# Lifetimes of the 246- and 46.7-keV Transitions in $Po^{210}$†

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The half-lives of the 1431- and 1478-keV levels in $Po^{210}$ have been measured, the experimental values being $1.8\pm0.2$ nsec and $29\pm6$ nsec, respectively. These levels are depopulated by $E2$ transitions of 246 and 46.7 keV whose transition probabilities are approximately three times greater than the single particle estimates.

ONE of the most sensitive tests of nuclear models is the determination of gamma-ray transition lifetimes. We have undertaken an extensive study of the levels of $Po^{210}$ as populated by the electron-capture decay of 8.3 h $At^{210}$. This nucleus is of particular interest since it has a closed neutron shell ($N=126$) and two protons outside of the closed proton shell at $Z=82$.

The decay of $At^{210}$ has been previously studied by Mihelich *et al.*[1] and Hoff and Hollander.[2] The pertinent portion of the level scheme as presented by Mihelich *et al.* is shown in the insert in Fig. 1(B). Sunyar[3] measured a half-life of $1.5\pm0.2$ nsec for a level in $Po^{210}$ which precedes the 246-keV transition and is itself preceded by a gamma ray of energy greater than 660 keV. This half-life was assumed to be that of the 1478-keV level, implying a considerable enhancement of the $E2$ transition probability for the 46.7-keV transition.

We have recently carried out a series of delayed-coincidence experiments using three different coincidence circuits: a time-to-amplitude converter (TAC) circuit similar to that described by Green and Bell,[4] and two standard fast-slow circuits with minimum resolving times ($2\tau$) of 10 and 100 nsec. The results indicate that the 1431- and 1478-keV levels in $Po^{210}$ have half-lives of $1.8\pm0.2$ nsec and $29\pm6$ nsec, respectively. Therefore, the 246-keV ($E2$) and 46.7-keV ($E2$) gamma-ray transition probabilities show some enhancement over the Weisskopf single-particle estimates.[5]

The TAC apparatus employed Pilot B scintillators and RCA 6342 A photomultipliers. The scintillators used for $\gamma$-ray detection were 1 in.×1 in., while thin scintillators (0.015–0.030 in.) were used for detection of electrons. The fast outputs were amplified by two-stage amplifiers employing 6688 pentodes and then limited by 404 A limiters of the Simms type.[6] The time-to amplitude converter was a 6BN6 circuit.[4] Internal conversion electron sources for the TAC measurements were deposited on 1-mg/cm² aluminized mylar and were mounted inside the light tight housing about ⅛ in. from the scintillator detecting the conversion electrons. The time calibration was obtained by changing cable lengths (RG-63U) whose delay had been measured with a fast oscilloscope. The circuit reliability had been checked by measuring several previously determined half-lives of between 1 and 2 nsec.

Figure 1(A), curve (b) shows the $At^{210}$ TAC spectrum of coincidences between (1441, 1488)-keV $\gamma$ rays and 1185-keV $\gamma$ rays (gates were set on the Compton distributions at ~1200–1400 keV and ~900–1100 keV). The data indicate the presence of both a short and a long half-life. A similar curve was obtained when gating (1441, 1488)-keV $\gamma$ rays and $K$ conversion electrons from the 246-keV transition. In order to obtain a better value for the longer half-life, a (1441, 1488)–246-keV $\gamma$-ray coincidence measurement was carried out using the moderately fast circuit ($2\tau=13$ nsec) and NaI detectors. The results as shown in Fig. 1(B), curve (e) yielded values of $29\pm6$ nsec and ~1.8 nsec for the two half-lives. When an assumed 29 nsec half-life curve was subtracted from the TAC data, the points shown as open circles in Fig. 1(A), curve (b) were obtained. A least-squares analysis of these data gave a half-life value of $1.9\pm0.2$ nsec.

Further measurements established that the short half-life should be assigned to the 1431-keV level and the 29 nsec half-life to the 1478-keV level. Figure 1(A), curve (a) shows the results of a 46.7-keV ($L+M$) conversion electron–246-keV $\gamma$-ray TAC coincidence experiment. A least-squares analysis of the data gave a half-life value of $1.7\pm0.2$ nsec. The $L$ and $M$ internal conversion electrons from the 46.7-keV transition were detected with a 0.015-in.-thick Pilot B scintillator. The conversion electrons were definitely discernible above noise. Another TAC run was taken with a 4-mg/cm² aluminum absorber covering the thin scintillator, and the decrease in the number of coincidences was consistent with the conclusion that the observed half-life was due to the 46.7–246-keV cascade. For the 46.7–246-keV TAC measurements a $Hg^{203}$ source was used to obtain a "prompt" coincidence curve (the 279-keV level in $Tl^{203}$ has a half-life of ~0.3 nsec).

Another method of detecting the 46.7-keV transition is via $L$ x rays since this transition is strongly $L$ con-

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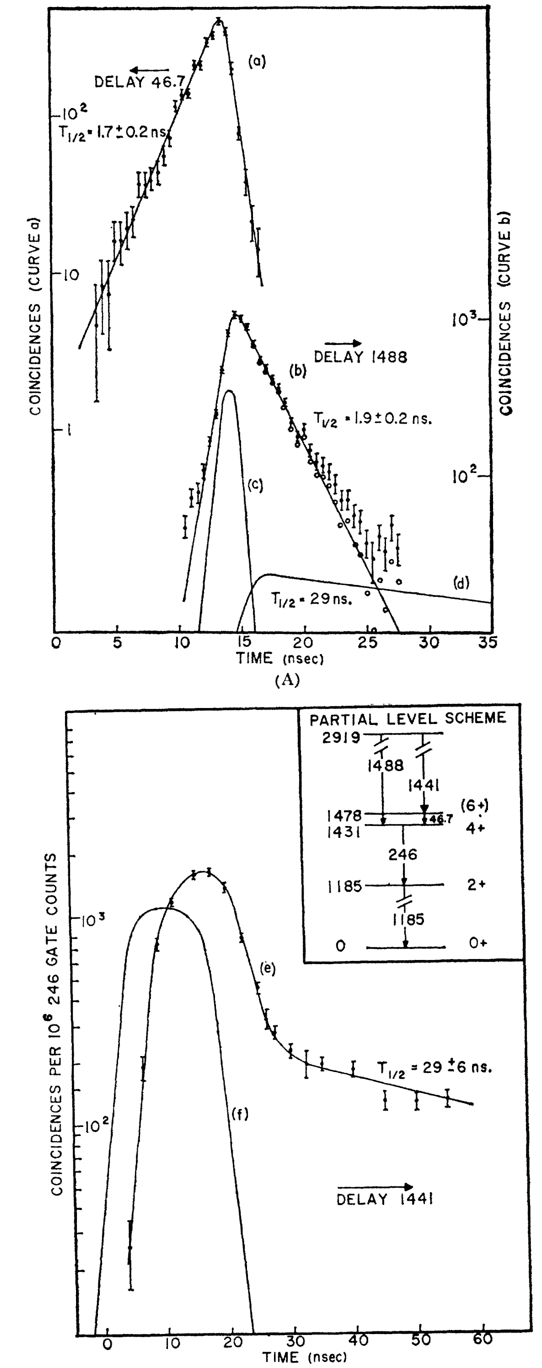


FIG. 1. (A). Curve (a) shows the time-to-amplitude converter (TAC) data obtained when gating on 46.7-keV electrons and 246-keV $\gamma$ rays; curve (b) the TAC data obtained when gating on (1441, 1488)- and 1185-keV $\gamma$ rays; curve (c) a prompt $Co^{60}$ curve for the (1441, 1488)–1185-keV run; and curve (d) an assumed 29-nsec half-life curve which when subtracted from the points on curve (b) yielded the points shown as open circles. (B) Curve (e) shows a delayed coincidence curve obtained when gating on (1441, 1488)- and 246-keV $\gamma$ rays and curve (f) a prompt $Co^{60}$ comparison curve for the 1441–246 keV run. The $Co^{60}$ curve has been shifted for clarity. A partial level scheme for $Po^{210}$ is shown in the insert.

verted. A (1441, 1488) $\gamma$-ray–$L$ x-ray delayed coincidence experiment was performed using the slower coincidence circuit ($2\tau\sim0.1$ $\mu$sec). The $L$ x rays were detected in a 2-mm NaI crystal. The delayed coincidence curve showed a slope on the delay "1400"-keV side corresponding to a half-life of about 30 nsec and confirmed the assignment of the 29±6 nsec half-life to the 1478-keV level.

On the basis of $K/L$ and $L$ subshell conversion electron ratios obtained from the data of Mihelich *et al.*[1] the 46.7- and 246-keV transitions are most likely pure $E2$ (although an admixture of a few percent $M1$ cannot be excluded). A comparison of the observed $E2$ gamma-ray transition probabilities with the Weisskopf single-particle estimates is presented in Table I. The value given for the half-life of the 1431-keV level is an average of the values obtained from the TAC measurements.

In Fig. 2 are presented the available data on comparative lifetimes for $E2$ transitions in even-even nuclei in the region around neutron number 126. The new data for $Po^{210}$ are consistent with the previously observed trend of comparative lifetimes for this region. One may note the order of magnitude difference between the $E2$ comparative lifetimes for the $N=126$ isotones $Pb^{208}$ and $Po^{210}$.

*Note added in proof.* The half-life of the 1478-keV level has been remeasured with improved statistics

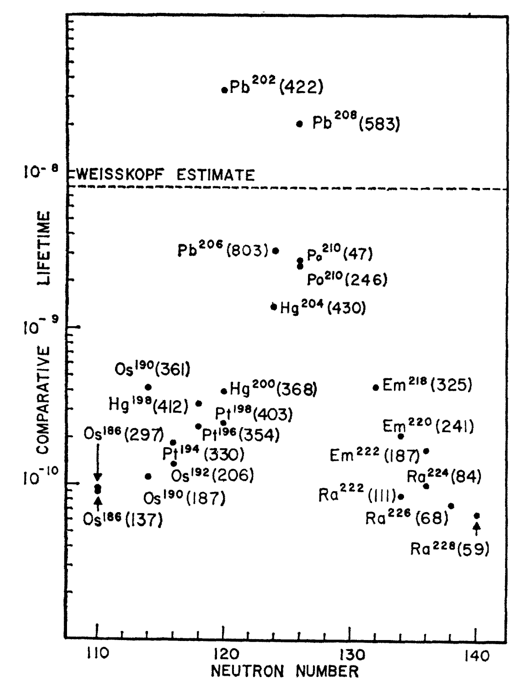


FIG. 2. Comparative lifetime data for $E2$ transitions in even-even nuclei with neutron number 110 to 140. The transition energy is given in parentheses. The comparative lifetime is defined as $\log_{10}\{\tau_\gamma A^{4/3}E^5\}$ where $\tau_\gamma$ is the $\gamma$-ray lifetime in sec, $A$ the mass number, and $E$ the transition energy in MeV.

TABLE I. Comparison of the 46.7- and 246-keV $\gamma$-ray transition probabilities with the Weisskopf single-particle estimate for $E2$ transitions

| Transition | $T_{1/2}$(sec)[a] | $\alpha_t$[b] | $\tau_\gamma$(sec) | $P_{sp}$(sec$^{-1}$)[c] | $P_{obs}$(sec$^{-1}$) | $P_{obs}/P_{sp}$ |
|---|---|---|---|---|---|---|
| 46.7 | $(29\pm6)\times10^{-9}$ | 339 | $1.40\times10^{-5}$ | $2.4\times10^{4}$ | $7.0\times10^{4}$ | 2.9 |
| 246 | $(1.8\pm0.2)\times10^{-9}$ | 0.235 | $3.20\times10^{-9}$ | $9.8\times10^{7}$ | $3.1\times10^{8}$ | 3.2 |

[a] Half-life of level from which transition proceeds.
[b] Theoretical $E2$ total internal conversion coefficients obtained from reference 7.
[c] Evaluated using a nuclear radius of $1.25\times10^{-13}A^{1/3}$ cm.

yielding a value of 38±5 nsec. The observed transition probability ($P_{obs}$) for the 46.7-keV $\gamma$-ray transition then would be $5.3\times10^4$ sec$^{-1}$ and $P_{obs}/P_{sp}$ would be 2.4. This revised half-life value does not change the value of the 1.8±0.2 nsec half-life obtained from the data shown in Fig. 1(A).

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# Polarization and Angular Distribution Measurements on the Neutrons from the $Be^9(p,n)B^9$ Reaction*

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The polarization of the neutrons from the $Be^9(p,n)B^9$ reaction has been measured for laboratory emission angles of 30°, 50°, 70°, and 90°, for proton bombarding energies of 2.4, 2.75, 3.35, and 3.7 MeV. Angular distributions of the neutrons from this reaction have also been measured for nine proton bombarding energies between 2.5 and 4.1 MeV. For the polarization measurements, neutrons were scattered from analyzers of magnesium, oxygen, and carbon, and the asymmetries in the scattering were measured with the aid of an electromagnet which could rotate the polarization vector of the neutrons between the source and the scatterer. In detecting the neutrons, energy discrimination was employed to eliminate the effect of the three-body-breakup neutrons. The polarization is very small at 2.4 MeV, and at the higher energies is positive (Basel convention) at 30°, small at 50°, and negative at 70° and 90°. The largest value of the polarization found was 0.29±0.04 at an emission angle of 30° and a bombarding energy of 3.7 MeV. Above 3.0-MeV proton energy the angular distributions show a broad maximum in the backward direction. Calculations of the cross section and polarization were made assuming the reaction involves only three levels in the compound nucleus. Although partially successful in reproducing the polarization data, these calculations were unable to reproduce the measured cross sections.

## INTRODUCTION

PREVIOUS studies[1–5] of the $Be^9(p,n)B^9$ reaction indicate that there are resonances in the neutron yield at bombarding energies of 2.56, 3.5, and 4.6 MeV, corresponding to levels in $B^{10}$ at excitation energies of 8.89, 9.7, and 10.7 MeV, respectively. The angular distribution data of Marion,[5] taken with a long counter, suggest that the two higher energy states are of opposite parity. Using isotopic spin considerations, Marion[5] and Marion and Levin[6] assigned spin and parity values of $3^+$, $2^+$, and $3^-$ to these levels in $B^{10}$. Recently Altman *et al.*[7] have concluded that the 8.89 MeV level is more probably $3^-$. Using a long counter, Albert *et al.*[8] have measured the angular distribution of neutrons from both the $Be^9(p,n)B^9$ and the $B^{11}(p,n)C^{11}$ reactions. From a comparison of the results for the two reactions they conclude that these reactions very likely proceed largely through a direct interaction.

The measurements of Marion and Levin[6] on the spectra of neutrons from the proton bombardment of

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