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ABSTRACT

Isomeric states in the 3 to 500 nanosecond range have been measured by a new method depending on the fast timing properties of Ge(Li) detectors and the small time spread of beam bunches in a sector-focussed cyclotron. New isomeric transitions are reported in ^{208}Po and ^{210}Po.

Studies of gamma-ray spectra following (particle, xn) reactions have provided much information on low-lying nuclear levels[1)] and by using pulsed beams the life-times of many isomers have been measured in the $\gtrsim 1$ msec range[2,3)] and the $\gtrsim 5$ μsec range[4,5)]. The extension of time measurements down to a few nanoseconds greatly extends the range of nuclear isomers that can be easily identified and enables higher energy transitions and lower multipole transitions to be measured.

In this letter we report some results obtained by a simple method of measuring the half-lives of isomeric transitions in the 3 to 500 nsec region populated in nuclear reactions. The method depends on the fast timing properties of Ge(Li) detectors and the small time spread of the beam bunches in a

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sector-focussed cyclotron. The cyclotron r. f. oscillator is used to generate a zero time signal associated with a beam bunch and the energy and time distribution of γ-rays produced in a target are measured with a Ge(Li) γ-ray spectrometer. The time and energy spectra are recorded simultaneously in a two-dimensional analyzer. Details of the electronics used for timing will be discussed elsewhere. The beam characteristics of the cyclotron set a lower limit on the half-life that can be easily measured and an upper limit on the time range that can be studied with this technique. The analyzed beam bunch from the Berkeley 88" cyclotron has a time spread of ~ 4 nsec (FWHM) and a repetition period of ~ 100 - 170 nsec.

Figure 1 shows part of the two-dimensional γ-ray spectrum observed in the $^{208}Pb(\alpha, 4n)^{208}Po$ reaction with a 2 cm^2 × 5 mm deep thin window Ge(Li) detector. The analyzer was operated with 256 channels for energy analysis and 16 channels for time analysis. The 145 keV peak and several other peaks observed in the prompt spectrum decay very rapidly and give the prompt time distribution curves at these energies. The 147 keV transition decays more slowly with a half-life of 8 ± 2 nsec. The 176 keV transition has a prompt component and a very long-lived component with a half-life of 400 ± 70 nsec. The prompt component arises from direct feeding in the reaction and the delayed component from an isomeric transition preceding the transition under study. The high energy region of the γ-ray spectrum was studied in a similar manner with a 5 cm^2 × 13 mm deep Ge(Li) detector. The time distributions for the 660 keV and 685 keV transitions showed a prompt component and a delayed component of 390 ± 90 nsec.

We have also studied levels in ^{210}Po, populated in the ^{208}Pb(α, 2n)^{210}Po reaction. Previously levels up to the 6+ member of the ground state $(h_{9/2})^2$ configuration have been observed in the radioactive decay of ^{210}At. The 6+ level has a measured half-life of 38 nsec[6]. The 8+ member of this configuration is expected to be isomeric and to be highly populated in the (α, 2n) reaction. Figure 2 shows time distribution curves for some of the transitions observed. The 1180 keV 2+ $\rightarrow$ 0+ and 245 keV 4+ $\rightarrow$ 2+ transitions have a long-lived component as well as a prompt component. These transitions are also preceded by 38 nsec and 24 nsec isomers and so their decay curves are complex. The present results show the presence of a long-lived (~ 150 nsec) isomeric state above the 4+ level. This is tentatively assigned as the 8+ level although neither the 8+ $\rightarrow$ 6+ nor the 46 keV 6+ $\rightarrow$ 4+ transition was seen in the γ-ray spectrum because of their high internal conversion coefficients.

The 1292 keV transition shown in fig. 2 has a half-life of 24 ± 5 nsec and no appreciable prompt component. This indicates that it proceeds directly from an isomeric level. To establish its position in the level scheme, γ-γ coincidence experiments would be necessary, and this was not practicable with the experimental arrangement used. However, since there is no other transition of similar half-life, it probably feeds the 8+ state. The measured half-life (24 nsec) is close to the single-proton estimate for E3 (71 nsec), and so, the transition is tentatively assigned as an E3 transition from an 11- level to the 8+ level. This is consistent with the shell model calculation of Kim and Rasmussen[7] who predict that the lowest level of the $h_{9/2}i_{13/2}$ configuration around 3 MeV excitation energy will be the 11- level. However, their theoretical E3 transition probability between the pure shell configurations,

$(h_{9/2}i_{13/2})_{11-}$ and $(h_{9/2})^2_{8+}$, is 150 times less than the present experimental value. This may indicate a contribution due to octupole excitation of the core. A tentative level scheme for ^{210}Po, based partly on the theoretical prediction, is also given in fig. 2.

The method discussed above has been used to survey the reactions $^{206,208}Pb(\alpha, xn)^{206-210}Po$ and $^{110-116}Cd(\alpha, 2n)^{112-118}Sn$. Several previously unknown isomers have been observed and a detailed report will be prepared shortly.

Several measurements of a similar type can be made by using this method. One obvious extension is to study conversion electrons with an electron spectrometer and study their time distribution relative to the cyclotron beam pulse. This could be useful for studying the isomeric transitions directly as these often have high internal conversion coefficients and are not observed in the γ-ray spectrum. Another application depends on the fact that the nuclear states formed in (particle, xn) reactions are often highly aligned. By studying the time-dependent angular distributions of the γ-rays it is possible to examine the time dependence of the alignments of the isomeric states, and other problems associated with extra-nuclear fields.

We would like to express thanks to Dr. F. S. Goulding and Mr. D. A. Landis for their assistance with the electronic system, to Drs. B. G. Harvey, D. L. Hendrie and others at the 88" cyclotron for their support and to Dr. S. G. Prussin for his assistance. One of us (T. Y.) is grateful for the receipt of the Miller Research Fellowship. The other (G. T. E.) would like to thank Drs. I. Perlman and J. O. Rasmussen for their kind hospitality during his visit.

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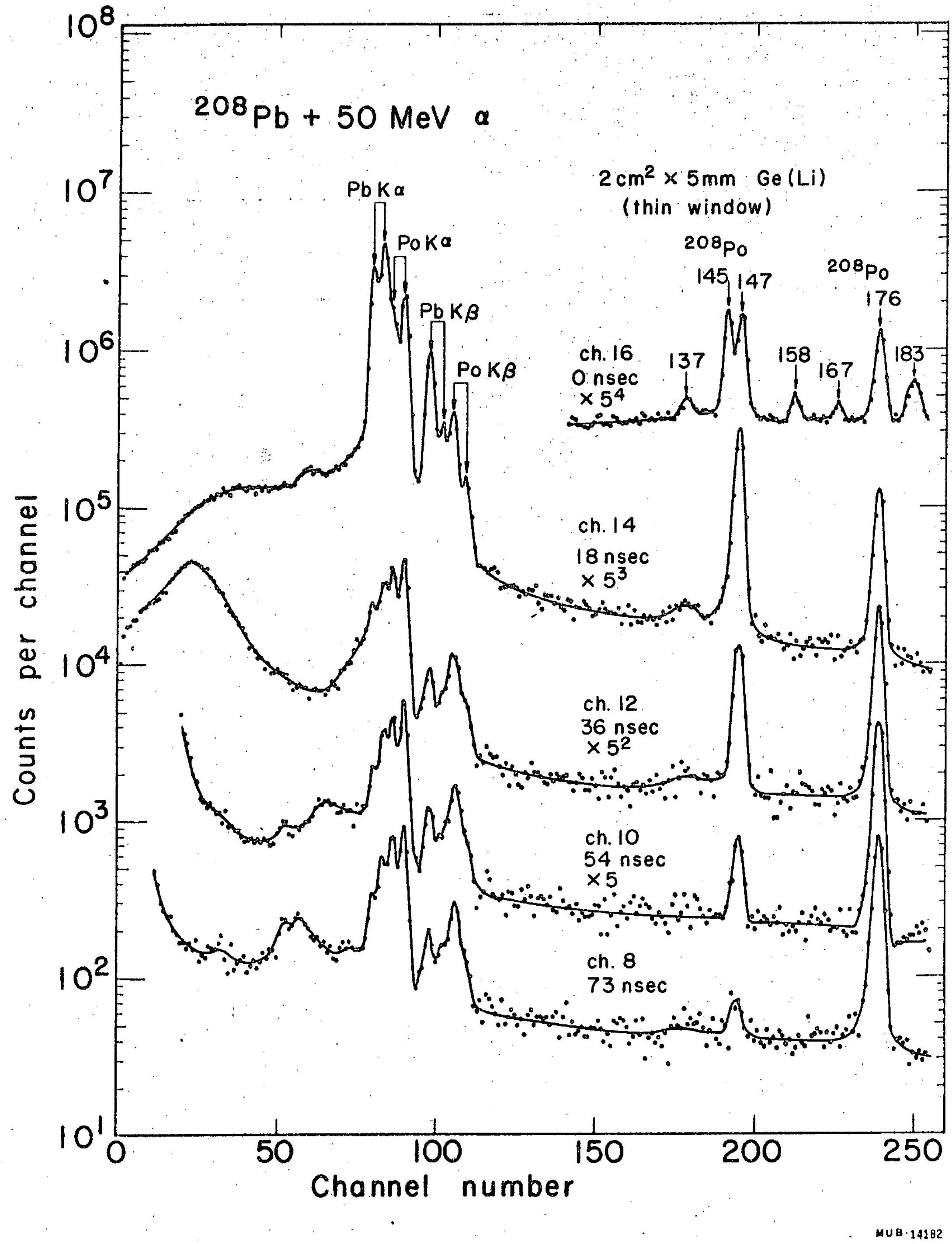
Figure Captions

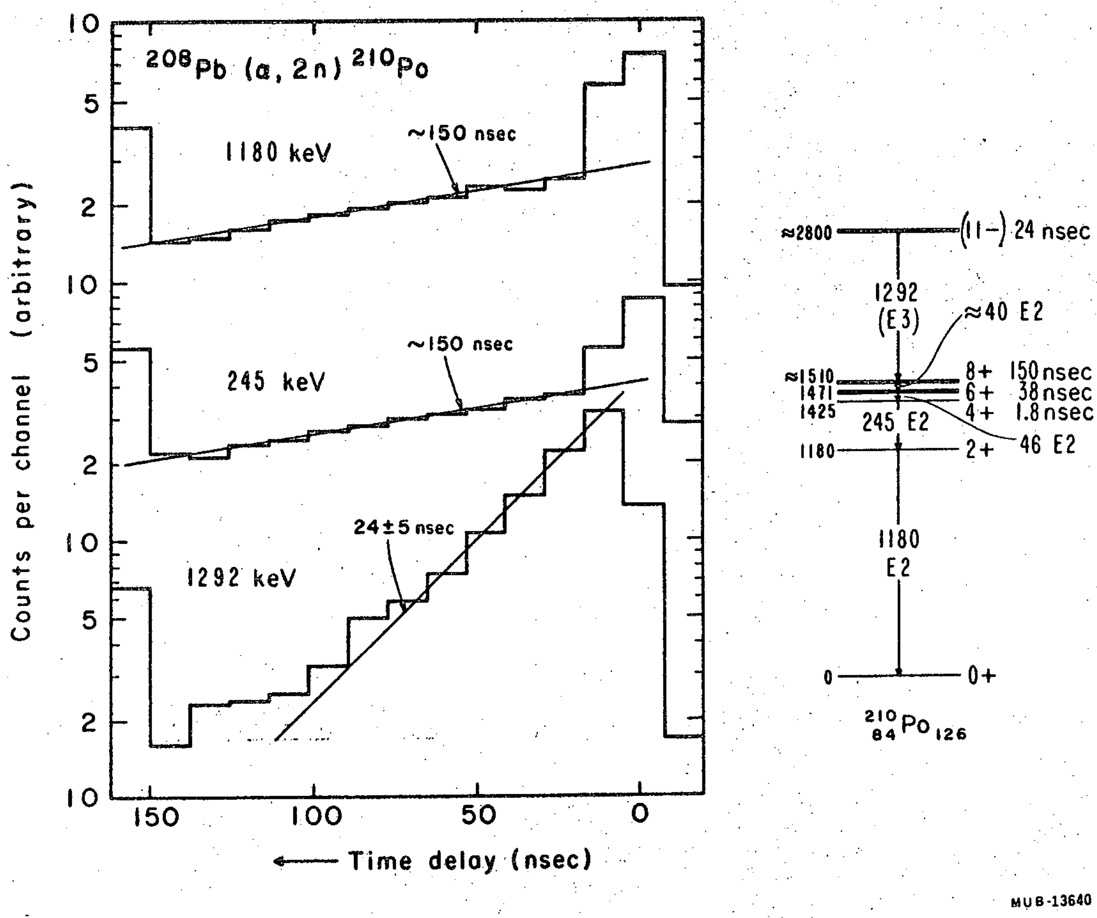
Fig. 1. Part of the 256 channel (energy) × 16 channel (time) spectrum observed in the $^{208}Pb(\alpha, 4n)^{208}Po$ reaction at 50 MeV. This data was obtained with a 2 cm^2 × 5 mm thick thin-window Ge(Li) detector. The 147 keV and 176 keV γ-rays have delayed components with $t_{1/2} = 8 \pm 2$ nsec and $t_{1/2} \sim 400$ nsec, respectively.

Fig. 2. To the left are shown the time distribution curves of three transitions observed in the reaction $^{208}Pb(\alpha, 2n)^{210}Po$ at 28 MeV. To the right is shown a tentative level scheme for ^{210}Po. The 1292 keV transition has been assigned E3 multipolarity on basis of its half-life. Its location has not definitely been established but is based on a theoretical prediction[7].



^{208}Pb + 50 MeV α
2 cm² × 5mm Ge(Li)
(thin window)
Pb Kα
Po Kα
Pb Kβ
Po Kβ
208Po
145
147
208Po
176
137
158
167
183
ch. 16
0 nsec
× 5⁴
ch. 14
18 nsec
× 5³
ch. 12
36 nsec
× 5²
ch. 10
54 nsec
× 5
ch. 8
73 nsec
Counts per channel
Channel number
MUB-14182

Fig. 1.



$^{208}Pb(\alpha,2n)^{210}Po$
1180 keV
~150 nsec
245 keV
~150 nsec
1292 keV
24±5 nsec
Counts per channel (arbitrary)
Time delay (nsec)
≈2800
(11−) 24 nsec
1292
(E3)
≈40 E2
≈1510
1471
1425
8+ 150 nsec
6+ 38 nsec
4+ 1.8 nsec
245 E2
1180
2+
46 E2
1180
E2
0
0+
$^{210}_{84}Po_{126}$
MUB-13640

Fig. 2.