Internal Conversion of Valence-Shell Electrons : Measurement and Analysis for the 10.84 KeV Transition in 206Bi

V. 12 Internal Conversion of Valence-Shell Electrons: Measurement and Analysis for the 10.84 keV Transition in ^{206}Bi

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Measurement of low-energy conversion spectrum including the *valence shell* conversion can give a valuable information in the interpretation of the Mössbauer isomer shift and the chemical state. The 10.84 keV M1 transition in ^{206}Bi fed from the decay of 8.8 d ^{206}Po is one of such transitions.[1] This transition is also interesting from the point of view of nuclear structure effect in M1 internal conversion, since ^{206}Bi is one of the heavy nuclei for which such an effect is easier to detect. We measured the internal conversion spectrum of the above mentioned transition from M_1 to P shells, the P shell being the valence one, and compared the results with theoretical conversion coefficients in order to obtain information on the nuclear structure effect in this transition and the chemical state of Bi atoms.[5]

The ^{206}Po was produced by the ^{209}Bi(p, 4n)^{206}Po reaction using a 39 MeV proton beam from the synchrocyclotron of INS (Insitute for Nuclear Study, University of Tokyo). The 5.7 h ^{207}Po needed for the analysis of overlapping Auger lines was produced similarly at the proton energy of 25 MeV. Sources of ^{206}Po and ^{207}Po for electron spectroscopy were prepared as described earlier.[1] The electrons were analysed by the INS iron-free $\pi\sqrt{2}$ β-spectrometer[2] equipped with a small-volume gas-flow-type proportional counter having a thin window corresponding to an electron cut-off energy of E_c = 1.35 ± 0.25 keV. The energy dependence of the detection efficiency of the counter system due to transmission through the window and discrimination level of the electronics was considered. The electron spectra were taken at an instrumental momentum resolution of R_{instr} = 0.1 %. The N_1 to N_3 and O_1 to P parts of the spectrum were analysed by the use of the spectrum-analysis program ACSEMP[3] (Analysis of Conversion Spectra using EMpirical Profiles), in which the ^{207}Po spectrum was used to subtract the Auger lines in the ^{206}Po spectrum. The spectrum analysis is shown in Fig. 1, where a narrower line profile of P-shell conversion is taken into account. The relative intensities of N_1 to P shell conversion lines combined with the M_1 to N_1 intensities from ref. 1 gave relative conversion coefficients of M_1 to P shells for the 10.84 keV transition in ^{206}Bi; the result is given in Table 1.

The theoretical internal conversion coefficients (ICC) were cauculated by the program of ref. 4 using the electron wave functions of the relativistic Hartree-Fock atomic model. The nuclear structure effect and the M1+E2 multipolarity mixture were taken into account expressing the ICC for the i-th subshell

in the form

$$\alpha_i = \alpha_i^{(0)}(M1)\cdot(1-\Delta)\cdot(1+b_{1i}\lambda+b_{1i}\lambda^2) + \alpha_i^{(0)}(E2)\cdot\Delta.$$

Here, λ is the nuclear structure parameter and Δ is the admixture of higher multipolarity. The $\alpha_i^{(0)}$ are the theoretical ICC in the no-penetration model ($\lambda = 0$), presented for the M1 multipolarity in Table 1.

By means of a least-squares fitting of theoretical to experimental values of the ICC ratios, M_3/M_1, N_2/N_1 and O_{2+3}/O_1, we obtained $\Delta = (-4\pm6)\cdot10^6$; hence we adopted $\Delta = 0$. Under this condition, we determined $\lambda = 1.66 \pm 0.73$.

The valence shell of a free neutral Bi atom contains five electrons in the configuration $(6s_{1/2})^{\ell}(6p_{1/2})^{m}(6p_{3/2})^{n}$ with $\ell = 2$, $m = 2$ and $n = 1$. We have calculated the ICC for 15 different configurations of the valence shell. As expected, the inner shell ICC almost did not change (Table 1), while drastic changes were obtained for the valence shell. In order to discuss the valence shell configuration of Bi atoms or ions after decay from ^{206}Po in the conversion source, we compared the theoretical and experimental values of ICC ratio, $(O_{4+5} + P)/O_1$, where the experimental value is

$$R_{exp} = [(O_{4+5} + P)/O_1]_{exp} = 0.160 \pm 0.05.$$

The corresponding theoretical values R_{theor} calculated for the defferent configurations are shown in Fig. 2, where $\lambda = 1.66$ was used. Fig. 2 shows that all the R_{theor} are smaller than R_{exp} except for R_{theor} with $\ell = 2$ and $m = n = 0$ which agrees with R_{exp} within the experimental error. Therefore, from the experimental valence-shell conversion coefficient relative to the inner-shell coefficient we can conclude the valence-shell configuration of the converting atom (ion) to be

$$Bi^{3+}: (6s_{1/2})^2.$$

The present conversion source of ^{206}Po was prepared by a spontaneous deposition[1] of ^{206}Po activity onto the surface of a silver foil from a 6N HCl solution. Although the chemical state of the deposited ^{206}Po and hence that of the daughter ^{206}Bi has been unknown, it is very likely that ^{206}Bi is in the form of Bi_2O_3. This is in accord with our assignment of the ^{206}Bi valence-shell configuration from internal conversion.

References

1) Fujioka M., Kanbe M. and Hisatake K., Phys. Rev. Letters 31 (1973) 114. See also Kanbe M. et al., J. Phys. Soc. Japan 38 (1975) 917 and 928.
2) Fujioka M. and Hisatake K., Inst. Nucl. Study Rept. INS TL-89 (1966). unpublished. See also the appendix of Fujioka M., Nucl. Phys. A153 (1970) 337.
3) Fujioka M. and Takashima M., J. Physique 40 (1979) C2-32.
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5) Fujioka M. et al., Z. Physik, to be published.

Table 1. Experimental and theoretical relative conversion coefficients of the 10.84 keV M1 transition in ^{206}Bi.

Shell	Relative conversion coefficients		
	Experimental[b]	Theoretical[c]	δ_{max}[a] (%)
M_1	1.00	1.00	0.7
M_2	1.12(-1)3	1.10(-1)	0.2
M_3	1.05(-2)9	9.97(-3)	0.0
M_4	<2.9(-3)	1.64(-3)	0.0
M_5	<2.0(-3)	8.82(-4)	0.0
N_1	2.45(-1)12	2.56(-1)	0.7
N_2	2.85(-2)11	2.76(-2)	0.2
N_3	2.77(-3)63	2.48(-3)	0.0
N_4	<5.5(-4)	4.13(-4)	0.1
N_5	<2.9(-4)	2.18(-4)	0.1
N_6	<2.4(-4)	1.22(-5)	0.1
N_7		9.27(-6)	0.1
O_1	5.48(-2)17	5.30(-2)	0.7
O_2	6.45(-3)47	5.16(-3)	0.5
O_3		4.45(-1)	1.0
O_4	9.33(-3)34	5.21(-5)	6.2
O_5		2.69(-5)	
P_1		6.56(-3)	
P_2		4.23(-4)	
P_3		7.63(-6)	

a) The maximum change of theoretical ICC caused by the change of the valence shell configuration.

b) Notation such as 1.12(-1)3 means $(1.12 \pm 0.03) \times 10^{-1}$.

c) Neutral atom, no-penetration model. $ICC(M_1)_{theor} = 2.36 \times 10^{2}$.

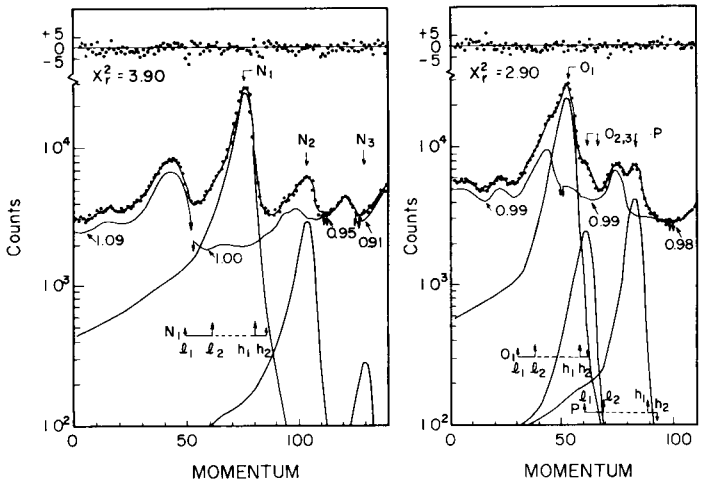

Fig. 1. Analysis of the conversion electron spectrum of the 10.84 keV M1 transition in ^{206}Bi around N (left) and O + P (right) shells. The Auger spectrum taken from the decay of ^{207}Po was cut into several parts in order to consider possible difference of Auger line intensities for the decay of ^{206}Po and ^{207}Po. Above the spectrum, the quality of the computer fit is illustrated by relative residuals. The origin and scale of the electron momentum are arbitrary.

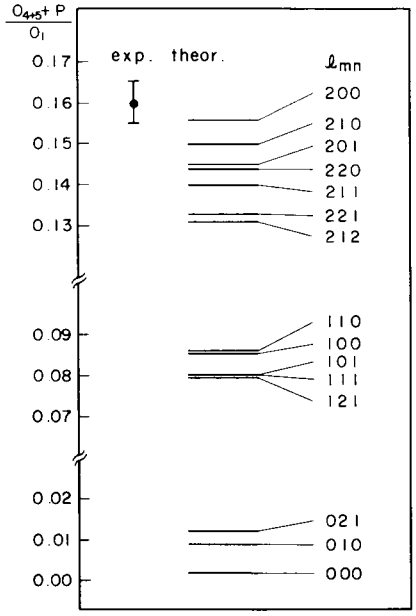

Fig. 2. Comparison of the theoretical ICC ratios, $(O_{4+5} + P)/O_1$, corresponding to various configurations of the Bi valence shell, with the experimental result. The triads of digits on the right-hand side stand for the occupation numbers of the $6s_{1/2}$, $6p_{1/2}$ and $6p_{3/2}$ subshells.