DECAY OF ^{199m,g}PO: ISOMERIC TRANSITIONS IN ^{199}PO AND ^{199}BI

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ABSTRACT

The M4 isomeric transition ($E\gamma$=238 keV) of the $13/2^+$ state in ^{199}Po to the $5/2^-$ level, with a half life of 4.17 min, has been observed in mass separated sources. An ∿72 keV transition in coincidence with the isomeric transition suggests the placement the $5/2^-$ level above the $3/2^-$, and when combined with α-decay Q values, this results in a placement of the $13/2^+$ isomeric state in ^{195}Pb at ∿200 keV. The transition rate for the M4 transition in ^{199}Po is similar to those for other M4 transitions in this region. Contrastingly, a M4 transition in ^{199}Bi, which is highly likely to occur on the basis of systematics of $\frac{1}{2}^+$ and $9/2^-$ states and a sequence of gamma rays among low spin states observed in our data, is highly retarded. Although, this M4 transition is not observable in our data, an upper limit for its strength is established at ∿1/1000 the intensity of typical M4 transitions in this region. Possible interpretations of this retardation will be discussed.

1. Introduction

The intrusion of shell model states ($h_{9/2}$ and $i_{13/2}$) from above the Z=82 shell closure into the low excitation region of light Tl nuclei has been a subject of considerable interest in recent years.[1-4] This intrusion can perhaps be explained in terms of proton-neutron interactions and one attempt to reproduce the systematic trend of the $h_{9/2}$ intruder states [5] yielded some success although it failed in reproducing the details of the structure. Since the Tl ground states are believed to be $\frac{1}{2}^+$ states while the $3/2^+$ state is low in excitation and thus a deep intrusion of the $h_{9/2}$ level results in its isomerism. It decays by an E3 transition as long as it is above the $3/2^+$ state (e.g. in ^{193}Tl); for ^{191}Tl and ^{189}Tl the $h_{9/2}$ level is believed to be below the $3/2^+$ state and would have to decay by a M4 or E5 transition. These $h_{9/2}$ isomers have been observed to decay by electron capture; the isomeric transitions have not been observed. [3,6,7]

The present study was initiated to investigate the possibility of the intrusion of holes from below the Z=82 closed shell in the region above. It is expected that the structure of the odd-A Bi isotopes will contain $h_{9/2}$, $f_{7/2}$, and $i_{13/2}$ particles coupled to a Pb core and possibly $h_{11/2}$, $d_{3/2}$ and $s_{\frac{1}{2}}$ holes in Po core. The relative spacing of these levels as one moves away from stability, as well as a detailed study of the bands built on the single particle levels, is of interest in investigating the role of the closed shell and the possible onset of deformation as one moves away from stability. A portion of the results of this study, relating to the placement and decay strength of the $\frac{1}{2}^+$ isomer in ^{199}Bi, was previously reported and are cited here also for comparison with other results. [8]

The relevant levels in ^{199}Po are odd neutron states $p_{3/2}$, $f_{5/2}$ and $i_{13/2}$. The $i_{13/2}$ state was known to be isomeric from α-decay studies; [9,10] in the present study the location of the $i_{13/2}$ isomer and its decay characteristics are investigated. The M4 decay strength for this isomeric state is compared with those for other M4 transitions in the Pb-Po region and with a Weisskopf estimate.

2. Experimental Details and Results

The ^{199}Po was produced by bombarding natural iridium foils in the ion source of the University Isotope Separator (UNISOR) with 115-MeV $^{14}N^{4+}$ ions from the Oak Ridge isochronous cyclotron. The ^{199}Po atoms, ionized in the high temperature source, were mass separated and collected on an automated tape system which periodically moved the freshly collected source into a detector system. Part of the time the detector system was comprised of two large volume Ge(Li) detectors from which γ-ray multiscaled singles spectra and γ-γ-time coincidence data were obtained. For the remainder of the time an electron Si(Li) detector replaced one of the Ge(Li) detectors and e^- singles and e^--γ-time coincidence data were obtained.

The low energy portion of the electron spectrum is shown in Fig. 1. The dominance of the 99 keV E3 transition in ^{195}Pb and the 424-keV M4 transition in ^{199}Pb is apparent. These two transitions and the 384 keV transition in ^{195}Pb were used for final calibration of the e^- detector. A group of conversion electrons corresponding to a transition energy of 238 keV in ^{199}Po are also apparent in Fig. 1. The measured half life for these lines is 4.3±0.2 min, which agrees with the half life of the $13/2^+$ isomer (4.17 min) obtained from a summary of the α-decay results. [11] A coincidence gate set on the K line for the 238 keV transition showed Po

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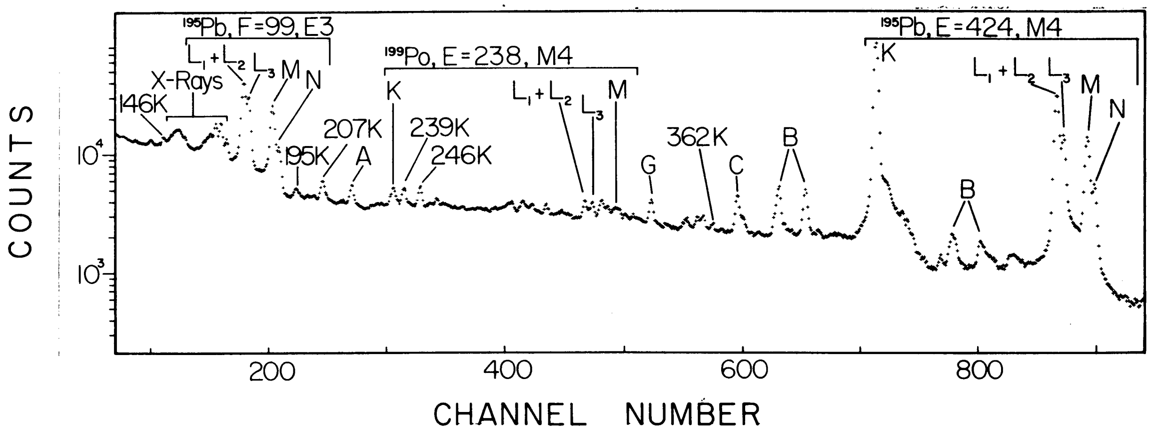

Fig. 1 The low energy portion of the electron spectrum from ^{199}Po decay. Some peaks of decay products or contaminants are identified as A = ^{199}Bi, B = ^{195}Pb, C = ^{199}Pb, and G = unidentified Pb.

x-rays in coincidence confirming it to be a transition in Po. In addition, a gamma ray peak at about 72 keV was observed in the coincidence spectrum. The K/L and K/M ratios for the electron peaks from this transition establish that it is a M4 transition.

3. Isomeric Energy Levels in Po, Bi, and Pb

The coincidence of Po x-rays and a 72 keV gamma ray with the 238-keV isomeric transition establishes that there are two states below the $13/2^+$ isomer in ^{199}Po. A spin of $5/2^-$ can be assigned to the upper one of these two states due to the M4 multipolarity of the isomeric transition. An assignment of $3/2^-$ for the ground state of ^{199}Po can then be deduced from the systematics of the odd-A Po isotopes, shown in Fig. 2.

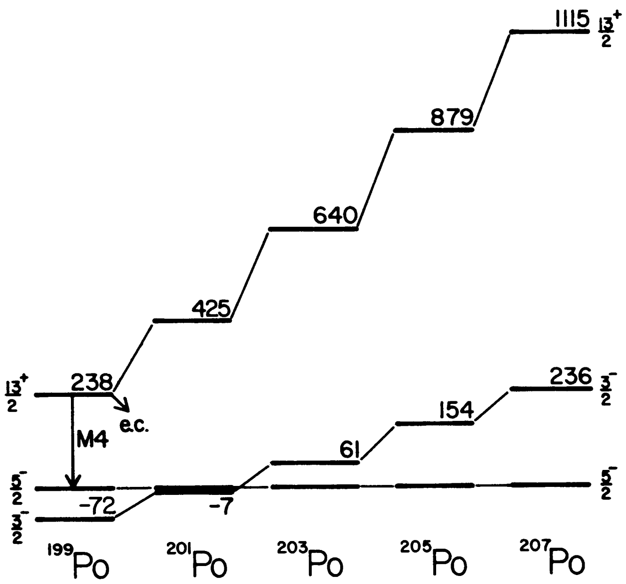

Fig. 2 Systematics in odd-A Po isotopes. Data for $^{201-207}Po$ are from Ref. 18.

The establishment of the energy of the $13/2^+$ isomer in ^{199}Po permits the placement of the $13/2^+$ isomer in ^{195}Pb as shown in Fig. 3. Alpha decay studies of the $13/2^+$ isomer in ^{199}Po yield a weighted average Q value of 6183 keV [11], while the study of the ground state decay gives a Q-value of 6074 keV. Since the excitation energy of the $13/2^+$ state in Po is ∿310 keV, the excitation energy of the $13/2^+$ state in ^{195}Pb is ∿200 keV.

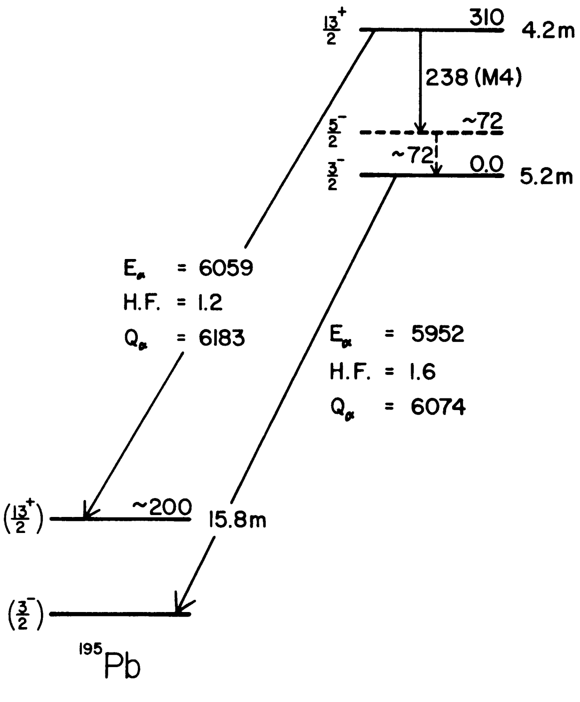

Fig. 3 Placement of the $13/2^+$ state in ^{195}Pb by combining present results with α-decay Q-values.

The ground state of ^{199}Bi is the $h_{9/2}$ proton level. A low spin isomer of ^{199}Bi has been observed to α-decay to the ground state of ^{195}Tl in several previous experiments [13-16] with an adopted half life and energy of 24.7 min and 5484 keV. Combining the α-decay Q-value (5596 keV) with the Q-value estimated from mass systematics [11] for the $h_{9/2}$ ground state (∿4820 keV), we obtain an estimate of ∿776 keV for the excitation energy of the low spin isomer in ^{199}Bi. A low spin isomer was also observed in ^{201}Bi and based on the systematics of $\frac{1}{2}^+$ states in odd-A Bi isotopes (see Fig. 4) it is apparently also a $\frac{1}{2}^+$ state. [8] The measured multi-

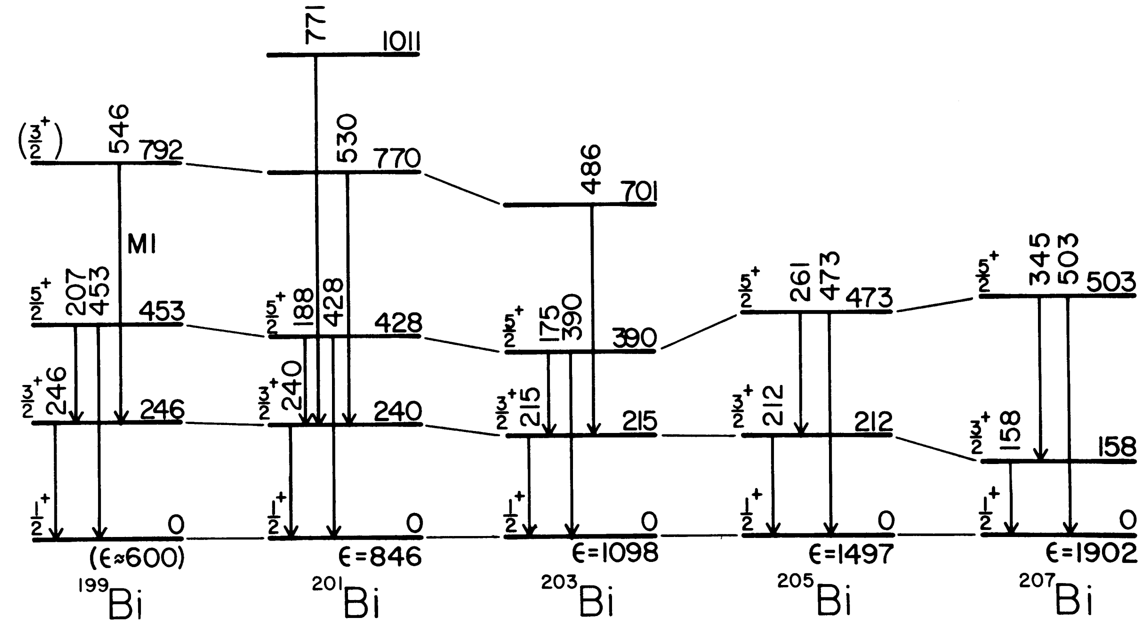

Fig. 4 Relative positions of the 5/2+ and 3/2+ states with respect to the ½+ state in odd-A Bi isotopes. The energies of the ½+ state relative to the ground states are given under the bottom line of each isotope. Data for $^{201-207}$Bi are from Ref. 8, 19, 20, 21, 22, 23.

polarity (M4) of the decay of this state to the h $_{9/2}$ ground state confirms that assignment. Also shown in Fig. 4 are level structures known to decay to the ½+ state in the different isotopes. A similar level structure was observed in ^{199}Bi in the present work and probably assignments of spins can be made based on these systematics as indicated in Fig. 4. The decay of the ½+ isomer to the ground state was not observed in the present data, but from the systematic trend of the ½+ state excitation energy (shown under the bottom line for each isotope in Fig. 4) an estimate for the excitation energy for the ½+ state in ^{199}Bi of 600 keV is made. This is close to the estimate deduced from α-decay and mass systematics above.

4. Isomeric Transition Rates

Relative intensities were determined for each transition mentioned above as well as for the other transitions in ^{199}Bi leading to the h $_{9/2}$ ground state. The electron intensities for the 238 keV transition were combined with the known conversion coefficients for a M4 transition [17] in order to obtain the total intensity of that isomeric transition. The γ-ray intensities observed in ^{199}Bi were also corrected for internal conversion. The intensity of the e.c.-B+ decay of the 13/2+ isomer in ^{199}Po is somewhat more uncertain since the 3/2- ground state also decays to ^{199}Bi. It was assumed that the population of the ½+ isomer and the 5/2- level in ^{199}Bi was from the decay of the 3/2- ground state and that the remaining levels in ^{199}Bi were populated by decay of the 13/2+ isomer in ^{199}Po. Since ~70% of the intensity assigned to the 13/2+ decay originated with population of states with assigned high spins, it is clear that the assumed intensity cannot be grossly in error. The relative strength of the isomeric transition to the e.c.-B+ decay was thus found to be 0.034. Since the α-decay branching ratio for the 13/2+ isomer is 39% [11], the branching ratio for the isomeric transition is 2.1% while that for the e.c.-B+ decay is 59%. Using these branching ratios and the known half life (4.17 min) the probability for isomeric γ-ray decay is found to be 8.5×10^{-7} s^{-1} which can be compared with a Weisskopf single particle estimate [17] of 3.2×10^{-7} s^{-1}. The experimental transition rate is thus equal to 2.6 Weisskopf units or the transition has a retardation factor of 0.38. This value is similar to the retardation factors for several other M4 transitions in odd-A nuclei as illustrated by several examples in Table I.

Table I

A comparison of M4 retardation factors for ^{199}Po and other odd-A nuclei*

Isomer	Transition Energy (keV)	Retardation Factor
^{197m}Hg	165	0.5
^{197m}Pb	319	0.33
^{195m}Hg	123	0.33
^{195m}Pt	130	0.76
^{199m}Hg	374	0.48
^{199m}Pb	424	0.31
^{199m}Po	238	0.37

*See Ref. 11 and 12.

Although a group of transitions feeding the ½+ state in ^{199}Bi was observed, the expected isomeric transition of this state to the 9/2- ground state was not observed. A search for a M4 transition in the 500-1000 keV energy range yielded no likely candidate. Nevertheless, the largest unexplained electron line was intrepreted as the K line for such a transition and corresponds to a Bi transition energy of 667 keV, which is between the two estimates made in Sect. 3. This upper limit on the K electron intensity and internal conversion coefficients for a M4 transition were used to project a γ-ray intensity which was well below our threshold for observation. The feeding of the $\frac{1}{2}^+$ level was assumed to be entirely due to the 246 and 453 keV transitions (see Fig. 4); this estimate is clearly a lower limit of the feeding since the $3/2^-$ ground state of ^{199}Po may decay directly to the $\frac{1}{2}^+$ isomer. A correction factor to account for the finite counting time and half lives of the ^{199}Po and ^{199m}Bi was made. Thus, an upper limit on the isomeric transition branch in the decay of the $\frac{1}{2}^+$ state of 3.2% was deduced. Correcting for conversion and using the measured 24.7 min half life, one obtains an upper limit to the γ-ray transition rate of $\sim$1/390 Weisskopf estimate for a M4 transition. As seen in Table I, this lower limit on the retardation factor (390) is about 1000 times larger than typical retardation factors for M4 transitions in odd-A nuclei.

In summary we note that the isomeric decay rate for the $13/2^+ \rightarrow 5/2^-$ transition in ^{199}Po is closely comparable to those of other M4 transitions (see Table I and a more extensive survey of M4 transition rates in Ref. 8). However, the retardation of the $\frac{1}{2}^+ \rightarrow 9/2^-$ isomeric transition in ^{199}Bi is $\sim$1000 times as retarded as typical M4 transitions. The only other case of such a large reported retardation factor [8] is for the same transition ($\frac{1}{2}^+ \rightarrow 9/2^-$) in ^{201}Bi. This is no doubt related to the fact that the $\frac{1}{2}^+$ state is predominantly a $s_{\frac{1}{2}}$ hole state in a Po core whereas the $9/2^-$ is predominantly a $h_{9/2}$ proton coupled to a Pb core. In a similar situation [3], the intrusion of the $h_{9/2}$ level to become the first excited state in ^{189}Tl and ^{191}Tl, the M4 isomeric decay to the $s_{\frac{1}{2}}$ ground state of these nuclei has not been reported, perhaps also because of large retardation. The transitions could be retarded due to the ℓ selection rule for transitions between pure single particle shell model states, thus indicating extreme purity of these states. Considered as an E5 transition, the retardation would be less extreme. Nevertheless, for the one case where the isomeric transition was observed, [8] ^{201}Bi, it was shown to be an almost pure M4 transition with a retardation factor of $\sim$2000. This would indicate that the retardation is not merely due to ℓ forbiddeness, but that other factors related to the different cores for the particle and hole states are involved.

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