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A HIGHLY EXCITED ISOMER IN ^{200}Bi

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1. Introduction

In a recent study[1] a high spin isomeric state with $I^{\pi} = 16^{+}$ has been found in ^{204}Bi, which can be interpreted as one of the levels of the four-quasiparticle configuration $\nu(i_{13/2})^{-2}\nu(f_{5/2})^{-1}\pi(h_{9/2})^{1}$. This isomeric level is related to the 9^{-} state in the adjacent even-even core ^{202}Pb. The two-quasiparticle states with $I^{\pi} = 9^{-}, 7^{-}$ and 5^{-}, known in ^{202}Pb appear also[2,3] in the even-even lead isotopes $^{200,198,196,194}Pb$. Furthermore, the two-quasiparticle configuration $\nu(i_{13/2})^{-1}\pi(h_{9/2})^{1}$ has been found[4] in the doubly-odd nuclei ^{198}Bi and ^{200}Bi, where it forms isomeric states with $I^{\pi} = 10^{-}$. Similar isomeric four-particle states may, therefore, also be expected in these nuclei. In ^{200}Bi an isomeric state of 46 ns half-life has been observed[4], for which in the present paper a tentative level scheme is given. The results are compared with the shell-model calculations.

2. Experimental Method and Results

The experimental arrangement has already been described[5]. A newly installed beam tube led to a considerably lower back-ground level for in-beam γ-ray studies. The nanosecond beam bunching of the U-300 cyclotron with a period duration of 238 ns for $^{12}C^{2+}$ ions has been used to measure two-dimensional energy-time spectra. The γ-rays have been recorded in the energy range from 100 keV to 1.5 MeV. Figure 1 shows a part of the two-dimensional energy-time spectrum recorded with a Ge(Li) planar detector (1.4 cm^2 x x 1.1 cm), the resolution being 2.8 keV at 300 keV. A 7.7 mg cm^{-2} ^{193}Ir target (enriched to 98%) was bombarded with 81 MeV ^{12}C ions. Four prominent ns-delayed transitions with energies of 253.0 keV, 286.1 keV, 630.3 keV and 644.2 keV were observed. As found from this spectrum, these lines decay within the experimental errors with the same half-life (fig. 2). The average half-life amounts to $T_{1/2}$ = 46 ± 4 ns. The 197.5 keV line of ^{19}F with 87 ns half-life, which is always present in our spectra, is a good check for the accuracy of the half-life determination. For the 253.2 keV transition no prompt component is found (fig. 2), which suggests the assumption that this transition de-excites the isomeric level directly. Apart from the four strong γ-transitions, four other lines with similar half-lifes were found, namely 149 keV, 389.3 keV, 615.5 keV and 930 keV (fig. 3). The energy values given in figures 1-4 are computer fits from a single prompt spectrum. The accuracy of the energy determination amounts to ± 0.5 keV. For the 149 and 389.3 keV lines it is, however, poorer and the actual error seems to be about ± 1.5 keV. This is due to the fact that both these lines contain significant unresolved admixtures of prompt transitions of somewhat lower energies. It follows from our measurements that the 615.5 keV line tends to a somewhat larger half-life whereas the half-life of the 149 keV, 389.3 keV and 930 keV lines agree within quite large statistical errors with the half-life of the prominent lines 253.0 keV, 286.1 keV, 630.3 keV and 644.2 keV. The 630.3 keV line contains an admixture of the 629.1 keV line of ^{201m}Pb, populated in the ground-state decay of ^{201}Bi. We regard this admixture by substraction of the long-lived background in the ns-delayed spectra. A contribution of about 10% from the 629.1 keV transition was found.

Figure 4 shows the relative intensities of the four prominent γ-transitions as a function of the incident carbon-beam energy. The intensity values were normalized with the intensity of the 428.2 keV transitions which de-excites the 10^- two-quasiparticle state in ^{200}Bi. Apart from the 630.3 keV transition, every γ-transition shows an increase of its intensity with increasing beam energy and, therefore, favours spin values $I > 10$.

3. Discussion of the Decay Scheme

The intensities of the delayed lines ascribed to ^{200}Bi are given in table 1. The intensities calculated from the prompt part of the spectrum establish the sequence of the transitions as shown in the proposed scheme in fig. 5. In addition to the main cascade we included in the level scheme the weak 149 keV, 389.3 keV and 930 keV transitions, which results in a better intensity balance.

The half-life of the isomeric level corresponds to an $E2$ transition. Within the whole decay scheme we obtain for the transitions deexciting the 1988.8 keV level a reasonable intensity balance if we assume an $E1+M2$ multipole order of the 286.1 keV transition (see also the total conversion coefficients in table 2).

In fig. 5 the deexcitation cascade of the 46 ns state excites the 10^- two-quasiparticle isomer. If we, on the other hand, assume, that the cascase enters the ground state of ^{200}Bi, we should observe branching transitions of energies E_γ = 202.1 and 846.3 keV to the 10^- level, outgoing from the 630.3 and 1274.5 keV states, respectively. But such transitions are absent in our spectra.

The tentative spin assignments of the decay scheme are suggested by the spin ordering in the analogous isomeric decay of ^{204}Bi.

4. Shell-Model Calculations for ^{200}Bi

The level character of nuclei, which have only a few particles or holes outside the core of closed proton and neutron shells, is mainly determined by the residual pair-interaction /8,9/. The corresponding many-particle matrix elements can be calculated by making use of the Racah formalism /10/. In order to investigate the level structure of ^{200}Bi with 9 neutrons less than the magic number we calculated the matrix elements of residual pairing forces and the multiplet splitting for the configuration

$$\{\pi(1h_{9/2})^1 \nu(3p_{1/2})^{-1}\}_{J_{12}=5} \{\nu(1i_{13/2})^{-2}\}_{J_3=12} .$$

This configuration is related to the $[\nu(1i_{13/2})^{-1} \nu(3p_{1/2})^{-1}]_7$ level at 2142 keV in the adjacent core ^{198}Pb. For J_{12} and J_3 the maximum spin values 5^+ and 12^+, respectively, were taken into account in order to find the highest spin values for the lowest lying states of the multiplet. The matrix elements of the residual pairing interaction of Wigner and singlet type were calculated with oscillator wave functions. Figure 6 shows the dependence of the matrix elements of the total angular momentum of the system for a Wigner interaction. The calculations were performed for a Gaussian potential with a potential parameter $\lambda = r_0 (\nu_0/2)^{1/2} = 0.6$. As seen from this figure, the multiplet levels with $I^\pi = 15^+$, 14^+, 13^+ and 12^+ are pushed down and one of them, namely, the 15^+ level can be responsible for the observed isomerism in ^{200}Bi.

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Table 1
Intensities of delayed γ -rays ascribed to ^{200}Bi

E_γ (keV)	I_γ(%) delayed	I_γ (%) prompt
149	6 ± 3	...
253.0	55 ± 6	45
286.1	40 ± 3	63
389.3	18 ± 3	...
630.3	100	100
644.2	71 ± 4	80
930	15 ± 5	35

Table 2
Total conversion coefficients $\alpha_{tot} = \alpha_K + \alpha_L + \alpha_M$ for delayed γ-rays in ^{200}Bi according to Hager and Seltzer [6].

E_γ (keV)	M1	M2	E1	E2
149	3.40(0)	2.01(1)	1.68(-1)	1.21(0)
253	7.79(-1)	3.10(0)	4.50(-2)	2.03(-1)
286.1	5.59(-1)	2.10(0)	3.40(-2)	1.40(-1)
389.3	2.42(-1)	7.70(-1)	1.70(-2)	5.90(-2)
630.3	6.54(-2)	1.75(-1)	6.20(-3)	1.81(-2)
644.2	6.16(-2)	1.61(-1)	5.90(-3)	1.70(-2)

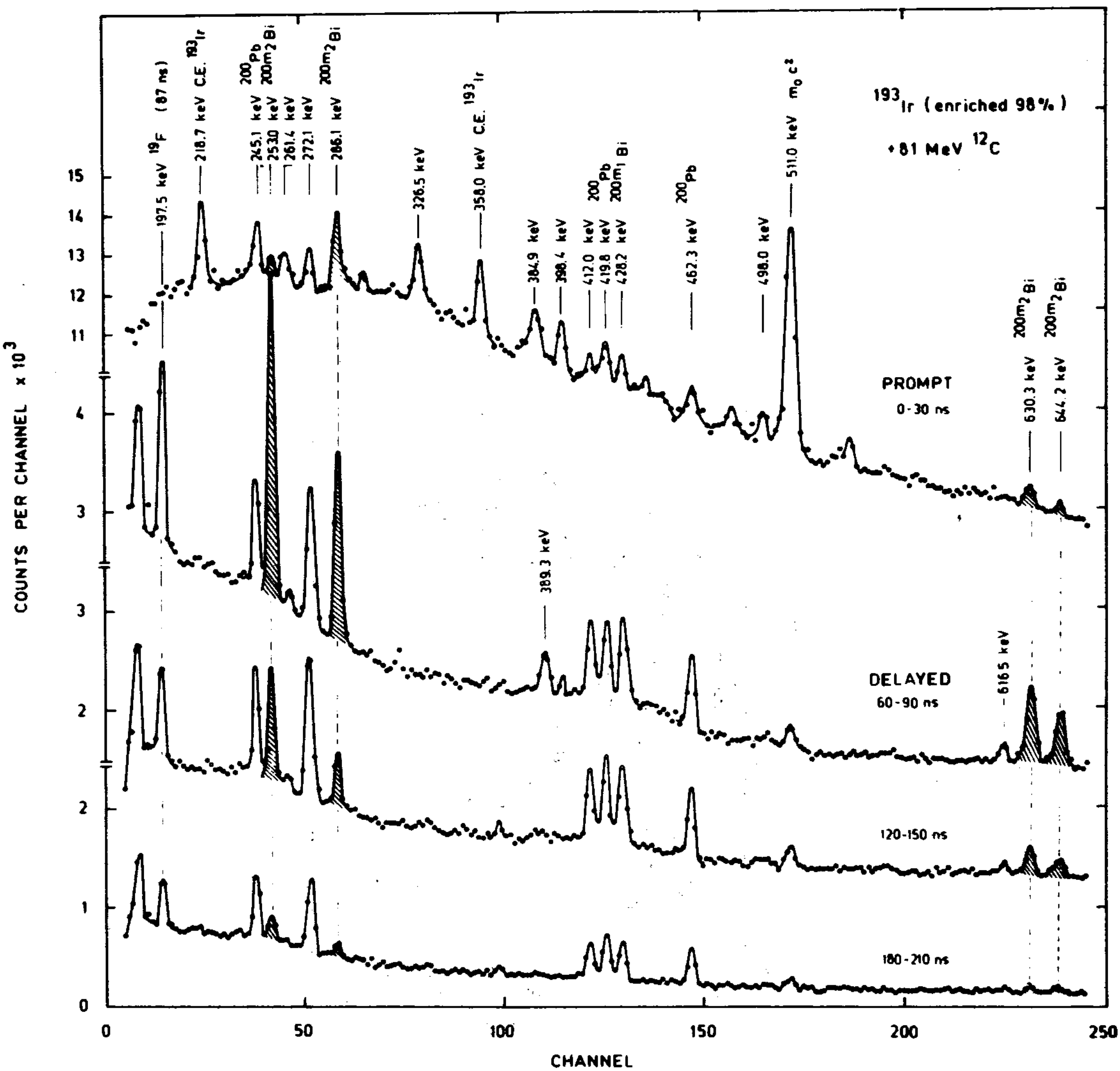


Fig. 1. Part of the two-dimensional energy-time spectrum obtained by bombardment of a 7.7 mg cm^{-2} ^{193}Ir target with 81 MeV ^{12}C ions.

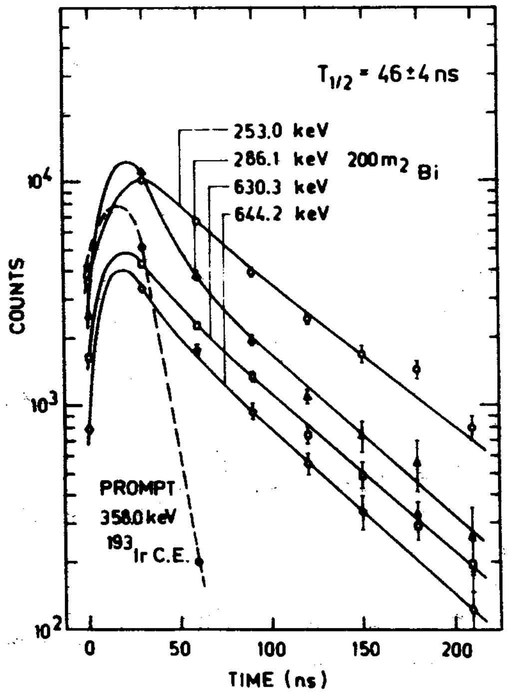
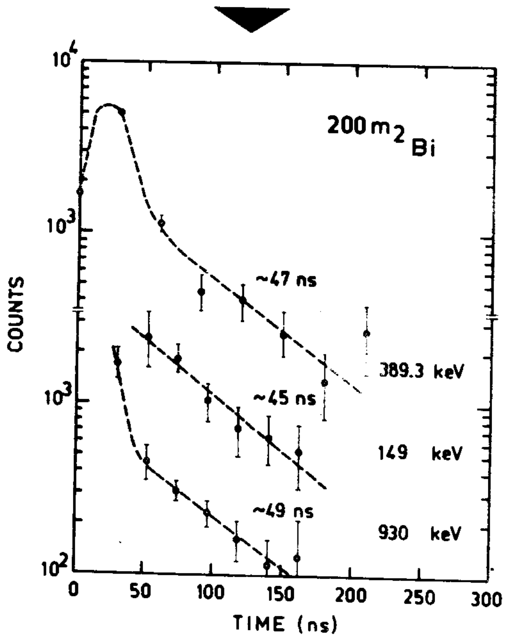


Fig. 2. Half-life curves for the strong transitions in ^{200}Bi. The prompt curve was derived from the Coulomb excited 358 keV transition in ^{193}Ir (see ref. /7/).

Fig. 3. Half-life curves for the weak transitions assigned to ^{200}Bi. The half-life curves for the 149 keV and 930 keV lines were taken from a separate measurement.



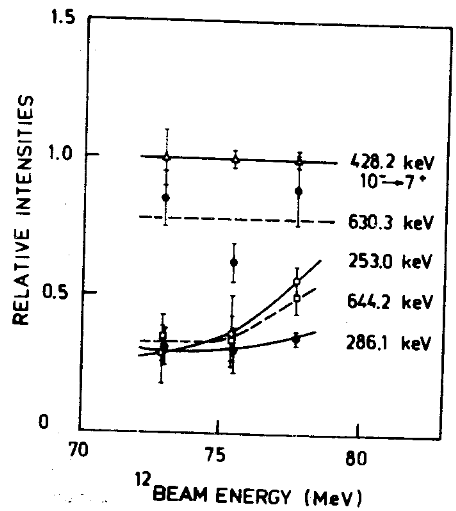


Fig. 4. Excitation functions of the 286.1, 253.0, 630.0 and 644.2 keV transitions relative to the 428.2 keV $10^- \rightarrow 7^+$ transition in ^{200}Bi derived from single prompt spectra at different incident energies.

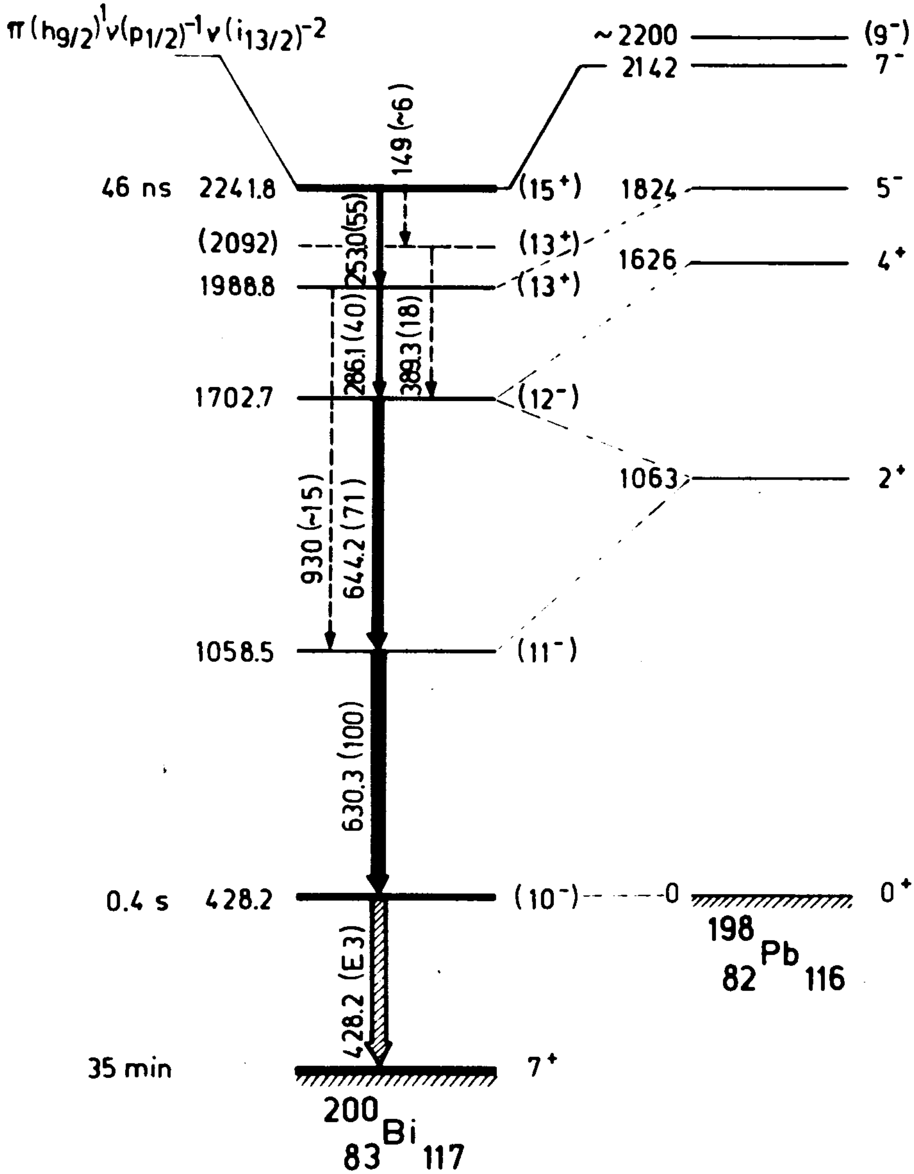


Fig. 5. Proposed decay scheme of the 46 ns isomeric state in ^{200}Bi.

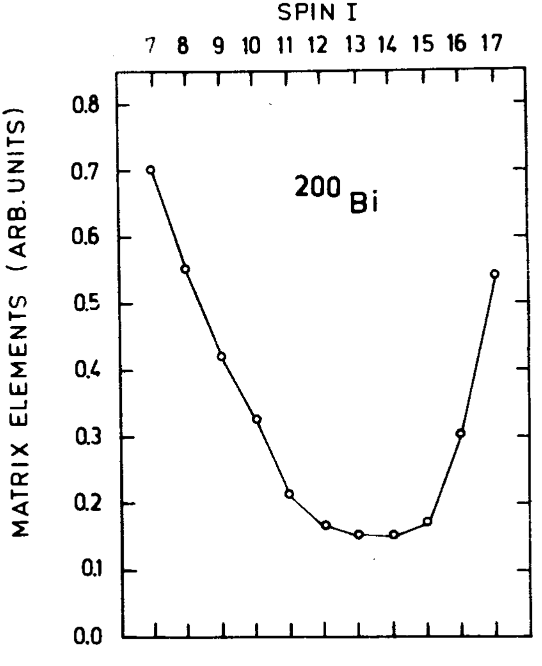


Fig. 6. Matrix elements of Wigner and singlet type residual interaction for the configuration $\pi(h_{9/2})^{1}\,\nu(p_{1/2})^{-1}\,\nu(i_{13/2})^{-2}$ versus the total angular momentum of the system.