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Abstract:

A 100 nsec isomer was found in ^{209}Po. The angular distribution of delayed γ-rays have been studied in the pulsed generation of this isomer in (α,xn) reactions with the use of cyclotron beam bursts. With a metallic lead target no perturbation of the angular distribution during approximately one half life could be detected. The g-factor of the isomeric state was determined to be $g = +0.88 \pm 0.05$, which supports an interpretation of this isomer as the 17/2- three-particle state.

A recently developed method[1)] of nanosecond time analysis of γ-rays emitted in (particle, xn) reactions, utilizing natural beam bunches of a cyclotron and fast time characteristics of a Ge (Li)-detector, has revealed the presence of a number of high-spin isomers which were hitherto unknown. Due to the large angular momentum transfer such states are at t=0 highly aligned perpendicularly to the beam direction[2)3)]. This fact can be used to investigate hyperfine interactions in these isomeric levels.

So far, hyperfine interactions of nuclear excited states have mainly been studied by means of perturbed angular correlations (PAC)[4)] which involves successive radiations through an intermediate state with a half-life of less than 10^{-6} sec. The use of nuclear reactions to form aligned states is a natural extension of the PAC method. In principle, there are two possibilities: one can either study the time variation of the alignment by measuring the time-differential angular distribution, or one can destroy the alignment by inducing nuclear magnetic resonance transitions and observing the resonance frequencies. Here, we report on a time-differential observation of a perturbed angular distribution following the pulsed generation of an aligned isomeric state in ^{209}Po.

Compared to PAC following radioactive decay (which is, for $T_{\frac{1}{2}} \gtrsim 10^{-7}$ sec, limited by the choice of sources to only a very few cases) in-beam measurements of perturbed angular distributions (PAD) offer the following advantages: 1) By choosing the proper target and beam energy a large variety of new isomers can be reached. Since (particle, xn) reactions populate any isomeric state if it exists at all, the present method maximizes the use of existing isomers. Especially very high spin states can be studied. 2) A large alignment is formed at t=0 and can be observed without measuring reemitted particles or preceding γ-transitions in coincidence with the delayed γ-radiation. This permits the use of only one detector at an angle with respect to the beam. Furthermore, we do not lose yield by making time analysis, and therefore PAD counting rates can be made as fast as normal singles counting rates. 3) Large recoil energies are available and can be used to implant the product nuclei into different host environments. 4) For timing measurements a sufficiently sharp time width of the individual beam bursts (2-4 nsec FWHM) ensures measurement of the time-differential PAD with a time resolution of typically a few nanoseconds. This is comparable to the resolution achieved with conventional fast electronics and solid state detectors.[1)]

In the following we shall describe such measurements with the $^{207(208)}$Pb(α,2(3)n)^{209}Po reaction. The Berkeley 88-inch sector-focused cyclotron was used. The block diagram of the electronic system was similar to the one used in ref.1 for time analysis. A Ge(Li)-detector was set to detect γ-rays from a target at any angle between 20 and 160 degrees. The fast signal from the preamplifier was amplified and discriminated to generate the "start" signal for the time-to-amplitude converter, while every second or third signal from the cyclotron RF-oscillator served as a "stop" signal. In this way, time distributions as shown, for example, in Figs.2 and 3 were recorded. The output of the time-to-amplitude converter as well as the energy signal were fed into a two-dimensional analyser. The phase drift of the RF signal with respect to real zero time of each beam burst, which would cause a serious shift of the time spectrum, was artificially compensated by using a digital base-line stabilizer.

The goal of our measurements was twofold. First, a suitable target structure had to be found in which any nuclear relaxation time was comparable to or longer than the half life of the isomeric state. Second, after being able to preserve the alignment for sufficiently long time a determination of the g-factor of the 100 nsec state in ^{209}Po was planned. As has been discussed elsewhere[5)] a diamagnetic metallic cubic target is most advantageous as long as half lives are concerned that are shorter than typical nuclear relaxation time ($T_1T \sim 10^{-2}$ sec °K for heavy elements). Thus a thick target of metallic lead seemed to be a perfect choice for the reaction Pb(α,xn)Po. No static quadrupole interaction is expected since in a thick lead target the product nuclei will be stopped ultimately at a site of cubic symmetry. It is not known whether there occurs any time-dependent interaction in connection with the slowing-down and stopping mechanism in thick targets as, in general, the available information on perturbations of angular distributions following nuclear reactions is very scarce. For this reason we found it important to measure the anisotropy as a function of time and to determine how long the nuclear alignment is preserved.

The 100 nsec isomeric state of ^{209}Po was discovered when searching for isomers at the beginning of these experiments. Two delayed γ-rays of 545 and 782 keV are emitted in the decay of the isomeric state (see Fig.1) but neither of them is the isomeric transition itself because of the presence of a prompt component. Fig.1b shows a tentative level scheme which was obtained by comparison with the ^{210}Po and ^{207}Pb levels[6]. One can understand this level structure in terms of the $(h_{9/2}(p))^2 J_p$ states appearing in ^{210}Po[1)7)8)] coupled to the $p_{\frac{1}{2}}$ neutron hole. The residual interaction between proton and neutron makes this sequence $(I=J_p+\frac{1}{2})$ energetically favourable.

First, we measured the angular distribution of the 545 and 782 keV γ-rays in the $^{208}Pb(\alpha,3n)^{209}Po$ reaction at E_α=40 MeV. Only the time-integrated portion outside the prompt region was taken into account. A 20 mg/cm^2 thick metallic ^{208}Pb foil was used as a target. Within the statistical error the angular distribution is identical for both γ-rays and the coefficients are

$$A_2 = 0.24 \pm 0.02, \qquad A_4 = 0.01 \pm 0.03$$

which is compatible with the E2 assignment in the proposed spin sequence (Fig.1b). This result indicated that the large alignment is preserved at least for the period of about one half life. A measurement of the time-differential angular distribution of the 545 keV γ-ray proved this indication. The quantities $N_0(t)$ and $A_2(t)$ of the time spectrum

$$I(\theta,t) = N_0(t)\,[\,1 + A_2(t)P_2(\cos\theta) + A_4(t)P_4(\cos\theta)]$$

are plotted in Fig.2. Within statistics the anisotropy is not attenuated. Any possible perturbation, if present at all, must be very weak; a lower limit of the relaxation time $1/\lambda_2$ is 350 nsec and indicated by the dashed line. Of course, from these data it is impossible to distinguish between a static or time-dependent perturbation. These questions must be left open for further investigation with sufficiently longer in-between-beam intervals, allowing longer time-ranges without additional effects originating from preceding beam bursts.

After it was clear that with a metallic lead target there was little or no attenuation of the alignment in the isomeric state, a spin rotation measurement was carried out in an external magnetic field. A 30 cm^3 Ge(Li)-detector was placed at 135 degrees with respect to the beam direction and a field of 2.76 kG was applied perpendicular to the beam-detector plane. In this case the target was enriched metallic ^{207}Pb. Fig.3 displays the time distributions of the 782 keV γ-ray in the $^{207}Pb(\alpha,2n)^{209}Po$ reaction at E_α=30 MeV with magnetic field up and down. Since it was established before that $A_4 \approx 0$, the normalized difference, plotted in the lower part of Fig.3, was fitted by a function $A \cdot \sin(2\omega_L t - \varphi)$. The fit yielded a Larmor precession frequency of ω_L=11.6±0.7 MHz which gives with an external field of 2.760 kG

$$g = 0.88 \pm 0.05$$

This g-factor is extremely far off the Schmidt limits: -0.22 and 0.20 for an odd-neutron state of 17/2 spin. This fact strongly supports that this 100 nsec state is not a single-particle state at all but the three-particle state, as indicated in Fig.1b. The g-factor can, then, be expressed in terms of the known g-factors of the ^{209}Bi and ^{207}Pb ground states in the following way

$$g[(h_{9/2}(p))^2 J_p\,,\ j_n = 1/2\ ;\ I = J_p + 1/2\,,\ ^{209}Po]$$

$$= \frac{2I-1}{2I}\, g(9/2-,\ ^{209}Bi) + \frac{1}{2I}\, g(1/2-,\ ^{207}Pb)$$

$$= \begin{cases} 0.923 & \text{for } I = 17/2- \\ 0.928 & \text{for } I = 13/2- \end{cases}$$

The contribution of the neutron hole is almost negligible. The present experimental value agrees well with this prediction but, as for the 9/2- ground state of ^{209}Bi, it deviates seriously from the single-particle estimate. The g-factor of the 8+ state of ^{210}Po was investigated in the same way and a preliminary result was reported elsewhere[7)8)]. These two results have demonstrated that the anomalous magnetism of the isomeric states in ^{209}Po and ^{210}Po must be ascribed to the same origin as in ^{209}Bi, i.e., to magnetic core polarization of the $h_{9/2}$ proton.[9)]

As to the method, it was our intention to use the interesting case of ^{209}Po as an example to demonstrate the usefulness of this type of measurement. In view of the great number of existing isomers in the half-life range between 10^{-9} and 10^{-6} sec, and those which will undoubtedly be discovered in near future, we feel that this is a most promising way to study hyperfine interactions with a cyclotron beam. Such investigations must not only involve g-factor measurements but also studies of quadrupole interactions and relaxation phenomena.

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References

1) T. Yamazaki and G. T. Ewan, Phys. Letters. 24B, 278(1967); Nucl. Instr. Methods, in press

2) H. Ejiri, M. Ishihara, M. Sakai, K. Katori and T. Inamura, Phys. Letters 18, 314(1965)

3) R. M. Diamond, E. Matthias, J. O. Newton and F. S. Stephens, Phys. Rev. Letters 16, 1205(1966)

4) See, for instance, H. Frauenfelder and R. M. Steffen, in "Alpha-, Beta- and Gamma- Ray Spectroscopy" Vol.2, ed. K. Siegbahn (North-Holland Publishing Co;, 1965, Amsterdam) Chapter XIX, p.997

5) E. Matthias, in "Hyperfine Interaction in Matter" ed. A. J. Freeman and R. B. Frankel (Academic Press, New York, 1967) Chapter 13, p.595

6) The 13/2- state can also be an isomeric state, but we tentatively assign the upper level as the 100 nsec state. If such an isomer doublet is present, the decay curve of the 545 and 782 keV transitions must be complex, depending upon initial population of both isomers. This might be the reason why a different value of the half life, 130 nsec, is obtained in Fig.2. This ambiguity, however, does not affect the g-factor measurement, since the g-factors of both states are expected to be equal, as shown later.

7) T. Yamazaki, E. Matthias, S. G. Prussin, C. M. Lederer, J. M. Jaklevic and J. M. Hollander, Contribution to the International Conference on Nuclear Structure (September 1967, Tokyo)

8) T. Yamazaki, to be published in the Proceedings of the 1967 International School of Physics at Varenna

9) See, for instance, E. Bodenstedt and J. D. Rogers, in "Perturbed Angular Correlations" ed. E. Karlsson, E. Matthias and K. Siegbahn (North-Holland Publishing Co., 1964, Amsterdam) Chapter II, p. 93

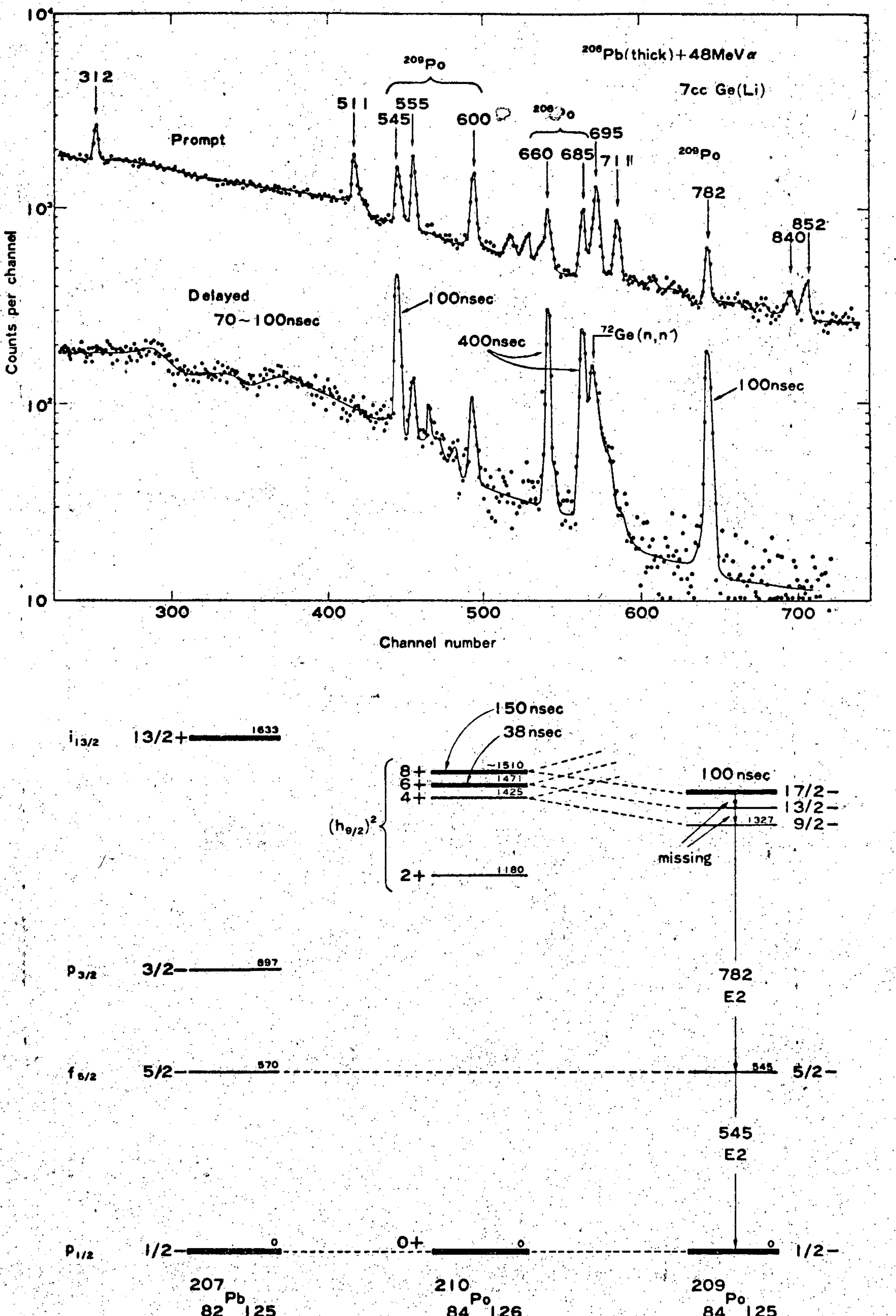
Figure Captions:

Fig.1 Upper part(a): Example of prompt and delayed γ-ray spectra in the $^{208}Pb(\alpha, 4(3)n)^{208(209)}Po$ reactions, where a thick target (50 mg/cm^2) was bombarded with 48-MeV α-beam.

Lower part(b): Proposed level scheme of ^{209}Po in comparison with related levels in ^{207}Pb and ^{210}Po.

Fig.2 Time-differential angular distribution of the 782 keV γ-rays of ^{209}Po to check for perturbations in the target. The quantities $N_0(t)$ and $A_2(t)$ are defined in the text.

Fig.3 Time spectra of the 782 keV γ-radiation of ^{209}Po in the presence of an external magnetic field. The data were taken for opposite field directions and show the opposite direction of the Larmor precession. Normalized differences are plotted in the lower part of the figure including the result of a least squares fit (solid line).



²⁰⁸Pb(thick)+48MeV α
7cc Ge(Li)
209Po
Prompt
312
511
545
555
600
208Po
660
685
695
711
209Po
782
840
852
Delayed
70 ~ 100nsec
100nsec
400nsec
72Ge(n,n')
100nsec
Counts per channel
Channel number
10
300
400
500
600
700
150 nsec
38 nsec
i13/2
13/2+
1633
8+
6+
4+
1510
1471
1425
(h9/2)²
2+
1180
100 nsec
17/2−
13/2−
9/2−
1327
missing
p3/2
3/2−
897
782
E2
f5/2
5/2−
570
545
5/2−
545
E2
p1/2
1/2−
0
0+
0
0
1/2−
207 82 Pb 125
210 84 Po 126
209 84 Po 125

Fig. 1