СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E6 - 7289

A.Korman, D.Chlebowska, Z.Haratym,
T.Kempisty, Nguyen Tat To, S.Chojnacki

DECAY OF THE i13/2 ISOMERIC STATES IN THE ^{199}Po AND ^{201}Po ISOTOPES

1973

ЛАБОРАТОРИЯ ЯДЕРНЫХ РЕАКЦИЙ

E6 - 7289

A.Korman, D.Chlebowska, Z.Haratym,
T.Kempisty, Nguyen Tat To, S.Chojnacki

DECAY OF THE i13/2 ISOMERIC STATES IN THE ^{199}Po AND ^{201}Po ISOTOPES

Корман А., Хлебовска Д., Харатым З., Кэмписты Т., Нгуен Тат То, Хойнацки С.

E6- 7289

Распад изомерных состояний $i13/2$ в изотопах ^{199}Po и ^{201}Po.

Исследовались β^+-EC-распады изомерных состояний в изотопах ^{199}Po и ^{201}Po, полученных из реакции $Au(^{10}B,xn)^{199,201}Po$. В результате проведенных измерений простых γ-спектров, спектров γ-γ совпадений и спектров электронов внутренней конверсии предположены схемы распада изомерных состояний в этих изотопах. Экспериментальные данные сравнивались с результатами теоретических расчетов.

Сообщение Объединенного института ядерных исследований
Дубна, 1973

Korman A., Chlebowska D., Haratym Z., Kempisty T., Nguyen Tat To, Chojnacki S.

E6 - 7289

Decay of the $i13/2$ Isomeric States in the ^{199}Po and ^{201}Po Isotopes

The β^+-EC-decays of isomeric states in the $^{199,201}Po$ isotopes produced in the reaction $Au(^{10}B,xn)^{199,201}Po$ have been investigated. On the basis of the simple γ-spectra, γ-γ coincidence and conversion electron measurements the decay schemes of ^{199m}Po and ^{201m}Po isomeric states are presented. The experimental data and the results of theoretical calculations are compared.

Communications of the Joint Institute for Nuclear Research.
Dubna, 1973

Introduction

The investigation of bismuth isotopes in the neighbourhood of the double magic nucleus of ^{208}Pb is a good source of information on the nature of the effective nuclear forces inside nuclei. Owing to their proximity to the double magic nucleus of ^{208}Po, bismuth isotopes present a region of particular interest.

The higher mass isotopes situated not far from the double magic nucleus have been the subject of numerous studies. Nevertheless, very little is still known about the nuclear energy levels of the more neutron-deficient isotopes of bismuth.

Levels in $^{199,201}Bi$ isotopes may be populated by the electron-capture decay of the $^{199,201}Po$ isotopes. These isotopes have been identified in alpha decay studies by Tielsch-Cassel /1/ and Brun /2/. They have also established isomerism in $^{199,201}Po$. However, at the moment of the beginning of our investigation, the decay schemes of the $^{199,201}Po$ isotopes were unknown.

Siivola /3/ reported on isomerism in ^{201}Bi. Alpsten and Astner /4/ observed a strongly converted 846 keV gamma transition with a half-life of 50÷60 min, which they assigned to the decay of the ^{201m}Bi isomeric state.

Experimental Method

The radioactive sources were obtained by irradiating a golden target in the external beam of the U-300 heavy ion cyclotron of the JINR Laboratory of Nuclear Reactions, Dubna. The nuclei of $^{199,201}Po$ were produced in the reaction $^{197}Au(^{10}B, xn)^{207-x}Po$. After irradiation the samples without chemical separation were transported to the detector system.

Two Ge(Li) detectors, one a 13 cm^3 planar crystal detector with resolution of 2 keV (FWHM) at 122 keV under udeal conditions, and the other of 37 cm^3 in volume and resolution of 2.5 keV (FWHM), were used for the measurements of gamma rays. Low-noise commercially available amplifiers and associated electronic components, including a 4096-channel pulse height analyzer, were employed.

Gamma-gamma coincidence spectra have been obtained using a Ge(Li)-NaJ(Tl) set up. The electronics used were of the standard slow-fast coincidence type. A time-to-amplitude converter and a single-channel analyzer replaced the conventional slow-coincidence circuit. Time pick-up units were employed for fast coincidence measurements. A gamma-gamma coincidence regime was achieved by means of a $1\frac{1}{2} \times 2''$ NaJ(Tl) crystal as a gating detector, and the 37 cm^3 coaxial Ge(Li) detector for an analysis.

Conversion electron spectra were recorded using a 2.5 mm thick Si(Li) detector with an energy resolution of about 6 keV for all energies.

For the analysis of the gamma spectra a CDC-1604A computer was used. The computer programme fitted the peaks with a variable-width symmetrical Gaussian and used an exponential approximation for the background. The code employed contained many automatical possibilities, including peak searching and error analysis. It provided different ways of obtaining energy, efficiency and half-life of gamma lines. The output consisted of printer plots of the fit along with the tabulation of the results.

Results

The ^{201m}Po isomeric state decay. The ^{201}Po isotope was obtained in the reaction $^{197}Au(^{10}B,6n)^{201}Po$. The maximum cross section was found to be at an energy of

88 ± 3 MeV. The single gamma-ray spectrum of the ^{201}Po source measured with the Ge(Li) spectrometer is shown in fig. 1. The presence of the polonium isotopes $^{199,200,201,202}Po$ in the sample is confirmed by their excitation functions and half-lives, well established from alpha decay studies /1,2,5,6,7/.

In the gamma-ray spectrum we have observed four gamma transitions with a half-life $T_{1/2}$ = 9.0 ± 0.3 min and energies of 968.0, 419.0, 412.4 and 272.7 keV, which have been assigned to the decay of the $i\,13/2$ isomeric state in the ^{201}Po isotope. The coincidence measurements (see fig. 2) show that the 968.0, 412.4 and 272.7 keV gamma transitions form a cascade. Our results are in good agreement with those obtained by Kaun et al. /8/ in investigations of the short-lived isomeric state in the ^{201}Po isotope.

From the electron conversion spectra, we have found the relative electron conversion coefficients for these gamma transitions. We have observed a very strongly converted gamma transition with an energy of 419.0 keV. The normalization between the electron and gamma-ray intensities for the ^{201m}Po isotopes was done on the assumption of the 419.0 keV gamma transition to have a pure M4 character indicated by the K/L ratio of 1.7 ± 0.3. The theoretical value for the M4 transition is equal to $(K/L)_{th}$ = 1.86 (ref. /9/). Under this assumption we have found the 968.0, 412.4 and 272.7 keV gamma transitions to have a $M1$ character.

The gamma and conversion electron data obtained are listed in Table 1. The decay scheme of the ^{201m}Po isomeric states is shown in fig. 3.

The estimated Q value for ^{201}Po electron capture has been obtained from Seeger's Table /11/ and is equal to 4.997 MeV. From this and the direct level feedings that we determined from the intensity balance in this paper, the log ft values are calculated.

The ^{199m}Po isomeric state decay. The sources of the ^{199}Po isotope have been obtained in the reaction $^{197}Au(^{10}B, 8n)^{199}Po$ at the beam energy of 100 MeV, i.e.,

Table I
The Transition Observed in the Decay of the ^{201m}Po
Isomeric State

Transition energy(keV)	Gamma intensity	Total transition intensity	K-conversion coefficient	Multipolarity assignment
272.7	7±I	IO±2	0.25	MI
4I2.4	27±2	31.5 ± 2	0.I68	MI
4I9.0	I4±2	51.8 ± 2	2.7	M4
968.0	I00	I00	0.0I5	MI

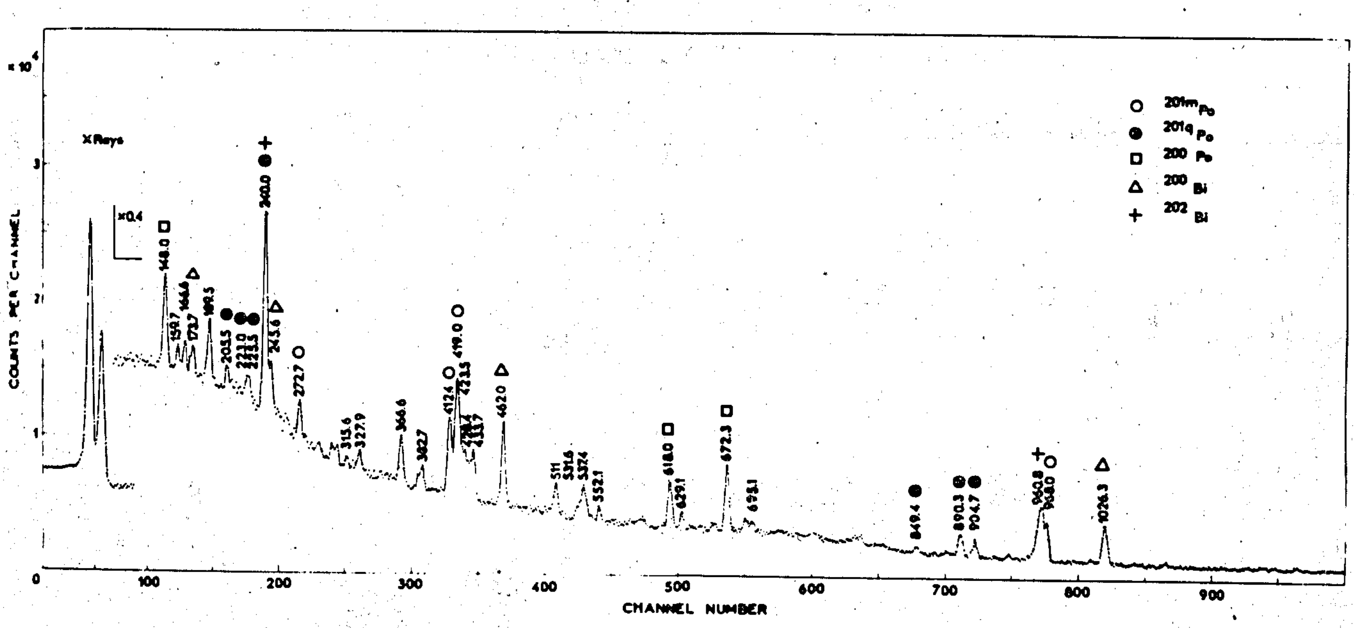


Fig. 1. The gamma-ray spectrum observed in the $^{197}Au(^{10}B, 6n)^{201}Po$ reaction.

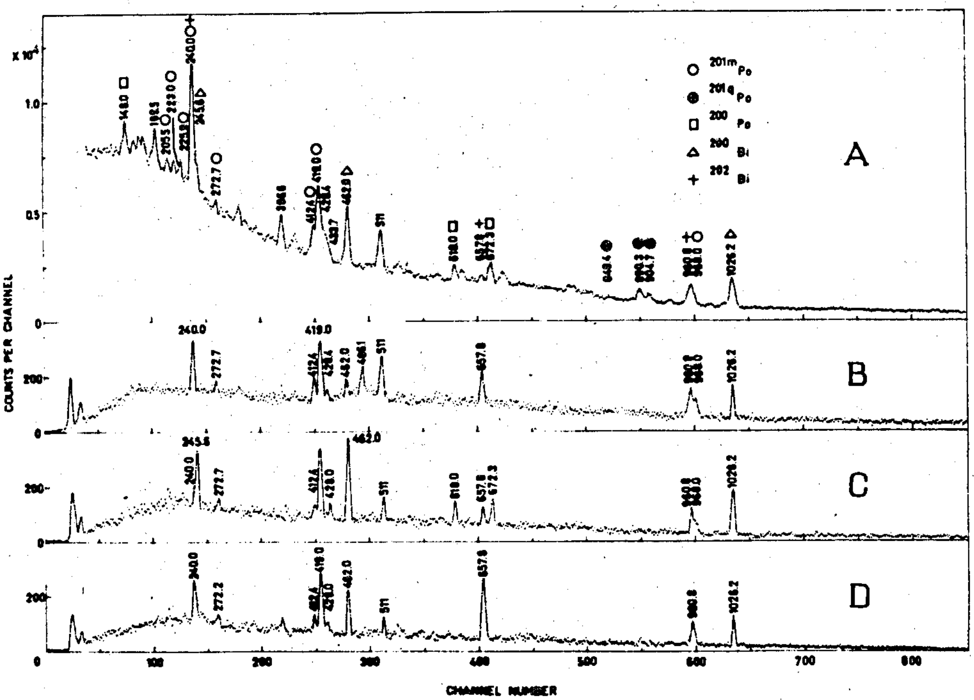
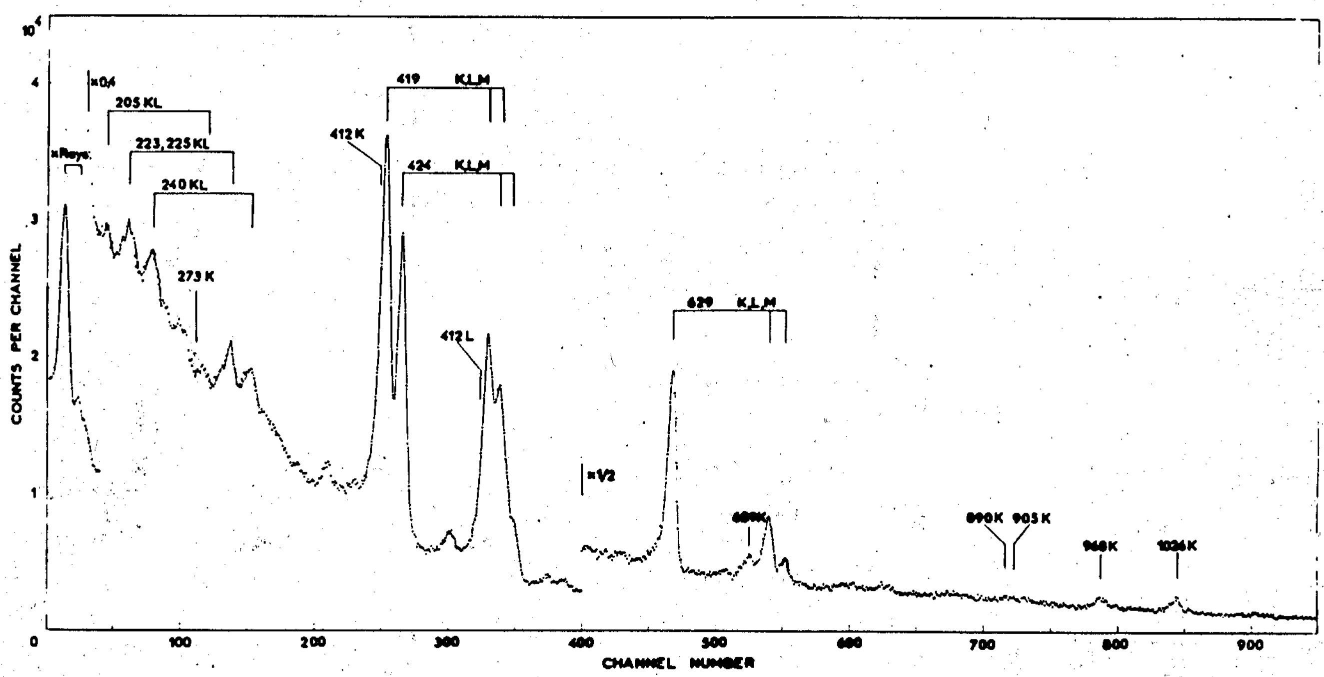


Fig. 2. The gamma-gamma coincidence measurement results. A: the simple γ-spectrum observed in the $^{197}Au(^{10}B,6n)^{201}Po$ reaction. B: the γ-spectrum in coincidence with 272.7 keV. C: the γ-spectrum in coincidence with 412.4 keV. D: the γ-spectrum in coincidence with 968.0 keV.



2a. Conversion electron spectrum observed in the $^{197}Au(^{10}B,6n)^{201}Po$ reaction.

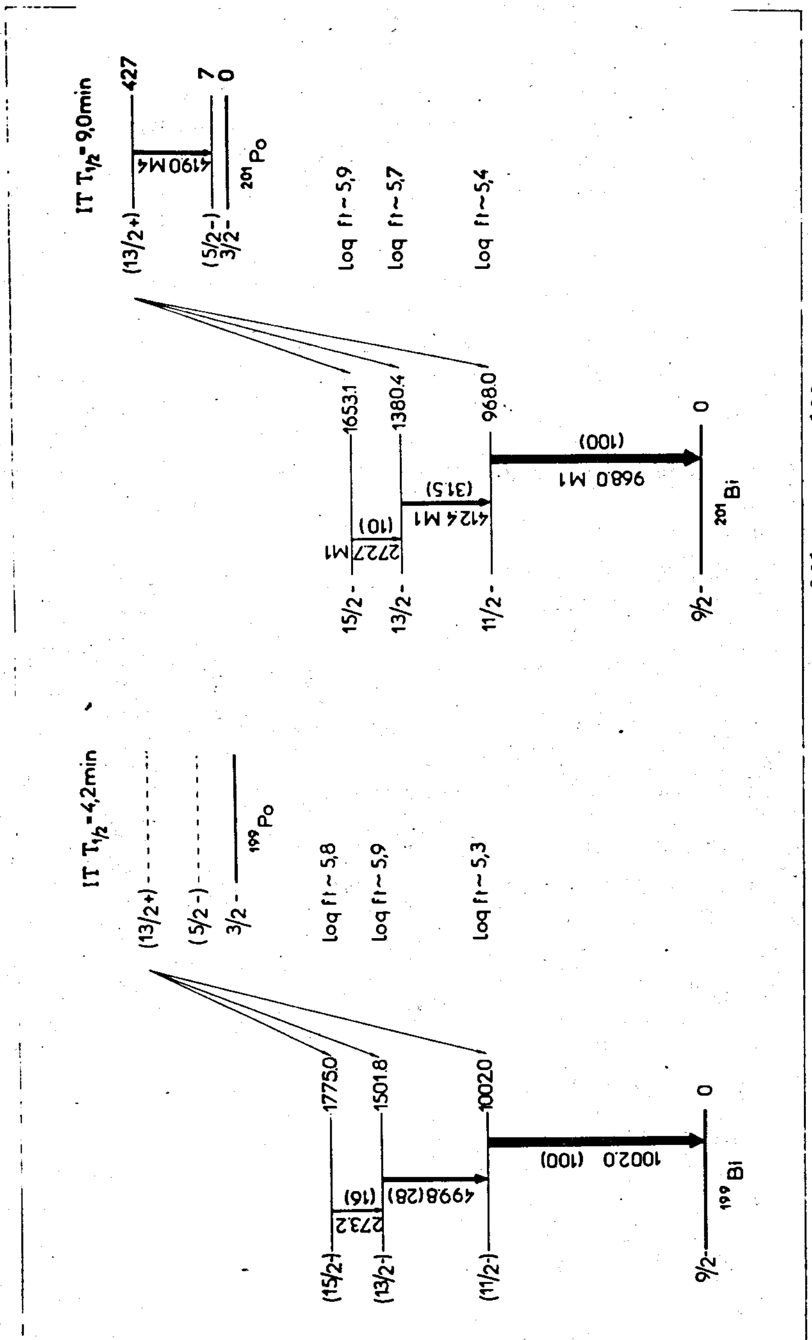


Fig. 3. The decay schemes of the ^{201m}Po and ^{199m}Po isomeric states.

at the maximum energy of the ^{10}B beam. The single gamma ray spectrum of the ^{199}Po source, measured with the 37 cm^3 Ge(Li) detector, is shown in fig. 4. In the current ^{199m}Po measurements the 1002.0, 499.8 and 273.2 keV gamma-ray lines were observed to decay with a half-life of about 4 min. These lines have been assigned to the $EC-\beta^+$- decay of the ^{199m}Po isomeric state. Such an assignment of these gamma transitions was substantiated by the excitation function measurements. The half-life of the ^{199m}Po has been determined to be 4.2 ± 0.3 min, from the gamma measurements, which is in good agreement with the results obtained from the decay of the alpha group/1,2,5,6,7/.

Kaun et al. /8/ carried out on-line measurements to investigate the decay of the short-lived isomeric state in the ^{199}Bi isotope. They observed the same gamma transitions in the cascade to decay with the half-life $300\ ns \leq T_{1/2} \leq 20\ \mu s$ and with the same energy within experimental accuracy.

In the electron conversion spectrum of the ^{199m}Po isomeric state decay we have not observed any strongly converted gamma transition with a half-life of about 4 min. and an energy $E<100$ keV. No search was carried out for low energy conversion electrons.

We would like to note that the $i13/2$ isomeric states in even polonium isotopes can undergo alpha, $EC-\beta^+$decay, as well as they can decay by the M4 type gamma transition. In the heavier bismuth isotopes with $A > 201$ gamma transitions are predominant, but as one moves away from the $N=126$ neutron shell the possibility of beta-electron-capture decay is increasing, and may be expected to dominate in the ^{199}Po isotope.

The data on the ^{199m}Po isomeric state decay gamma lines obtained in the present investigations are listed in Table II.

The decay scheme of the ^{199m}Po isomeric state is shown in fig. 3. The $\log ft$ values have been found in the same way as in the ^{201}Po isomeric state decay.

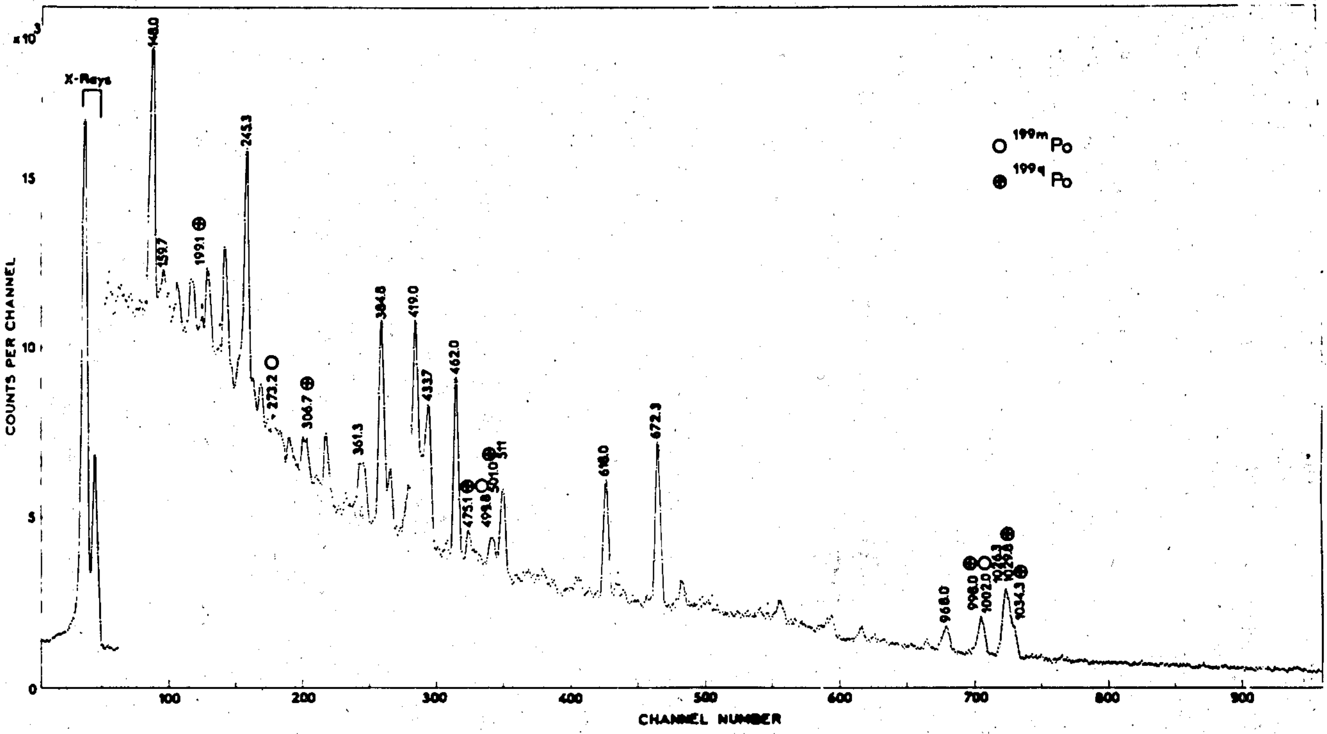


Fig. 4. Gamma ray spectrum observed in the $^{197}Au(^{10}B,8n)^{199}Po$ reaction.

Table II
The Transition Observed in the Decay of the ^{199m}Po Isomeric State

Transition energy (keV)	Gamma intensity	Total transition intensity	Multipolarity assumption
273.2	I0±2	I6±2	MI
499.8	25±2	28±2	MI
I002.0	I00	I00	MI

Calculations

From an analysis of the decay of the ^{199m}Po and ^{201m}Po isomeric states we obtain the values of energies and spins of the excited states of the ^{199}Bi and ^{201}Bi isotopes. For the theoretical interpretation of these levels we use the intermediate coupling approach in the unified nuclear model. The nucleus is treated as a system of the odd proton and the core which contains the even number of neutron holes. The motion of this core has the character of quadrupole vibrations of the surface. The total Hamiltonian for such a system can be written as

$$H = H_p + H_s + H_{int} \quad , \qquad (1)$$

where H_p is the Hamiltonian of the odd proton, H_s denotes the Hamiltonian of the quadrupole vibrations of the surface of the even-even core, and H_{int} is the proton-phonon interaction Hamiltonian. We diagonalize Hamiltonian (1), using, as basic states, the eigenvectors of the uncoupled system $|j; NR; IM\rangle$, which satisfy the equation

$$(H_s+H_p)|j;NR;IM\rangle=[\hbar\omega(N+5/2)+E_j]|j;NR;IM\rangle, \qquad (2)$$

where j denotes the angular momentum of the odd proton, N is the number of phonons, R is the total angular momentum of the vibrations, I is the total angular momentum of the nucleus, M is its Z component, ω is the frequency of the surface vibrations, E_j is the energy of the simple proton. The expression for the matrix elements of the nucleon-phonon interaction Hamiltonian has been obtained in ref. /12/ and reads as follows

$$\langle j;NR;IM|H_{int}|j';N'R';IM\rangle = (-1)^{R+I+1-j} k\sqrt{\frac{\hbar\omega}{2c}}\sqrt{(2j+1)(2R'+1)}$$
$$\times W(j'jR'R|2I)\langle \ell sj||Y_2||\ell' s' j'\rangle\langle NR||b||N'R'\rangle ,$$

where $W(j'jR'R|2I)$ is a Racah coefficient, b is the annihilation operator of phonons. The reduced matrix elements $\langle NR||b||N'R\rangle$ have been calculated in ref. /12/ for up to three phonons. The coupling constant $k=\langle k(r)\rangle$ is a radial average /13/.

In the case of odd isotopes of bismuth the lowest states available for the proton are $h9/2$ and $f7/2$. The "effective" single-particle spacing $E_p = E(f7/2)-E(h9/2)$ is treated as a parameter. The other parameter is the dimensionless particle-surface coupling constant $\xi = k(5/2\pi\omega\hbar c)^{1/2}$ where c is the nuclear surface deformation parameter. Our calculations include the single particle states $h9/2$ and $f7/2$ and the vibrational states of the even-even core for two phonons. The phonon energy $\hbar\omega$ is defined from the position of the first excited 2^+ states of the neighbouring isotopes of lead. Two first excited states of the ^{198}Pb nucleus have energies $E(2^+)$=1.062 MeV and $E(4^+)$=1.624 MeV, and for ^{200}Pb: $E(2^+)$= 1.026MeV and $E(4^+)$=1.488 MeV.

If we assume the experimentally observed states 4^+ in the ^{198}Pb and ^{200}Pb isotopes to have the character of two-phonon states, we shall obtain good agreement between the experimental and theoretical decay schemes ^{199}Bi and ^{201}Bi. The best fit of the parameters gives the values as follows

ξ = 1.2, E_p = 1.1 MeV for ^{199}Bi, and
ξ = 1.2, E_p = 1.0 MeV for ^{201}Bi.

A comparison of the experimental data with theoretical calculations is shown in fig. 5.

The authors are much indebted to Academician G.N.Flerov for his permanent interest in the work. We would also like to express our gratitude to Professor L.K.Peker for his support and many helpful suggestions. Thanks are also due to the cyclotron crew for the good cooperation which made this work possible.

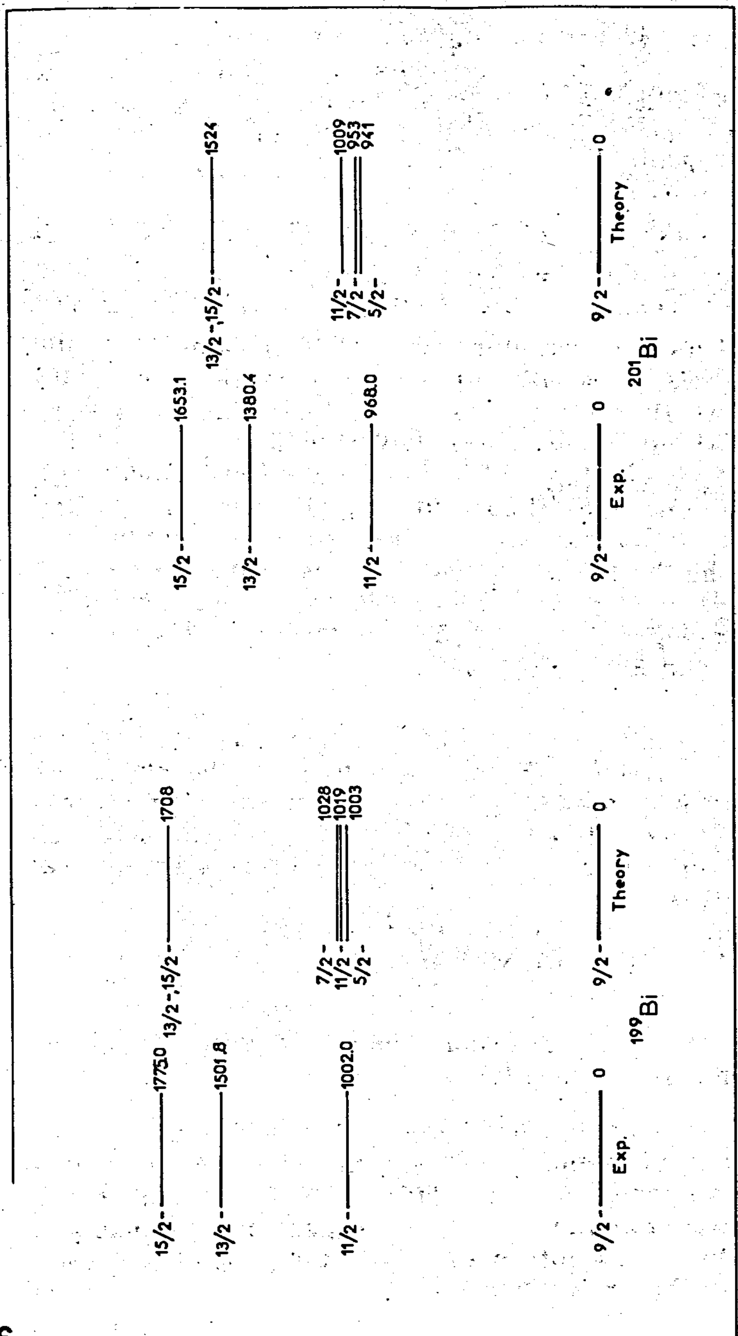


Fig. 5. Comparison of the experimental data with theoretical calculations.

References

1. E.Tielsch-Cassel. Nucl.Phys., A100, 425 (1967).
2. C.Brun, Y.Le Beyec, M.Lefort. Phys.Lett., 16, 286 (1965).
3. A.Siivola, P.Kauranen, B.Jung, J.Svedburg. Nucl. Phys., 52, 449 (1964).
4. M.Alpsten, G.Astner. Nucl.Phys., A134, 407 (1969). M.Alpsten, G.Astner. Phys. Scripta, vol. 5, 41 (1972).
5. T.Sikkeland, R.J.Silva, A.Ghiorso, M.J.Nurmia. Phys. Rev., C1, 1564 (1970).
6. A.G.Jones, A.H.W.Aten. Radiochim.Acta, v. 13, No. 1, 176 (1970).
7. P.Hornhoj. Nucl.Phys., A163, 277 (1971).
8. K.H.Kaun. XIII Symposium on Nucl. Spectroscopy and Nuclear Theory. Dubna, June, 19-23, 1973.
9. B.Jonson, M.Alpsten, A.Appelqvist, G.Astner. Nucl. Phys., A174, 225 (1971).
10. R.S.Hager, E.C.Seltzer. Nucl.Data. No. 1, 203 (1968).
11. P.A.Seeger. Nucl.Phys., 25, 1 (1961).
12. D.C.Choudhury. Mat.Fys.Medd.Dan. Vid. Selsk., 28, No. 4 (1954).
13. A.Bohr, B.R.Mottelson. Mat.Fys. Medd. Dan. Vid. Selsk., 27, No. 16 (1953).

Received by Publishing Department on July 6, 1973.