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γ-Ray Intensity Calculations for Isomeric Transition Decays

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Abstract How to calculate the γ-ray emission probability (absolute intensity) for isomeric transition decay is briefly introduced. The examples are given to illustrate their applications. The physical consistent checking and some discussions are also given.

Key words isomeric transition, intensity calculation, intensity balance, nuclear decay

1 Introduction

In an isomeric transition (IT) decay, a gamma-ray is emitted in the transitions of the nucleus from a highly excited state to a lower state or ground state, and an atomic radiation may be emitted as an alternative to the gamma-ray emission in the transition of the nucleus through the internal conversion electron process. In general, the IT decay gamma-rays can be divided into three kinds as follows: (a) primary gamma-rays from the highest excited state (isomeric state); (b) secondary gamma-rays from other excited states below the isomeric state; (c) gamma-rays of directly decaying to its ground state (sometime including primary and secondary gamma-rays).

From these gamma-ray measurements, the nuclear decay scheme can be known, and the decay gamma activation analysis can also be done.

In the experimental measurements, relative decay gamma-ray intensities are measured. In practical applications, the decay gamma-ray absolute intensities (emission probabilities) should be known. In general, the decay gamma-ray emission probabilities per 100 IT decays must be given for practical applications.

The calculation methods of the normalization factor of the gamma-ray intensities for IT decays and their practical applications are introduced briefly. The physical consistent checking and some discussions are also given in this paper.

2 Calculation methods

Main and general methods of the gamma-ray intensity calculation for IT decays are summarized as follows.

2.1 Calculation from direct gamma-ray decays to the ground state

In an IT decay, the nucleus decays into its ground state by emitting a γ-ray, as shown in Fig.1. If there are m gamma-rays in nuclear transitions decays to the ground state, I_k is the relative intensity for the k-th gamma-ray, α_k is its internal conversion coefficient, the equation can be written as follows,

$$N\sum_{k=1}^{m} I_k(1+\alpha_k) = 100,$$

here N is a normalization factor for the gamma-ray emission probability,

$$N = 100\Big/\sum_{k=1}^{m} I_k(1+\alpha_k). \qquad (2)$$

For light nuclides, the internal conversion coefficients α_k are quite small and can be neglceted. Therefore,

$$N = 100\Big/\sum_{k=1}^{m} I_k. \qquad (3)$$

From Eq. (2) or (3), the normalization factor N, and then, the absolute gamma-ray emission probabilities for IT decays can be calculated.

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Table 1. Gamma-ray data for ^{195m}Au IT decays[1].

E_γ/keV		E(level)/keV	I_γ^*		Mult.**	δ**			
56.80+	3	318.59	0.0435	14	E3			3360	
61.46	3	61.44	0.246	12	M1 + E2	0.45	1	12.5	3
200.38	4	261.79	2.41	9	E2			0.377	
261.75	4	261.79	100		M1 + E2		1	0.429	2
318.60	10	318.59	0.062	3	M4			12.05	

+ Uncertainties("Errors"): The uncertainty in any number is given one space after the number itself. For the example, 56.80 3 means 56.80 ± 0.03 (the same in following tables). * Relative intensity. ** Multipolarity and its mixture ratio for gamma-ray.

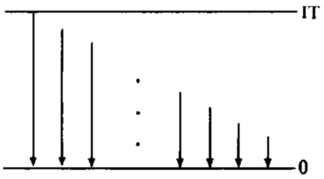

Fig.1. Skeleton scheme of gamma-rays to the ground state from high excitation states.

The relative gamma-ray data[1] for the ^{195m}Au($T_{1/2}$ = 30.5 s) IT decays are given in Table 1 and its decay scheme is shown in Fig.2. In Table 1, the gamma-ray energies, their relative intensities and levels are given. From Table 1 and by using Eq. (2), one finds $N = 0.680 \pm 0.006$, and the absolute gamma-ray decay intensities can also be calculated. The total intensities of the gamma emissions and internal conversions are shown in Fig.2.

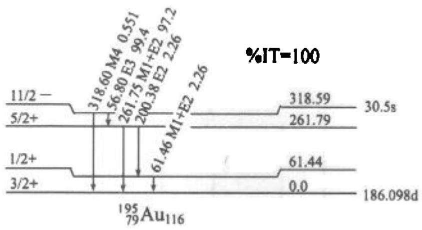

Fig.2. Decay scheme and the gamma-ray intensity for ^{195m}Au IT decays[1].

2.2 Calculation from primary gamma-ray decays from the IT state

In an IT decay, the nuclide is deexcited from its IT state by means of primary gamma-ray decays, as shown in Fig.3. Suppose that there are n primary gamma-rays, J_i is the relative intensity of the i-th primary gamma-ray and α_i is its internal conversion coefficient, then,

$$N \sum_{i=1}^{n} J_i (1 + \alpha_i) = 100, \tag{4}$$

or

$$100 \Big/ \sum_{i=1}^{n} J_i (1 + \alpha_i). \tag{5}$$

And for light nuclides, Eq. (5) becomes

$$100 \Big/ \sum_{i=1}^{n} J_i. \tag{6}$$

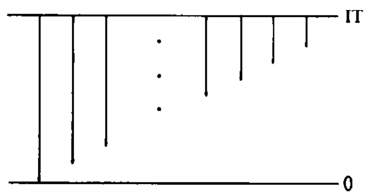

Fig.3. Skeleton scheme of primary gamma-ray from the IT state.

Table 2. Gamma-ray data from ^{195m}Pt (4.02 d)IT decays[1].

E_γ/keV		E(level)/keV	I_γ^*		Mult.**	δ**		α	
19.8		259.29			[M4]			6.95×10^8	
28.1		239.5	0.0114	7	[M1]			51.4	
30.89	9	129.790	20.0	13	M1 + E2	−0.021	4	39.3	3
98.90	2	98.900	100	5	M1 + E2	−0130	4	7.11	
129.5	2	259.29	0.74	4	M4			1179	
129.79	2	129.790	24.8	13	E2			1.75	
140.6		239.5	0.263	13	M1 + E2	−0.17	4	2.57	2
211.35	25	211.35	0.341	17	M1 + E2	+0.38	3	0.762	10
239.5	3	239.5	0.477	24	E2			0.200	

* Relative intensity. ** Multipolarity and its mixture ratio for gamma-ray.

The primary gamma-ray data[1] for the ^{195m}Pt($T_{1/2}$ = 4.02 d) IT decay are listed in Table 2, and their decay-scheme is given in Fig.4. From Table 2, the normalization factor $N = 0.114 \pm 0.006$ is calculated, and the gamma-ray absolute decay intensities for each gamma-ray can be also calculated. The total intensities of the gamma and internal conversion electron are shown in Fig.4.

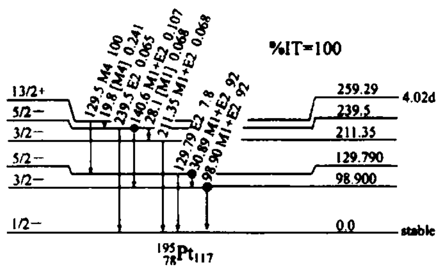

Fig.4. Decay scheme and gamma-ray intensities from the ^{195m}Pt(4.02d) IT decays[1].

2.3 Gamma-ray intensity calculation from above two methods combination

When a decay scheme for isomeric transition is very simple and there are several gamma-ray cascade transitions, the intensity calculation for each gamma-ray can be made on the basis of intensity balance and by combining the two methods described above. As an example, the gamma-ray intensity calculation of the IT decay for ^{83}Kr is made. In Fig.5, the decay scheme for ^{83}Kr is shown. In this case, we assume the gamma-ray normalization factor $N = 1$, from Eqs. (1) and (4), the intensity for each gamma-ray can be calculated, as shown in Table 3.

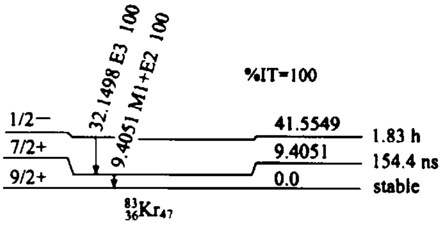

Fig.5. Decay scheme and gamma-ray intensities for ^{83}Kr IT decays[2].

Table 3. Gamma-ray intensity data for ^{83}Kr IT decays[2].

E_γ/keV		E(level)/keV	I_γ^*		Mult.**	δ**		α	
9.4051	8	9.4051	5.5	3	M1 + E2	0.0129	3	17.09	5
32.1498	8	41.5549	0.050	3	E3			1990	

* Absolute intensity. ** Multipolarity and its mixture ratio for gamma-ray.

3 Physical consistent checking

It is important to make a physical consistent check of the intensity balance for each levels.

For gamma-ray decays to the ground state, Eq. (1) becomes

$$\sum_{k=1}^{n} I_k(1+\alpha_k) = 100/N. \tag{7}$$

For the primary gamma-ray from the IT state, Eq. (4) becomes as follows,

$$\sum_{i=1}^{n} J_i(1+\alpha_i) = 100/N. \tag{8}$$

From Eqs. (7) and (8), one finds,

$$\sum_{i=1}^{n} J_i(1+\alpha_i) \approx \sum_{k=1}^{m} I_k(1+\alpha_k). \tag{9}$$

Eq. (9) is correct within their uncertainty ranges. For other levels besides the IT state and ground state, the intensities coming into and going out level j are the same within their uncertainty range, as shown in Fig.6.

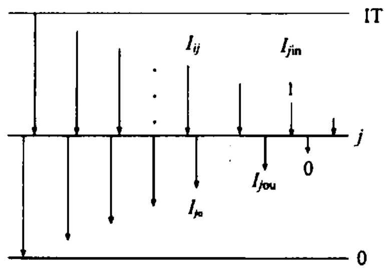

Fig.6. Skeleton scheme of the intensity balance calculation for excitation levels.

Table 4. Calculation and checking results of the intensity balance for each level from ^{195m}Pt(4.02 d) IT decays[1].

		RI*						TI**						NET FEEDING***	
LEVEL/keV		OUT		IN		NET		OUT		IN		NET		CALC	
0.0		0.000		126	6	−126	6	0.000		8.8E2	5	−8.8E2	5	0	8
98.900	20	100	5	20.3	13	80	6	8.1E2	5	8.1E2	5	0.0E2	7	0	8
129.79	2	44.8	19	0.74	4	44.1	19	8.8E2	5	8.8E2	4	0.0E2	6	0	7
211.35	25	0.341	17	0.0114	7	0.330	17	0.60	4	0.60	3	0.00	5	0.00	5
239.5	3	0.75	3	0.000		0.75	3	2.11	7	2.10	7	0.00	10	0.00	11
259.29	20	0.74	4	0.000	5	0.74	4	8.8E2	4	0.00		8.8E2	4	100	7

* relative intensity. ** relative intensity including internal conversion. *** absolute intensity balance.

$$\sum_{j=1}^{m} I_{jin}(1+\alpha_{jin}) - \sum_{j=1}^{n} I_{jou}(1+\alpha_{jou}) \approx 0. \quad (10)$$

In formula (10), I_{jin}, α_{jin}, I_{jou} and α_{jou} are the relative intensities and their internal conversion coefficients for coming into and going out level j, respectively.

In Table 4, the calculation and checking results of the intensity balance for each levels from ^{195m}Pt(4.02 d) IT decays are given. From Table 4 it can be seen that the intensities are consistent within their uncertainties.

4 Discussion

4.1 Internal conversion coefficient calculation

As described above, the internal conversion coefficients for gamma transitions must be known.

Assume the energy of the i-th γ-ray for a radionuclide is $E_{\gamma i}$, the internal conversion coefficients corresponding to the i-th γ-ray for K-, L-, M- and N-Shells are α_{Ki}, α_{Li}, α_{Mi} and α_{Ni}, respectively. The total internal conversion coefficient is then α_i,

$$\alpha_i = \alpha_{Ki} + \alpha_{Li} + \alpha_{Mi} + \alpha_{Ni} = \sum_n \alpha_{ni}. \quad (11)$$

The internal conversion coefficients α_{Ki}, α_{Li}, α_{Mi}, α_{Ni} and α_i can be calculated by using calculation code HSICC[3]. It is based on the theoretical internal conversion coefficients (the data tables and curves are given as functions of atomic number Z, γ-ray energy E_γ, and its multipolarity E1, E2, E3, E4 and M1, M2, M3, M4, respectively). The conversion coefficients for a specific γ-ray energy are determined by fitting the data with cubic spline functions and a set of fitting coefficients for a given, Z, E_γ and multipolarity can be obtained, and then the internal conversion coefficients can be calculated by using the coefficients.

4.2 Decay scheme

In general, the present calculation is based on the IT decay scheme. But it is noted that the IT decay scheme is not correct sometimes. As we know, it is not possible to measure the weak-intensity gamma-rays experimentally. Besides, the measured uncertainties from the background deduction and the gamma-spectra analysis lead to the gamma-ray intensity uncertainties. Strictly speaking, intensities of coming into and going out a level are not exactly same, and they are only consistent within their uncertainties. The normalization factors determined from primary gamma-rays from the IT state and the gamma-ray decays to the ground state can be different. In the data evaluation, normalization factor in the IT decay is usually calculated from the gamma-ray decays to the ground state.

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同核异能跃迁衰变的γ射线强度计算

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摘要 简要介绍了同核异能跃迁衰变的γ射线强度的计算方法,并以实例进行说明,还给出了有关的物理自洽检验方法及其讨论.

关键词 同核异能跃迁 γ射线强度计算 强度平衡 核衰变

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