt and delayed coincidence with the 1181.4 keV ($2^+ \rightarrow 0^+$) ground state transition in ^{210}Po. The 852.7 keV transition is shown to be in delayed coincidence with the 1181.4 keV transition.

Fig. 7. Gamma-ray spectrum in prompt coincidence with the 250.5 keV transition, establishing the 1289-250.5-630.9 keV gamma-ray cascade.

Fig. 8. Experimental decay scheme of ^{210}At. Absolute transition intensities are shown on the scheme.

Fig. 9. Summary of available data on levels in ^{210}Po below 4 MeV. The spin and parity assignments given in the composite level diagram have been deduced by a comparison of the data from reaction studies and the electron-capture decay of ^{210}At.

Fig. 10. Comparison of the experimental level scheme of ^{210}Po(b) with a shell-model calculation(a)[38]) and with the experimental level scheme of ^{208}Pb(c)[35]). The zero-order energies of the lowest 2-proton configurations in ^{210}Po are shown to the left.

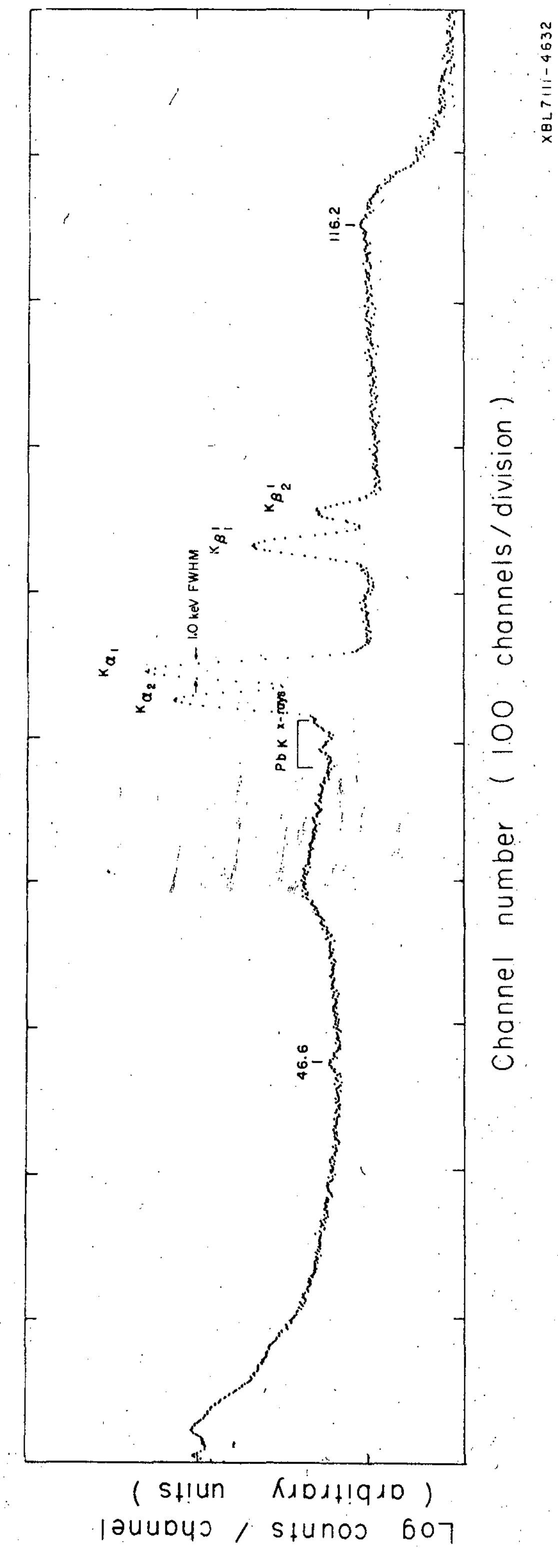

Log counts / channel
(arbitrary units)
Channel number (100 channels / division)
46.6
116.2
Kα1
Kα2
1.0 keV FWHM
Kβ1'
Kβ2'
XBL 711-4632

Fig. 1

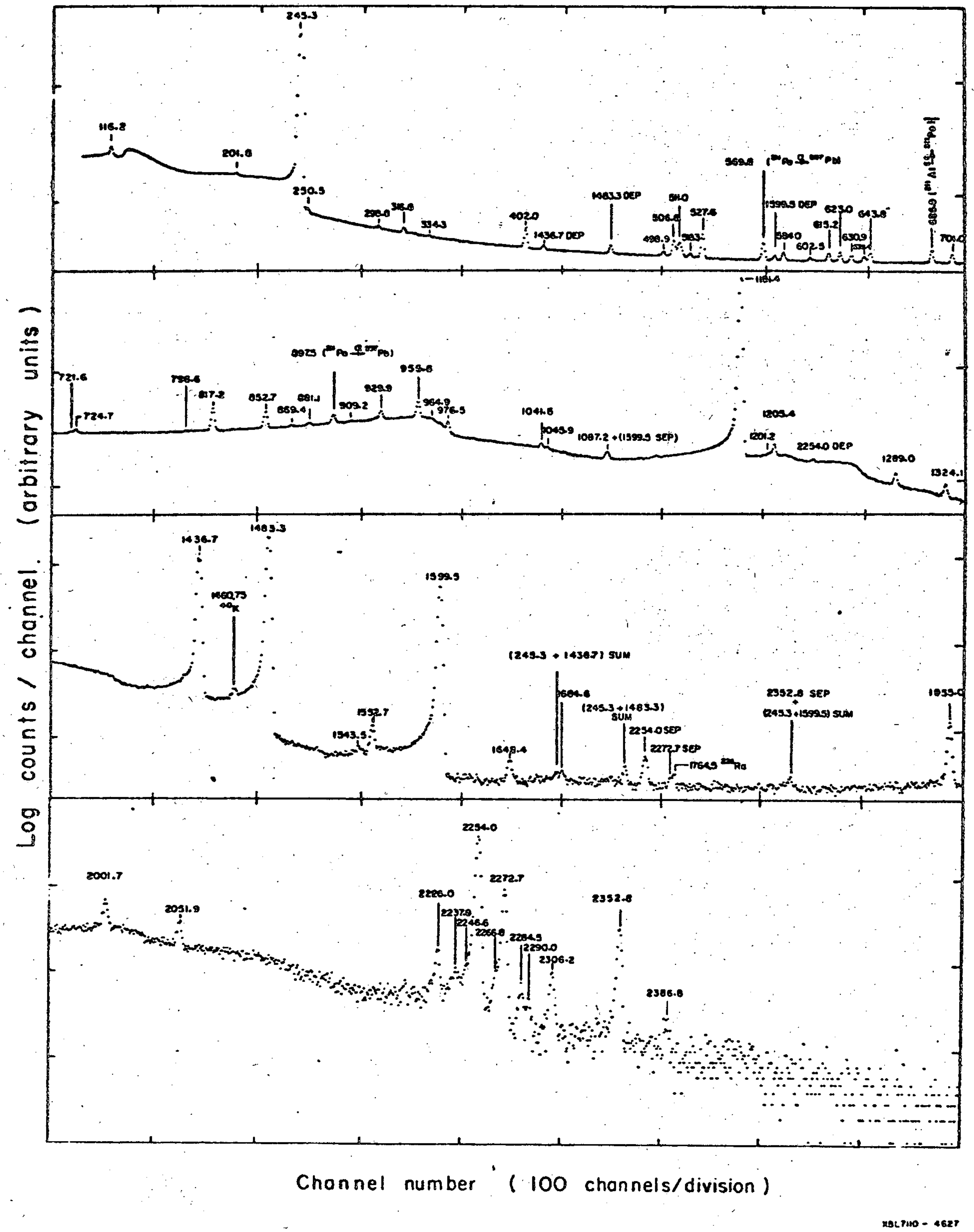

245.3
116.2
201.6
569.6
250.5
1483.3 DEP
511.0
527.6
298.0
316.6
334.3
402.0
1436.7 DEP
1599.5 DEP
623.0
643.8
701.0
721.6
724.7
796.6
817.2
852.7
869.4
881.1
909.2
929.9
955.6
964.9
976.5
1041.6
1045.9
1087.2 + (1599.5 SEP)
1205.4
1201.2
2254.0 DEP
1289.0
1324.1
1436.7
1483.3
1460.75
40K
1599.5
(245.3 + 1436.7) SUM
1684.6
(245.3 + 1483.3) SUM
2254.0 SEP
2272.7 SEP
1764.5
2352.8 SEP
(245.3 + 1599.5) SUM
1552.7
1543.5
1648.4
2254.0
2001.7
2051.9
2272.7
2226.0
2352.8
2237.9
2246.6
2266.8
2284.5
2290.0
2306.2
2386.8
Log counts / channel (arbitrary units)
Channel number (100 channels/division)
XBL 710 - 4627

Fig. 2

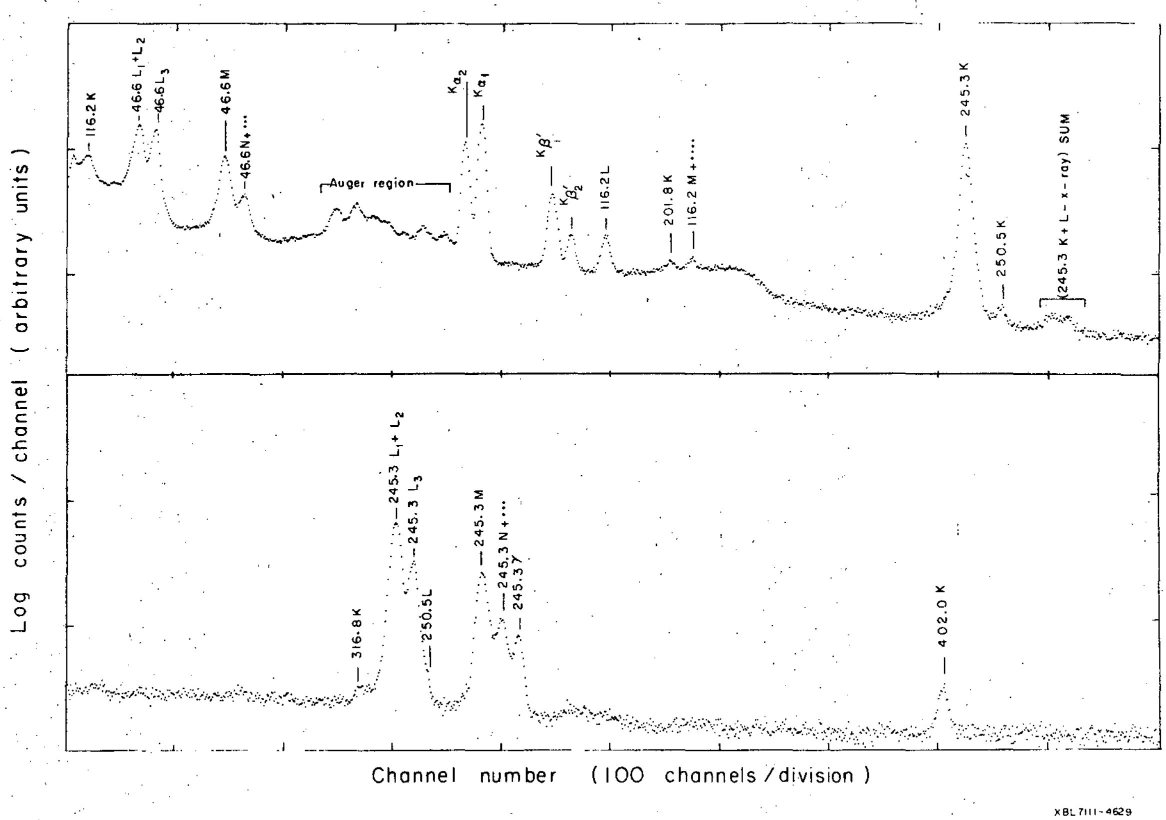

116.2 K
46.6 L1+L2
46.6 L3
46.6 M
46.6 N+···
Auger region
Kα2
Kα1
Kβ1'
Kβ2'
116.2 L
201.8 K
116.2 M+····
245.3 K
250.5 K
(245.3 K+L-x-ray) SUM
316.8 K
245.3 L1+L2
245.3 L3
250.5 L
245.3 M
245.3 N+···
245.3 γ
402.0 K
Log counts / channel (arbitrary units)
Channel number (100 channels / division)
XBL 7111-4629

Fig. 3

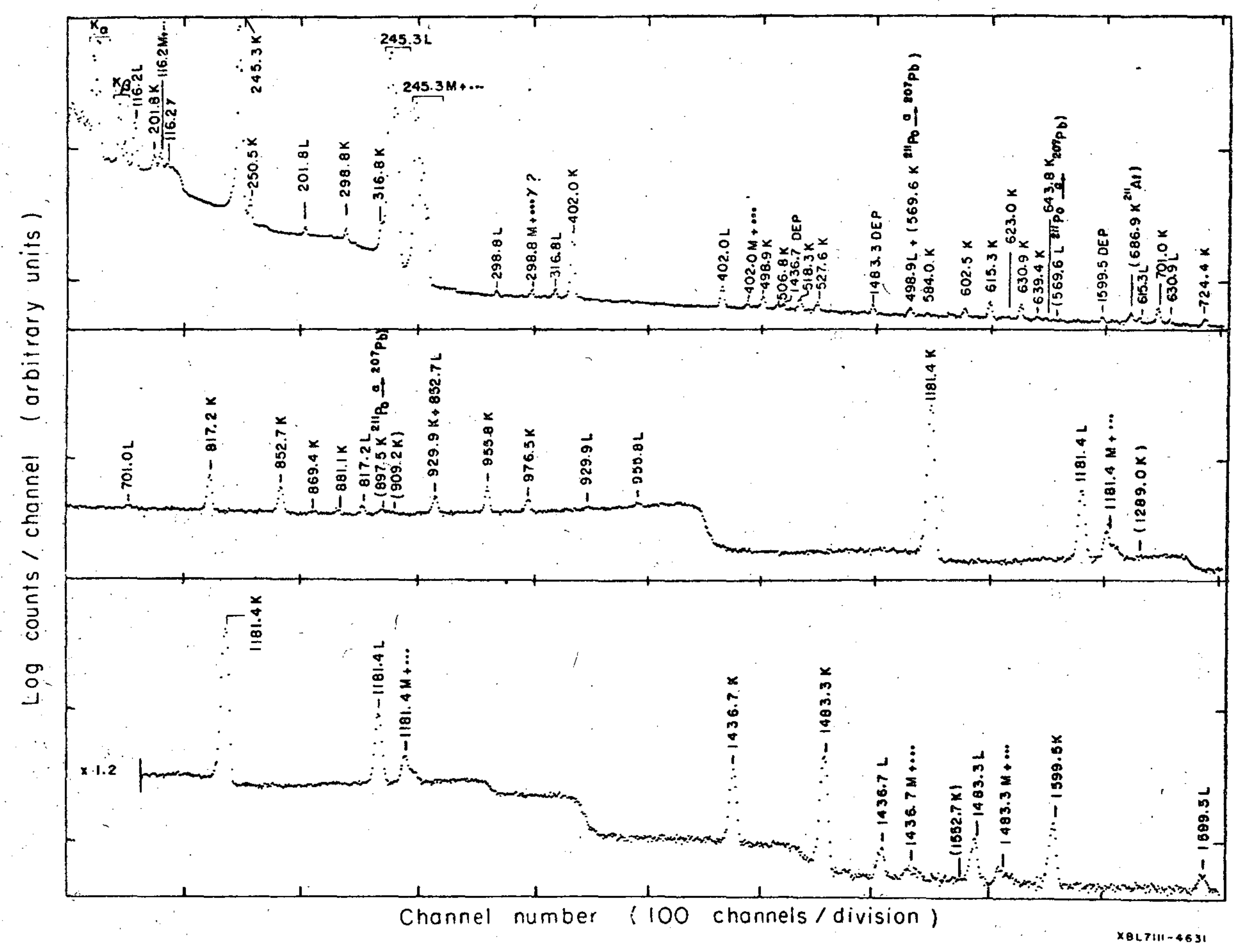
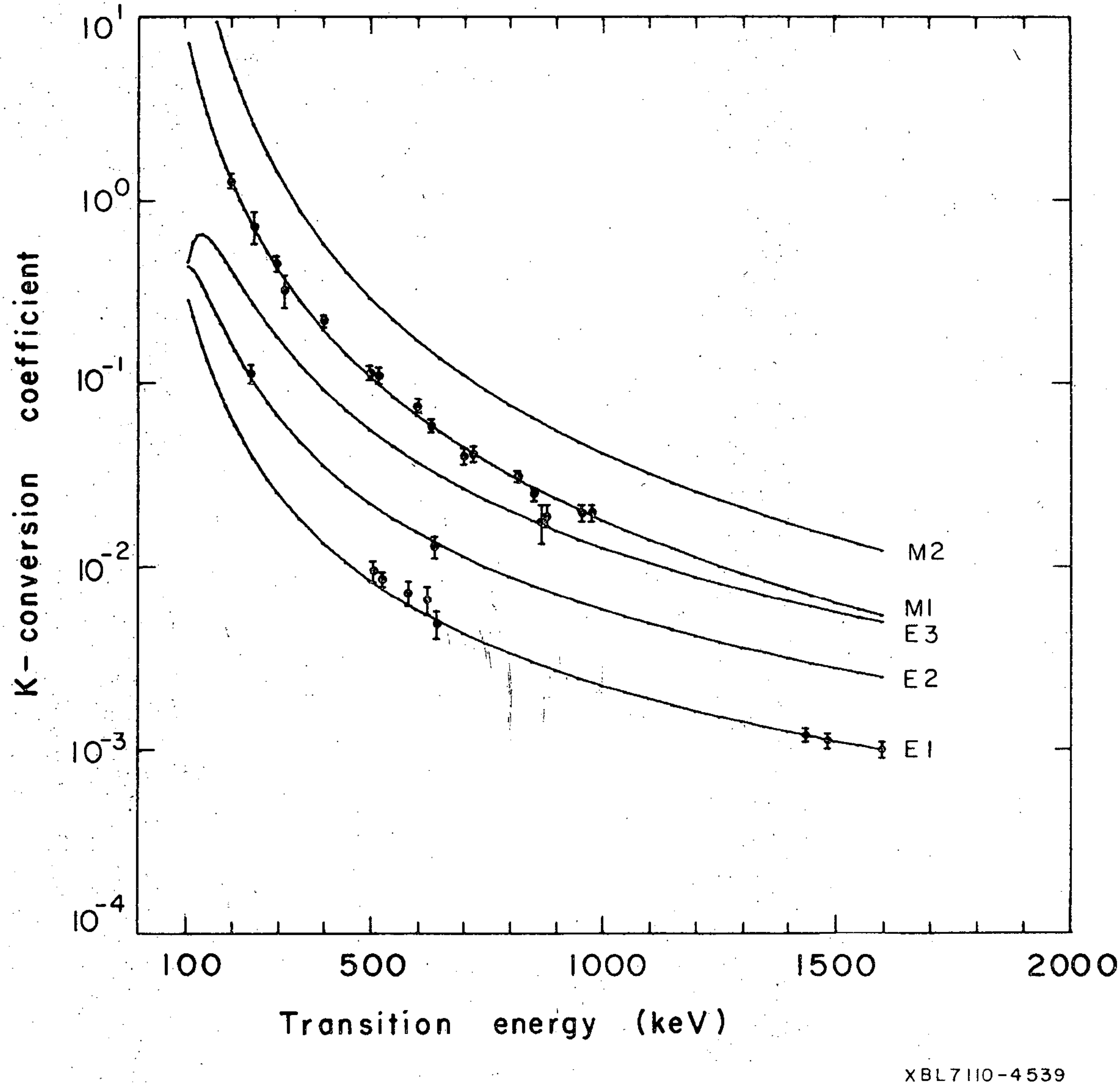

Log counts / channel (arbitrary units)
Channel number (100 channels / division)
XBL7111-4631

Fig. 4



10^1
10^0
10^-1
10^-2
10^-3
10^-4
K- conversion coefficient
M2
MI
E3
E2
E1
100
500
1000
1500
2000
Transition energy (keV)
XBL7110-4539

Fig. 5

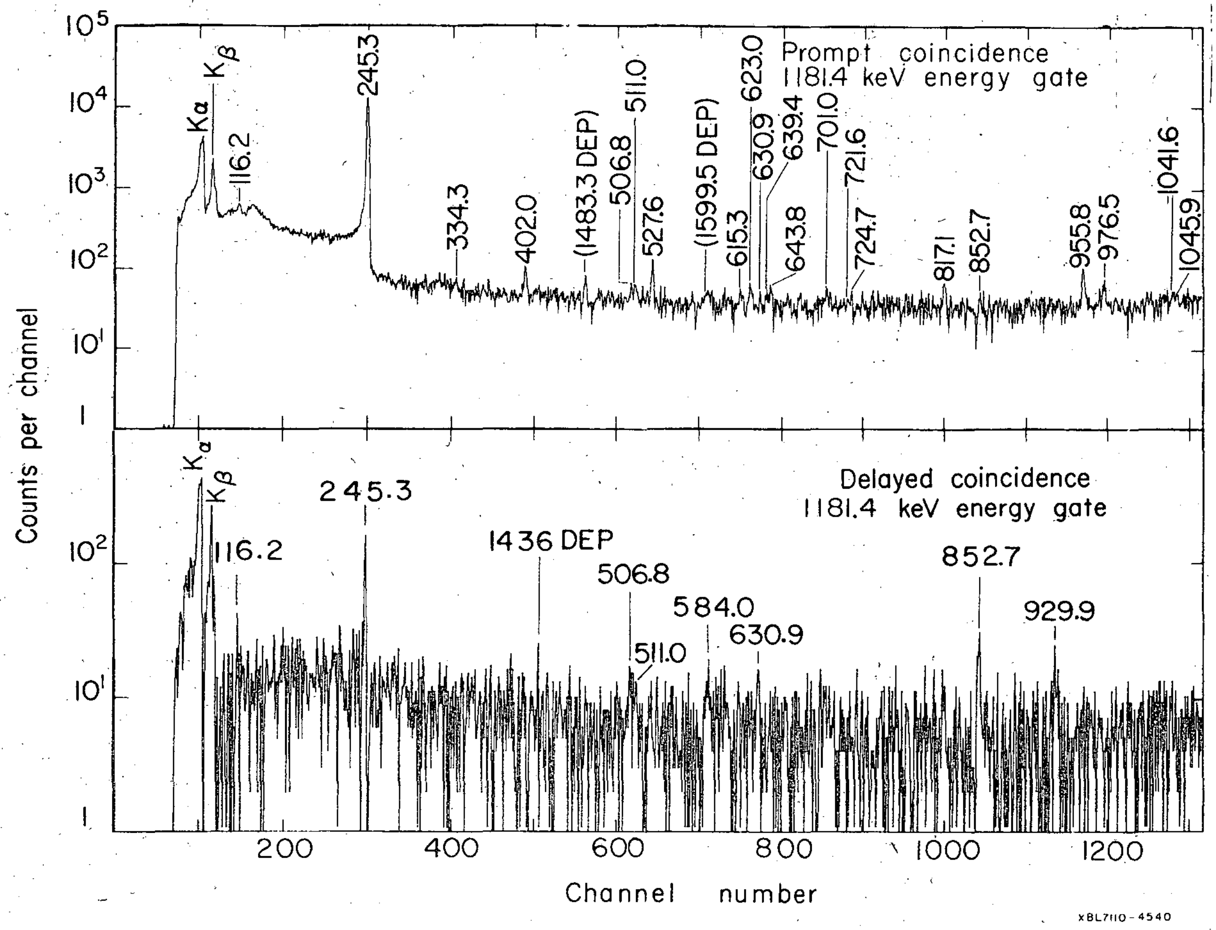

Prompt coincidence
1181.4 keV energy gate
Kα
Kβ
116.2
245.3
334.3
402.0
(1483.3 DEP)
506.8
511.0
527.6
(1599.5 DEP)
615.3
623.0
630.9
639.4
643.8
701.0
721.6
724.7
817.1
852.7
955.8
976.5
1041.6
1045.9
Delayed coincidence
1181.4 keV energy gate
Kα
Kβ
116.2
245.3
1436 DEP
506.8
511.0
584.0
630.9
852.7
929.9
Counts per channel
Channel number
XBL7110-4540

Fig. 6

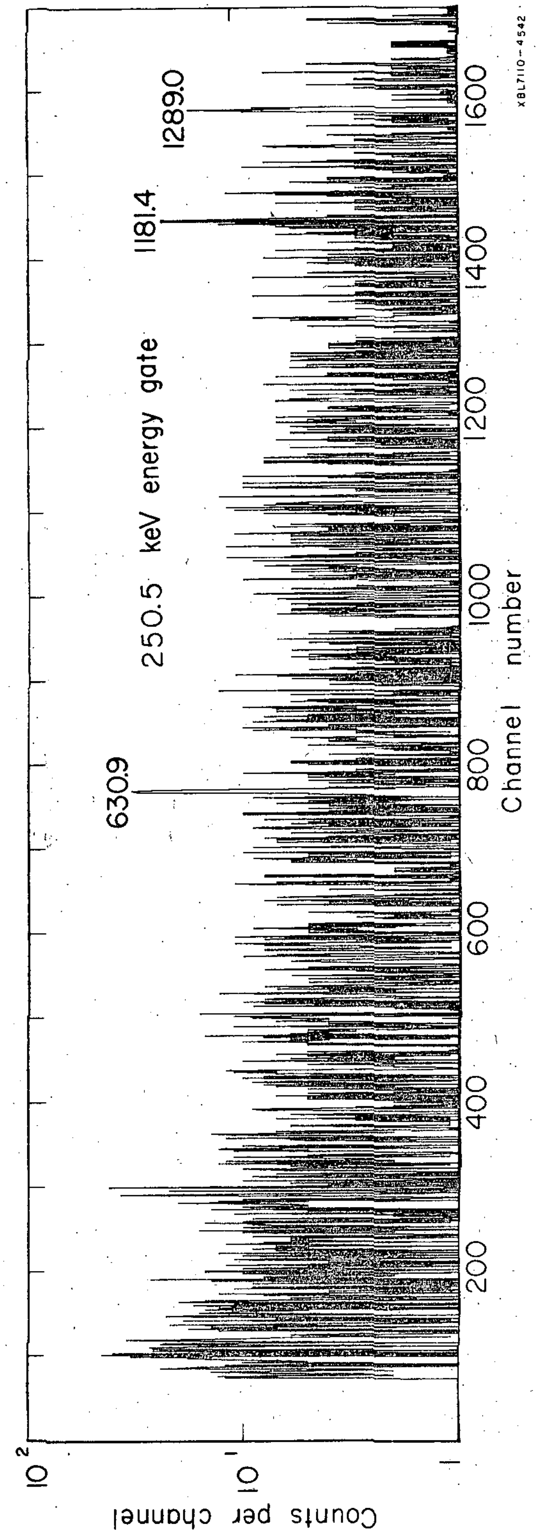
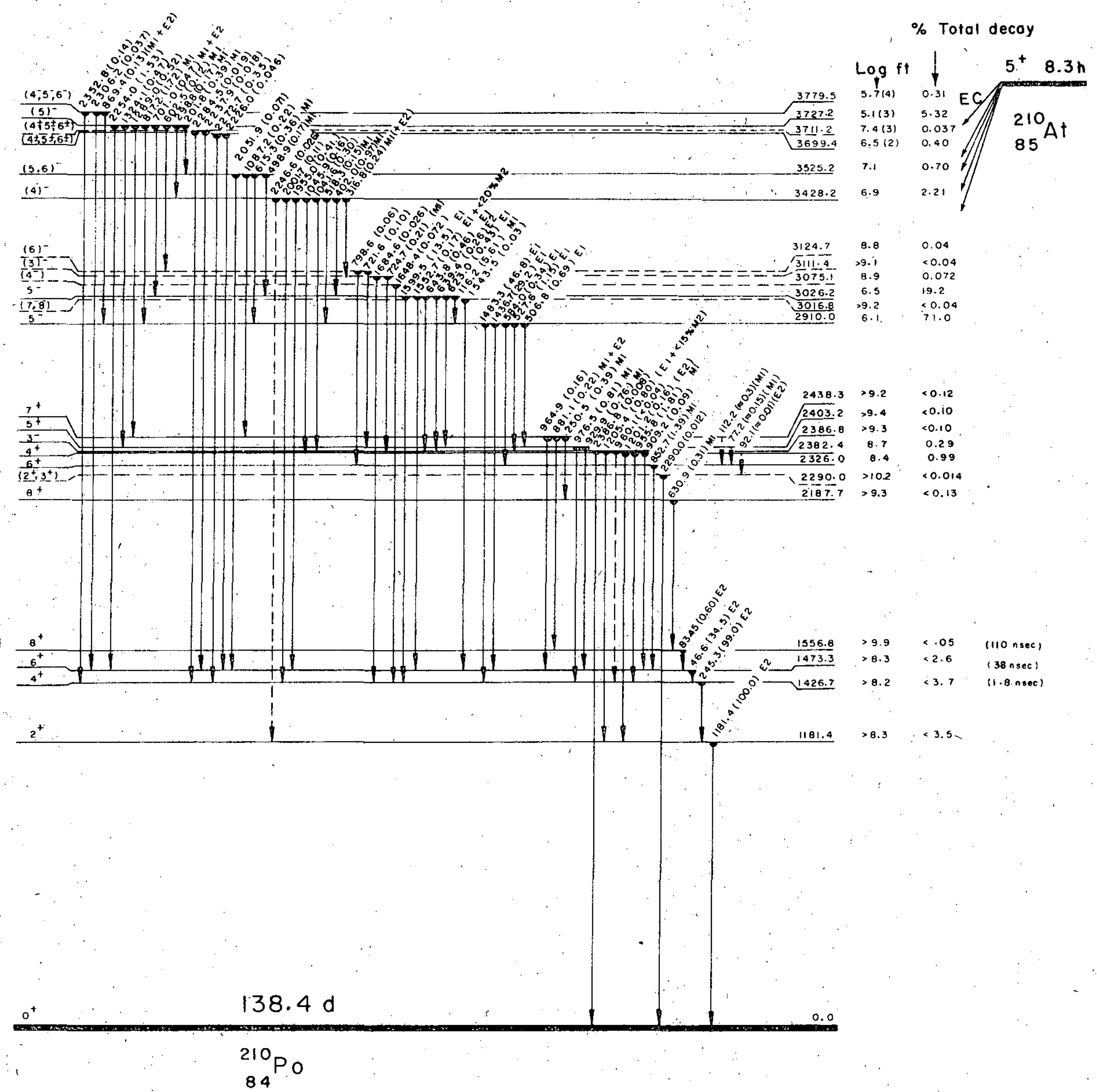

250.5 keV energy gate
630.9
1181.4
1289.0
Channel number
Counts per channel
200
400
600
800
1000
1200
1400
1600
10
XBL7110-4542

Fig. 7



XBL719-4407A

Fig. 8

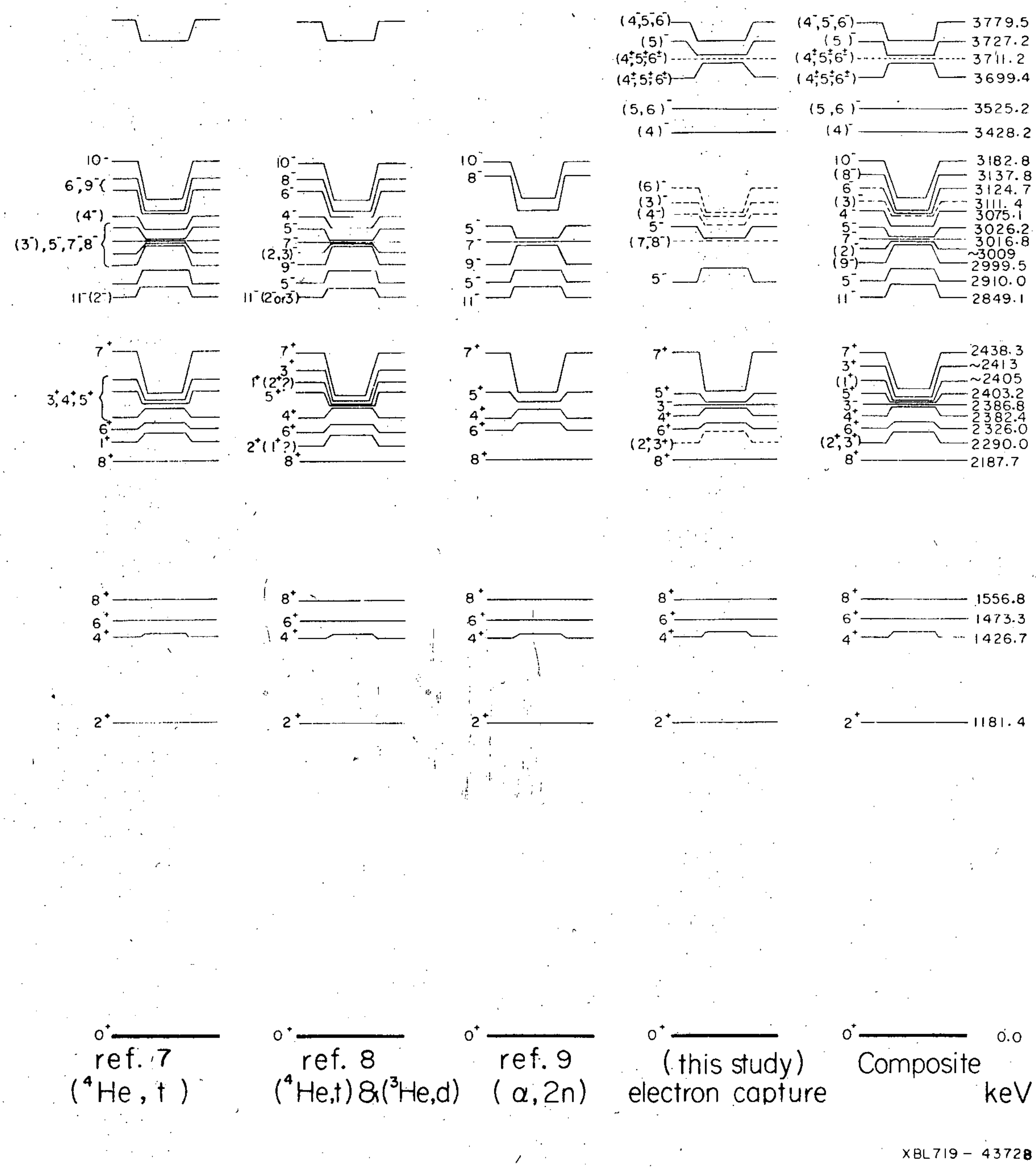

3779.5
3727.2
3711.2
3699.4
3525.2
3428.2
3182.8
3137.8
3124.7
3111.4
3075.1
3026.2
3016.8
~3009
2999.5
2910.0
2849.1
2438.3
~2413
~2405
2403.2
2386.8
2382.4
2326.0
2290.0
2187.7
1556.8
1473.3
1426.7
1181.4
0.0
ref. 7
(^{4}He, t)
ref. 8
(^{4}He,t) & (^{3}He,d)
ref. 9
(α, 2n)
(this study)
electron capture
Composite
keV
XBL719 - 43728

Fig. 9

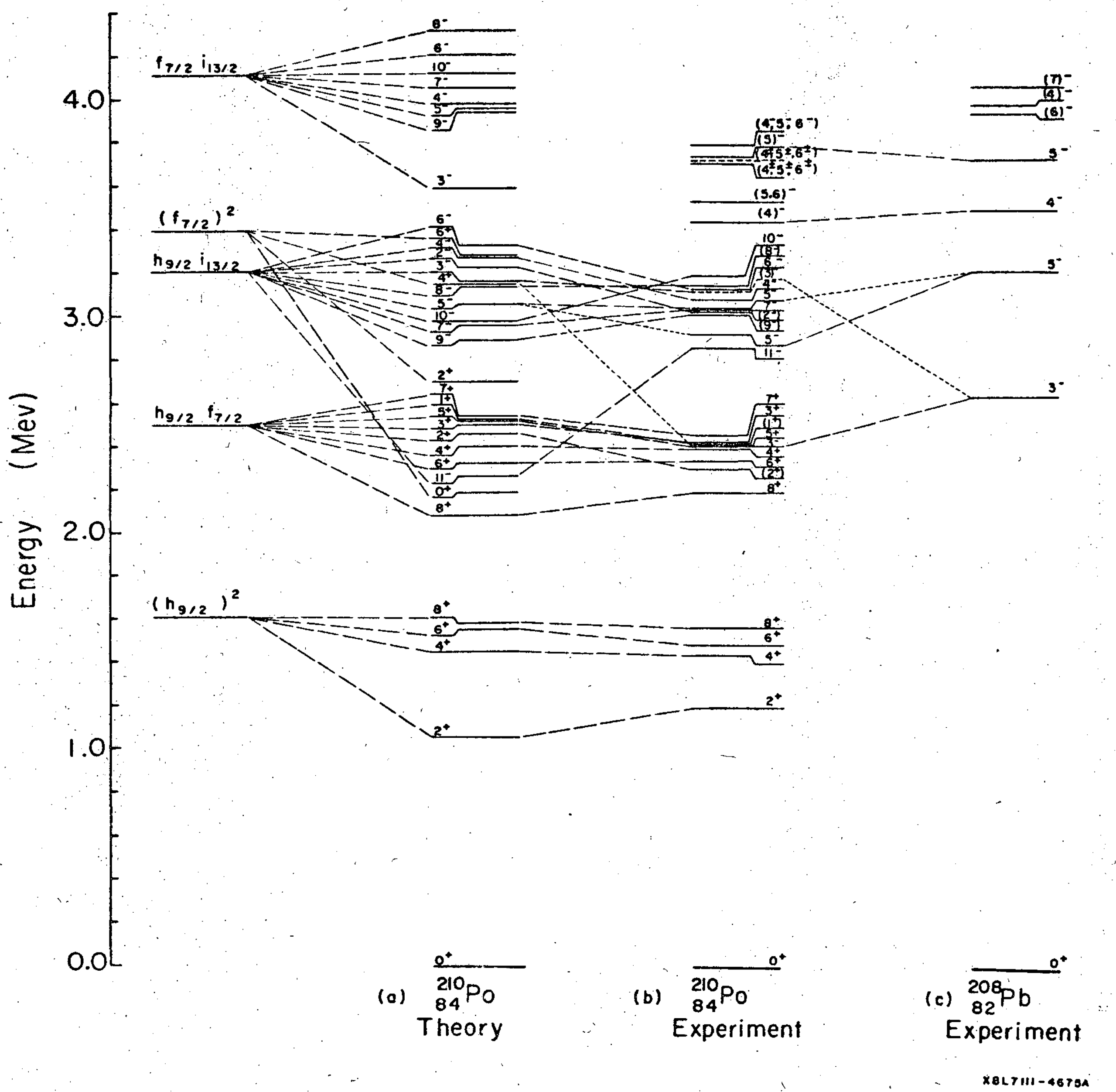

Energy (Mev)
0.0
1.0
2.0
3.0
4.0
$f_{7/2}\ i_{13/2}$
$(f_{7/2})^2$
$h_{9/2}\ i_{13/2}$
$h_{9/2}\ f_{7/2}$
$(h_{9/2})^2$
(a) $^{210}_{84}$Po Theory
(b) $^{210}_{84}$Po Experiment
(c) $^{208}_{82}$Pb Experiment
XBL7111-4675A

Fig. 10

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720