LEVELS IN ^{194}Pb AND ^{196}Pb POPULATED IN THE DECAY OF ^{194}Bi AND ^{196}Bi

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The neutron-deficient ^{194}Bi and ^{196}Bi isotopes were produced in the ^{181}Ta (^{20}Ne,xn) and ^{181}Ta (^{22}Ne, xn) reactions. The half-lives of ^{194}Bi and ^{196}Bi were found to be $T_{1/2} = 2.0 \pm 0.3$ min and $T_{1/2} = 4.6 \pm 0.5$ min, respectively. The $\gamma-\gamma$ coincidence measurements were carried out. The excited level schemes in ^{194}Pb and ^{196}Pb are presented. The possible spins of the ground states in ^{194}Bi and ^{196}Bi are discussed.

1. *Introduction*

There are two reasons for which the study of the β-decay of light bismuth isotopes is interesting. In the first place it allows us to look into the excited level scheme of light lead isotopes, and secondly it provides information on the ground state of bismuth isotopes. The initial results of our investigation of the β-decay of ^{194}Bi and ^{196}Bi were already published in earlier reports [1, 2], in which the half-lives were given and provisional excited level schemes proposed. The excited levels in ^{194}Pb and ^{196}Pb are now known also from in-beam measurements of γ-rays from ^{194}Pb and ^{196}Pb nuclei produced in a reaction with heavy ions [3, 4]. The β-decay of heavier, even bismuth isotopes was studied by Hanser [5] and Pautrat et al. [6].

Our interest in the decay of ^{194}Bi and ^{196}Bi has been aroused by the results published in Ref. [7] which allowed us to expect high-spin isomeric levels in even, light bismuth nuclei. The β-decay of these levels may feed high-spin levels in lead nuclei, competing with γ- and α-emission.

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2. *Experimental*

The experiment was conducted on the external beam of a heavy-ion cyclotron U-300 at the Joint Institute of Nuclear Research in Dubna. The ^{194}Bi and ^{196}Bi isotopes were obtained in the reactions:

$^{181}Ta\,(^{20}Ne, 5n)\,^{196}Bi$ at a ^{20}Ne ion energy of 110 MeV,

$^{181}Ta\,(^{20}Ne, 7n)\,^{194}Bi$ at a ^{20}Ne ion energy of 145 MeV,

$^{181}Ta\,(^{22}Ne, 7n)\,^{196}Bi$ at a ^{22}Ne ion energy of 150 MeV,

$^{181}Ta\,(^{22}Ne, 9n)\,^{194}Bi$ at a ^{22}Ne ion energy of 175 MeV.

The self-supporting targets about 3 mg/cm^2 thick were prepared by rolling practically mono-isotopic tantalum foil. The targets were transported to the detection system within 2 min from irradiation. In view of the small intensity of the source and short half-life of the activities obtained, neither mass nor chemical separation were applied. The identification of the reaction products was performed on the basis of the yield variation of the particular bismuth isotopes and their decay products with varying energy of the bombarding heavy ions. The analysis of the half-lives and measurements of $\gamma-\gamma$ coincidences were of assistance in assigning the γ-lines to the particular bismuth isotopes.

Measurements of γ-spectra were performed by means of a Ge(Li) detector of 13 cm^3 volume and 4.5 keV resolution at an energy of 1.33 MeV. The coincidence measurements were carried out using a standard fast-slow coincidence system with a Ge(Li) detector of 13 cm^3 volume in one branch and a NaI(Tl) $2'' \times 2''$ counter in the other branch.

3. *Results*

3.1. The ^{194}Pb isotope

Table I presents the energies and relative intensities of γ-radiation connected with ^{194}Bi decay. The γ-spectrum is shown in Fig. 1, which also includes the γ-radiation coincidence spectrum with the 965 keV line, the strongest among the lines from ^{194}Pb. This measurement made it possible to ascertain that the lines given in Table I belong to the

TABLE I

Energies and intensities of the gamma transitions observed in the decay of ^{194}Bi

E_γ (keV)	I_γ (arbitrary units)
166.1 ± 0.3	46 ± 3
174.0 ± 0.3	28 ± 2
280.2 ± 0.3	70 ± 5
421 ± 1	55 ± 10
575.4 ± 0.5	87 ± 8
965.0 ± 0.5	100

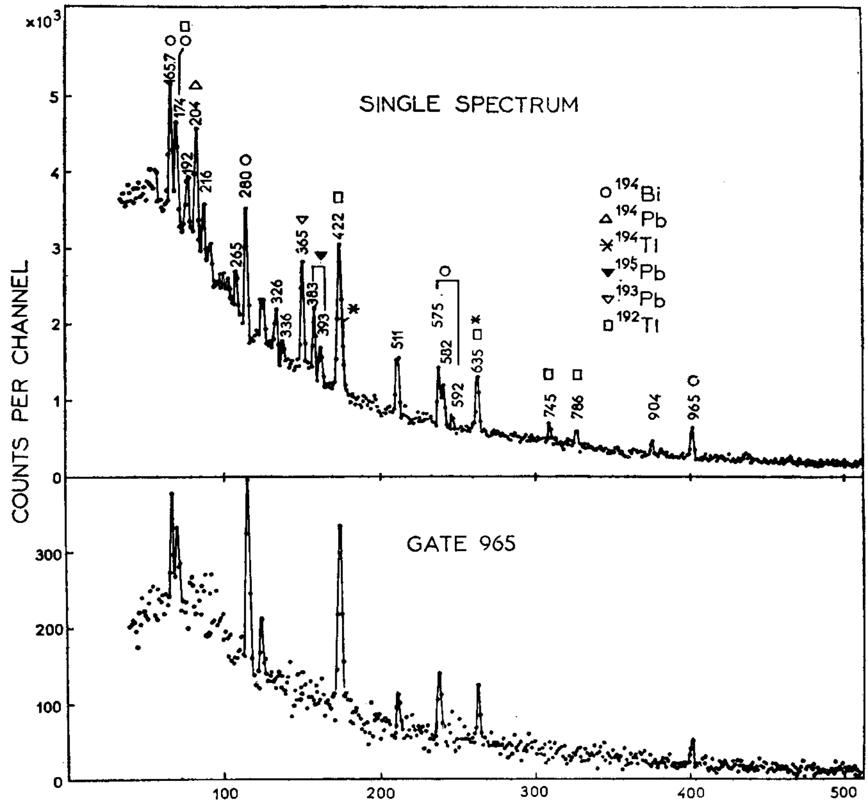

Fig. 1. Gamma spectrum of the ^{194}Bi decay. The symbols are used for lines belonging to contaminations. The low part of the figure shows the coincidence spectrum with gate set on the 965 keV peak

same isotope and provided confirmation of the proposed level scheme (Fig. 3). As it was already mentioned the activity of the samples was small, and therefore it was not possible to perform coincidence measurements for the weaker transitions.

The γ-transitions summarized in Table I have also been observed in Ref. [3], where the high-spin states in ^{194}Pb were produced in the ^{182}W(^{16}0,4n) ^{194}Pb and ^{185}Re (^{14}N, 5n) ^{194}Pb reactions. The spin values given in Fig. 3 have been taken from the latter publication.

The half-life of ^{194}Bi as measured by us in $T_{1/2} = 2.0 \pm 0.3$ min. Le Beyec et al. [8] obtained a value close to the latter when studying the α-decay of ^{194}Bi. This disagrees, however, with the value given by Tarantin [9].

3.2. The ^{196}Pb isotope

The γ-transitions observed in the ^{196}Bi decay, their energies and intensities are listed in Table II. In Fig. 2 we have the γ-spectrum and the coincidence spectra with the 688 keV and 1049 keV transitions. These data confirm the proposed level scheme for ^{196}Pb

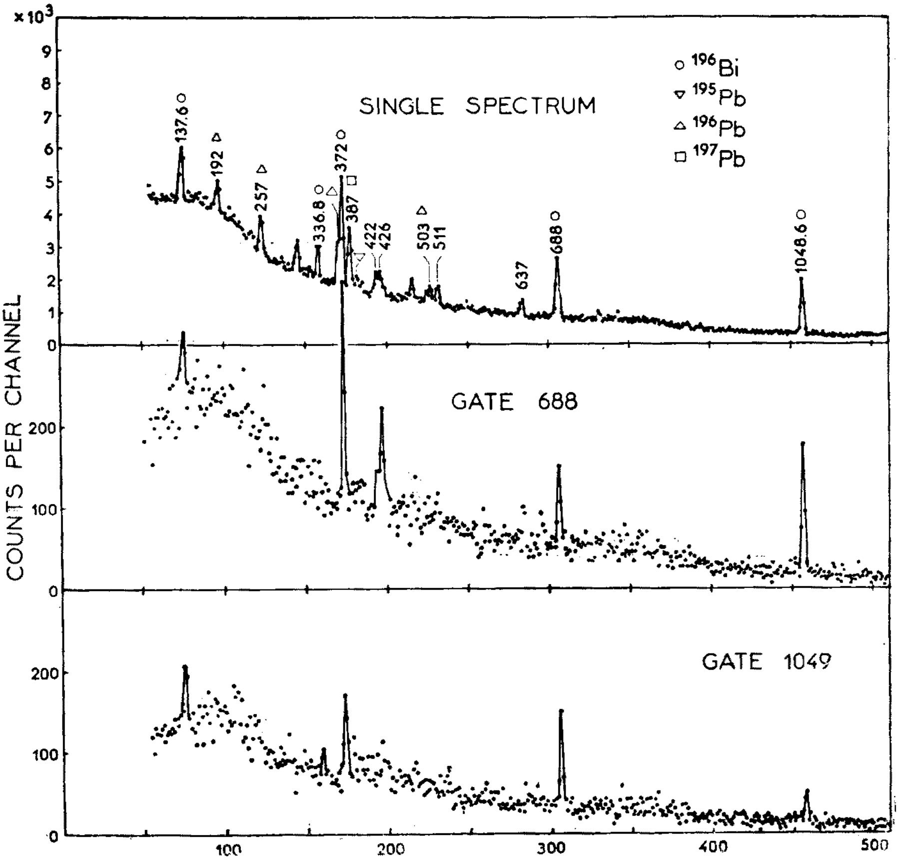

Fig. 2. Gamma spectrum of the ^{196}Bi decay. The symbols are used for lines belonging to contaminations. The low part of the figure shows the coincidence spectra with gates set on the 688 keV and 1049 keV peaks

TABLE II

Energies and intensities of the gamma transitions observed in the decay of ^{196}Bi

E_γ (keV)	I_γ (arbitrary units)
137.6±0.3	10±2
336.8±0.3	16±2
372.0±0.6	46±5
688.0±0.5	62±5
1048.6±0.5	100

(Fig. 3) in which all the transitions given in Table II proceed in cascade. The 59 keV transition was not observed by us, but has been placed in the scheme after Pautrat et al. [3]. In the latter work the high-spin states in ^{196}Pb were excited in the ^{188}Os (^{12}C, 4n) ^{196}Pb,

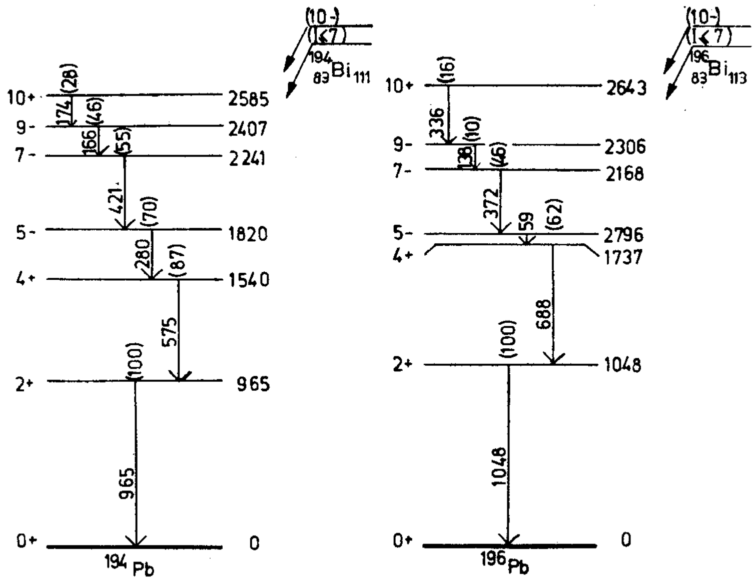

Fig. 3. The level schemes of ^{194}Pb and ^{196}Pb

^{187}Re (^{14}N, 5n) ^{196}Pb and ^{184}W (^{16}O, 4n) ^{196}Pb reactions. The spin values of the levels in ^{196}Pb given in Fig. 3 have also been taken from the above publication.

The half-life of ^{196}Bi as measured by us is $T_{1/2} = 4.6 \pm 0.5$ min.

4. Discussion

The ^{194}Pb and ^{196}Pb level schemes presented do not differ from those given in Refs [3, 4]. An interesting result of our experiment is the observation that high-spin up to $I = 10$ excited levels are fed in the β-decay.

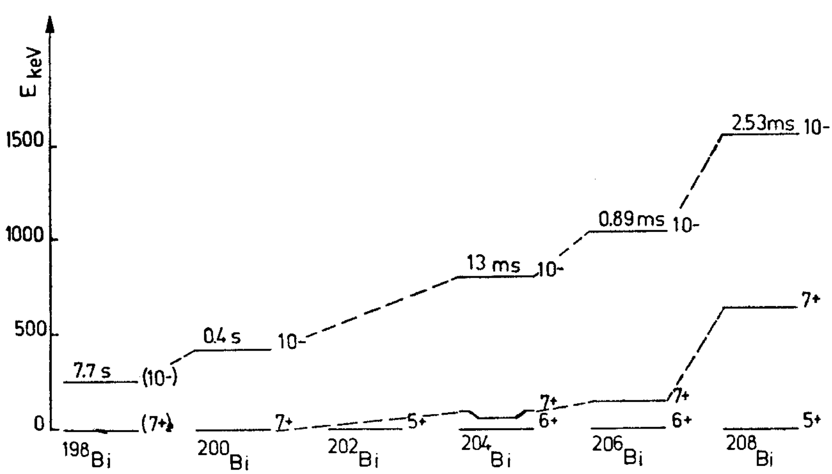

Fig. 4. Systematic of the 10$^-$ isomeric levels in odd Bi nuclei

If we assume in accordance with the shell model that in bismuth isotopes with $A < 197$ we encounter holes in the neutron orbit i 13/2 and the proton is in the h 9/2 state, it may be expected that the ^{194}Bi and ^{196}Bi ground states will have the $p(h\ 9/2)^1 n(i\ 13/2)^{-1}$ configuration. It follows from theoretical considerations [10] that in the case of a particle--hole configuration the spin of the lowest state has the value $I = I_{max} - 1$. Alford [11] showed that in ^{208}Bi the level with spin equal to 10^- is in fact the lowest one lying in the $p(h\ 9/2)^1\ n(i\ 13/2)^{-1}$ multiplet. In heavier even bismuth isotopes ($A = 198$ to 208) isomeric states exist [7] which have $I^\pi = 10^-$ and the above configuration, and their energy decreases systematically with the decreasing mass number. It may therefore be expected that the ground state spin in ^{194}Bi and ^{196}Bi will be $I^\pi = 10^-$. In this situation the existence of transitions to levels in ^{194}Pb and ^{196}Pb with $I^\pi = 10^+$ is not unexpected.

When summing up the transition intensities it may, however, be observed that in the β-decay levels with comparatively low spins are also fed. For instance this is the case with the $^{196}\text{Bi} \rightarrow {}^{196}\text{Pb}$ decay, where a β-transition to the levels with $I^\pi = 2^+$ and $I^\pi = 5^-$ must be assumed.

In these nuclei (at such a high spin of the ground state) isomeric states may be expected to appear with a relatively low spin, $I \leqslant 7$, which are the lowest levels of the $p(h\ 9/2)^1 n(f\ 5/2)^{-1}$ or $p(h\ 9/2)^1\ n(p\ 3/2)^{-1}$ multiplets. In the decay of such states, levels with low spins would be fed in ^{194}Pb and ^{196}Pb. However, our experiment did not allow us to ascertain this since the deficiencies in the intensity balance may be explained by the existence of unobserved weak transitions from high-lying levels.

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