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EVALUATION OF GAMMA-RAY INTENSITIES

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Yasukazu YOSHIZAWA*, Hikaru INOUE*, Masaharu HOSHI**
Kiyoshi SHIZUMA*** and Yosei IWATA*

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Japan Atomic Energy Research Institute

Evaluation of Gamma-ray Intensities

Yasukazu YOSHIZAWA*
Japanese Nuclear Data Committee, Tokai, JAERI
and

Hikaru INOUE	Faculty of Science, Hiroshima University, Hiroshima
Masaharu HOSHI	Oita Institute of Technology
Kiyoshi SHIZUMA	Faculty of Engineering, Hiroshima University, Hiroshima
Yosei IWATA	Faculty of Science, Hiroshima University, Hiroshima

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Relative intensities and intensities per decay of gamma rays were evaluated for 16 nuclides, ^{22}Na, ^{24}Na, ^{46}Sc, ^{54}Mn, ^{60}Co, ^{85}Sr, ^{88}Y, ^{95}Nb, ^{108m}Ag, ^{134}Cs, ^{133}Ba, ^{139}Ce, ^{180m}Hf, ^{198}Au, ^{203}Hg and ^{207}Bi. For most of these nuclides disintegration rates can be determined by means of $\beta-\gamma$ or X-γ coincidence method. Since decay schemes of these nuclides are established, intensities per decay of strong gamma rays were accurately evaluated by using weak beta-ray branching ratios, relative gamma-ray intensities and internal conversion coefficients. Half-lives of the nuclides were also evaluated. Use of the nuclides, therefore, are recommended for precision intensity calibration of the detectors.

Keywords: Decay, Gamma Ray, Gamma-Ray Intensity, Half-Life, Intensity Evaluation, Internal Conversion, Sodium 22, Sodium 24, Scandium 46, Manganese 54, Cobalt 60, Strontium 85, Yttrium 88, Niobium 95, Silver 108m, Cesium 134, Barium 133, Cerium 139, Hafnium 180m, Gold 198, Mercury 203, Bismuth 207

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* Permanent address, Department of Physics, Faculty of Science, Hiroshima University, Hiroshima

ガンマ線強度の評価

日本原子力研究所シグマ研究委員会
吉沢康和 *
広島大学理学部　井上　光
大分工業大学　星　正治
広島大学工学部　静間　清
広島大学理学部　岩田洋世

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標準ガンマ線として使われる16の核種について，ガンマ線の強度と半減期に関する文献調査と評価を行った。評価した核種は，^{22}Na，^{24}Na，^{46}Sc，^{54}Mn，^{60}Co，^{85}Sr，^{88}Y，^{95}Nb，^{108m}Ag，^{134}Cs，^{133}Ba，^{139}Ce，^{180m}Hf，^{198}Au，^{203}Hg，^{207}Biである。^{180m}Hf 以外は $\beta-\gamma$，またはX－γ同時計数法により，線源強度を正確に定めることができるので，これらの核種は，ガンマ線検出器の校正用として有用である。

＊1　広島大学理学部

この報告書は，シグマ研究委員会活動の一環として行われた核データの評価結果を利用し易い形にまとめたものである。この研究は，昭和50年度および51年度に，日本原子力研究所より広島大学に委託した調査（JAERI－M 7567），およびJAERI－M 8196の延長線上にも位置するものである。

Summary: Evaluated values of half-lives and gamma-ray intensities

Nuclide	Half-life	Gamma ray		
		Energy (keV)	Relative intensity (%)	Intensity per decay (%)
^{22}Na	950.6±0.5 d (2.6027±0.0013 y)	1274.5		99.94 ±0.02
^{24}Na	14.965±0.002 h	1368.8	100.000 ±0.003	99.994 ±0.003
		2754.1	99.887 ±0.008	99.881 ±0.008
^{46}Sc	83.79 ±0.03 d	889.2	99.9965±0.0016	99.9836±0.0016
		1120.5	100.0000±0.0012	99.9871±0.0012
^{54}Mn	312.21 ±0.05 d	834.8		99.9746±0.0025
^{60}Co	1924.6 ±0.3 d (5.2694 ±0.0008 y)	1173.3	99.91 ±0.02	99.89 ±0.02
		1332.5	100.0000±0.0015	99.9816±0.0015
^{85}Sr	64.84 ±0.03 d	514.0		98.4 ±0.4
^{88}Y	106.6 ±0.2 d	898.0	94.4 ±0.3 *	93.7 ±0.4
		1836.	100.0 ±0.3 *	99.24 ±0.07
^{95}Nb	34.98 ±0.02 d	765.8		99.80 ±0.02
^{108m}Ag	127 ±21 y	434.0	99.476 ±0.090	90.5 ±0.7
		614.4	100.000 ±0.034	91.0 ±0.7
		723.0	99.74 ±0.38	90.7 ±0.8
^{134}Cs	754.1 ±1.4 d (2.065±0.004 y)	563.3	8.57 ±0.03 *	
		569.3	15.78 ±0.06 *	15.40 ±0.08
		604.7	100.0 ±0.4 *	97.64 ±0.06
		795.8	87.5 ±0.3 *	85.52 ±0.05
		801.8	8.89 ±0.03 *	8.68 ±0.04
^{133}Ba	10.71±0.11 y	276.4	11.53 ±0.06 *	
		302.9	29.48 ±0.14 *	
		356.0	100.0 ±0.4 *	62.00 ±0.14
		383.9	14.39 ±0.06 *	
^{139}Ce	137.66±0.05 d	165.9		79.99 ±0.16
^{180m}Hf	5.5 ±0.1 h	215.3	86.3 ±1.6	81.5 ±1.5
		332.3	100.0 ±0.6	94.4 ±0.5
		443.2	87.0 ±0.8	82.1 ±0.7
^{198}Au	2.6937±0.0007 d	411.8		95.56 ±0.08
^{203}Hg	46.60±0.02 d	279.2		81.48 ±0.08
^{207}Bi	33.4 ±0.8 y	569.7	100.0 ±0.4 *	97.74 ±0.03
		1063.6	75.79 ±0.25 *	74.0 ±0.3
		1770.	7.026 ±0.029 *	6.87 ±0.04

* Obtained from relative intensity measurements.

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1. Introduction

Gamma-ray intensities have been usually measured with the accuracy of 2~5 %. Accurate values of gamma-ray intensities, i.e. relative intensities and intensities per decay, are useful for the safe guard technique of the atomic fuel. Therefore, precision measurements of gamma-ray intensities of the actinide nuclides and the long-lived fission products have been desired. The precision measurement of the gamma-ray intensity is also valuable for the nuclear spectroscopy, the burn up investigation of the atomic fuel, the activation analysis, etc.

The best measurements of gamma-ray intensities were performed by using Ge(Li) detector systems. Detectors must be calibrated with standard gamma-ray sources and cascade gamma-ray sources. For the standard gamma-ray sources, disintegration rates are determined by means of the β-γ or X-γ coincidence method, and the gamma-ray intensities per decays must be evaluated with good accuracies. When the gamma-ray intensity per decay is nearly 100 % and the decay scheme is well established, the intensity per decay can be accurately evaluated by using branching ratio of beta transition, relative gamma-ray intensities and internal conversion coefficients. In such cases the evaluated values are almost independent of the gamma-ray intensity measurement. We call these gamma rays "the primary standards". Such a gamma ray is emitted by the transition from the first 2^+ state to the ground state in the even-even nucleus and sometimes by the $4^+ \rightarrow 2^+ \rightarrow 0^+$ cascade transition. For the low energy region, such a gamma ray is found in the transitions from low-lying states in the odd-mass nucleus. Since the internal conversion coefficient is very large for the region lower than 100 keV, the accurate value of the intensity per decay cannot be obtained.

In this report gamma-ray intensities of 16 nuclides were evaluated within uncertainties of 0.5 % (mostly 0.1 %). Intensities per decays of these gamma rays are strong. These primary standards are useful for precision calibration of the detector. In addition, half-lives of these nuclides are also evaluated, because half-lives are important to correct decays of standard sources.

2. Method of Evaluation

2.1 Gamma-Ray Intensity Evaluation

Intensities per decays evaluated are 99~100 % except a few cases. The decay schemes of these nuclei are reliable. Branching ratios of weak beta-ray components feeding to lower states, relative intensities of weak cross over gamma rays and total internal conversion coefficients are important to evaluate these strong gamma-ray intensities. The evaluation methods of them are as follows.

a) Branching ratios of beta transitions

The weak beta branchings to the ground state and to the first 2^+ state are accounted for evaluation of the gamma-ray intensities of the ground-state transition and the $4^+ \rightarrow 2^+$ transition, respectively. When experimental values are available for the weak beta branching, the most reliable experimental value is adopted. When the experiment gives only upper limit Δ, the value $\Delta/2 \pm \Delta/2$ is used (for example, ^{54}Mn, ^{203}Hg).

If no experimental value is available, the branching Δ is obtained from the transition energy and the log ft value (for example, ^{108m}Ag, ^{133}Ba). The log ft value is estimated from log ft values of similar transitions in neighbouring nuclei. In this case the value of $\Delta \pm \Delta$ is adopted except ^{85}Sr.

For the highly forbidden transition such as the ground-state transition of $4^- \rightarrow 0^+$, $4^+ \rightarrow 0^+$ or $5^+ \rightarrow 0^+$, the log ft value is ~16. Then the branching ratio of such a transition is 10^{-6} ~ 10^{-10}. Therefore, branchings of the highly forbidden transitions are neglected (for example, ^{88}Y ($4^- \rightarrow 0^+$), ^{24}Na, ^{46}Sc, ^{134}Cs ($4^+ \rightarrow 0^+$), and ^{60}Co ($5^+ \rightarrow 0^+$)).

b) Relative gamma-ray intensities

Relative gamma-ray intensities are necessary to evaluated strong gamma-ray intensity per decay. For example, when a strong gamma ray and a weak gamma ray feed to the ground state, the intensity ratio of the weak gamma ray to the strong one and the total internal conversion coefficient of the strong one gives the intensity per decay of the strong gamma ray.

Relative intensities of weak gamma rays are obtained not only from the decay data but also from data in the decay of the other side, in the (n, γ) reaction, etc. In addition, unobserved weak gamma-ray intensities are estimated from level energies, spins and parities, and the enhancement or hinderance factor of nuclear systematic properties. Relative gamma-ray intensities more than 0.1 % must be known for accurate evaluation of the strong gamma-ray intensity per decay.

c) Internal conversion coefficients

The most required data for evaluation are the total internal conversion coefficients, especially for low energy gamma rays and heavier nuclei. The internal conversion coefficient is usually obtained from the intensity ratio of electrons to gamma ray, the electron

intensity per decay or the intensity ratio of electrons to the beta ray. Therefore, the experimental value of the internal conversion coefficient often depends on the gamma-ray intensity measurement. If the total internal conversion coefficient is less than 0.01, this error is not effective. However, the accurate conversion coefficient is important, when it is more than 0.01.

Agreements between experimental values and theoretical ones are not always good enough for the K-shell conversion coefficient. Sometimes, discrepancies between them are more than 10 %. A systematic deviation is observed in deformed nuclei. The discrepancy may be understood as the nuclear finite size effect or the nuclear structure effect, but the discrepancy cannot be always expalined. Therefore, when no good experimental value is available, the theoretical value is adopted with 10% error.

Multipole mixing often appears for the transition in the odd-mass nucleus, while the $2^+ \rightarrow 0^+$ and $4^+ \rightarrow 2^+$ transitions are pure E2 transition for the even-even nucleus. When the multipole mixing ratio was measured by means of the angular correlation method, the theoretical conversion coefficient with the multipole mixing is calculated.

For theoretical values we adopt the tables of Hager and Seltzer (68HaSe), Trusov (72Tr) and Band et al. (76Ba) for the K- and L-shell conversion coefficients and Dragoun and Brabec (75DrBr) for L/MNO. Interpolation is performed by the computer program given by Hager and Seltzer. We use extrapolated values for low Z nuclides, assuming that the coefficients are proportional to Z^3.

d) Internal pair formation and internal Compton effect

The effect of internal pair formation cannot be neglected for the gamma transition higher than 1.02 MeV. The internal pair formation probability rapidly increases with an increase of the transition energy, and is nearly equal to the internal conversion probability at 1.3 MeV for the light nucleus.

When an experimental value of the internal pair formation coefficient is available, this value is used. For other cases, the theoretical values given by Rose (49Ro) and Jaeger and Hulme (34JaHu) were adopted. We interpolate the theoretical value at the low energy, assuming that the coefficient is proportional to $(E_\gamma - 1.02)^2$.

Since the emission probability of the internal Compton electron is much smaller than that of the internal conversion electron, this probability is neglected.

e) Evaluation calculation

The intensity per decay is evaluated on the basis of the intensity balance, when the gamma ray is strong and no strong beta transition feeding to the lower lying state is observed as shown in Fig. 2.1.1. Especially, this method is useful for gamma rays, intensities per decays of which are nearly 100 %. From the intensity balance at the ground state one obtains the equation

$$\gamma_1(1+\alpha_1+\Gamma_1)+\gamma_4(1+\alpha_4+\Gamma_4)+\beta_1 = 1 \tag{2.1}$$

From the balance at the first excited state, one obtains

$$\gamma_1(1+\alpha_1+\Gamma_1) = \gamma_2(1+\alpha_2+\Gamma_2)+\gamma_3(1+\alpha_3+\Gamma_3)+\beta_2 \tag{2.2}$$

where γ_i, α_i and Γ_i indicate the gamma-ray intensity per decay, the total internal conversion coefficient and the internal pair formation coefficient, respectively, and β_i is the branching ratio of the beta transition.

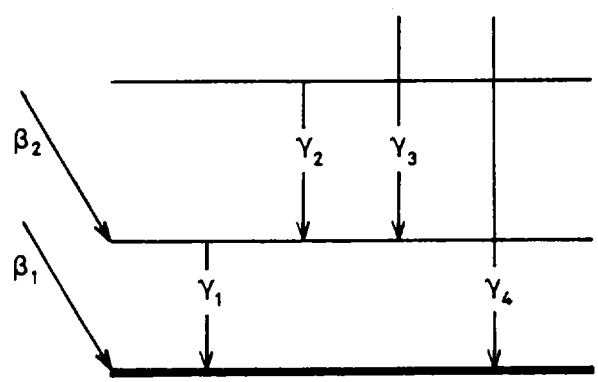

Fig. 2.1.1 Typical decay scheme

For the case of $\gamma_1 \gg \gamma_4$ and $\beta_1 \ll 1$, the intensity per decay of γ_1 is given by

$$\gamma_1 = \frac{1-\beta_1}{1+\alpha_1+\Gamma_1+\gamma_4\dagger(1+\alpha_4+\Gamma_4)} \tag{2.3}$$

where $\gamma_i\dagger$ denotes the relative intensity ($\gamma_1^\dagger=1$). This equation applied to most of ground state transitions. For the case of $\gamma_3^\dagger/\gamma_2^\dagger \ll 1$, $\gamma_4^\dagger/\gamma_2^\dagger \ll 1$, $\beta_1 \ll 1$ and $\beta_2 \ll 1$.

$$\gamma_2 = \frac{1-\beta_1-\beta_2}{1+\alpha_2+\Gamma_2+(\gamma_3\dagger/\gamma_2\dagger)(1+\alpha_3+\Gamma_3)+(\gamma_4\dagger/\gamma_2\dagger)(1+\alpha_4+\Gamma_4)} \tag{2.4}$$

where ($\gamma_i^\dagger/\gamma_2^\dagger$) means an observed relative intensity. Errors of them are given by

$$\left(\frac{\Delta\gamma_1}{\gamma_1}\right)^2 = \frac{\Delta\alpha_1{}^2+\Delta\Gamma_1{}^2+\Delta\gamma_4\dagger^2}{(1+\alpha_1+\Gamma_1+\gamma_4\dagger)^2} + \frac{\Delta\beta_1{}^2}{(1-\beta_1)^2} \tag{2.5}$$

for Eq.(2.3), and

$$\left(\frac{\Delta\gamma_2}{\gamma_2}\right)^2 \approx \frac{\Delta\alpha_2{}^2+\Delta\Gamma_2{}^2+\Delta(\gamma_3\dagger/\gamma_2\dagger)^2+\Delta(\gamma_4\dagger/\gamma_2\dagger)^2}{(1+\alpha_2+\Gamma_2+(\gamma_3\dagger/\gamma_2\dagger)+(\gamma_4\dagger/\gamma_2\dagger))^2} + \frac{\Delta\beta_1{}^2+\Delta\beta_2{}^2}{(1-\beta_1-\beta_2)^2} \tag{2.6}$$

for Eq. (2.4), where Δ indicates the error. Therefore, one obtains very accurately evaluated values of γ_1 or γ_2, when α_1, β_1 and $\gamma_4^\dagger$, or α_2, β_1, β_2, $\gamma_3^\dagger$ and $\gamma_4^\dagger$ are less than 1 %.

There are two methods to evaluate the relative gamma-ray intensity. First one is the usual method that one adopts the average value of the selected data of observed relative intensity. Second one is the method based on the intensity balance. This second method is also useful for strong cascade gamma rays as shown in Fig. 2.1.1. For the case of $\gamma_2 \gg \gamma_3$ and $\gamma_2 \gg \beta_2$, Eq. (2.2) gives the relative intensity $\gamma_2^\dagger$

$$\gamma_2\dagger = \frac{\gamma_2}{\gamma_1} = \frac{1+\alpha_1+\Gamma_1-\beta_2/\gamma_1}{1+\alpha_2+\Gamma_2+(\gamma_3\dagger/\gamma_2\dagger)(1+\alpha_3+\Gamma_3)} \tag{2.7}$$

where $(\gamma_3^\dagger/\gamma_2^\dagger)$ means an observed relative intensity. The error of $\gamma_2^\dagger$ is given by

$$\left(\frac{\Delta\gamma_2\dagger}{\gamma_2\dagger}\right)^2 \approx \frac{\Delta\alpha_1{}^2+\Delta\Gamma_1{}^2+\Delta\beta_2{}^2}{(1+\alpha_1+\Gamma_1-\beta_2)^2} + \frac{\Delta\alpha_2{}^2+\Delta\Gamma_2{}^2+\Delta(\gamma_3\dagger/\gamma_2\dagger)^2}{(1+\alpha_2+\Gamma_2+(\gamma_3\dagger/\gamma_2\dagger))^2} \tag{2.8}$$

If α_1, α_2, β_2 and $(\gamma_3^\dagger/\gamma_2^\dagger)$ are <1 % and errors of them are <10 %, the error of $\gamma_2^\dagger$ is obtained to be <0.1 %. This method is applied to the gamma rays of ^{24}Na, ^{46}Sc, ^{60}Co, etc.

The necessary conditions for the evaluation are as follows: (1) the decay scheme is well established, (2) weak gamma rays were already measured or no weak gamma ray (<0.1 %) was reported, (3) the branching ratio of the beta transition feeding to the lower lying state is small. When this ratio is not known experimentally, the ratio which is estimated from the systematic property of the log ft value should be small (<1 %). (4) spins and parities of the initial and final states are established for the requisite strong gamma transition and the multipolarity of the gamma transition is known. For the odd-mass nucleus it is necessary that a reliable experimental value of the internal conversion coefficient is available or the multipole mixing ratio is known.

2.2 Half-Life Evaluation

Half-lives are evaluated for 16 nuclides, intensities of which are evaluated in this report. Many experimental values are available for each nuclide except for ^{108m}Ag and ^{180m}Hf. These values are listed in Chapter 4. In most of measurements, decays were followed with radiation detectors. For the cases of long-lived nuclides (> 10 y), different

kinds of measurements were performed, and the accuracies are not good.

In general, the systematic error must be main part of the error. When one follows the decay, the systematic error is due to the impurity, the dead time of the detector system, change of the discriminator bias and others. Since the statistical error is usually small, the systematic error is often 3~10 times larger than the standard deviation. Some authors used only the standard deviations as their errors without estimate of the systematic error. In such a case we rewrite their errors to three or five times of the standard deviations. Since the systematic error is independent of the statistical error, this factor has not essential meaning.

Values before 1968 are rejected except for ^{180m}Hf, because estimates of the systematic errors were rough and stabilities of detectors and electronic circuits were not good enough in that age. Data after 1968 are discussed and a few reliable data are selected. Only one best value is adopted for some cases. When a few data are adopted, the weighted and unweighted averages and also the internal and external errors are calculated. Finally each ones of the averages and the errors are adopted as the evaluated value. The internal and external errors are discussed in next section.

Since the period of one year gradually changes year after year, "year" is not a good unit for the precision measurement of the half-life. Therefore the unit of "day" is used for the half-life shorter than 10 y. But "year" is used for the half-life longer than 10 y, because accuracy is worse for them. In our evaluation "year" is translated into "day" as 1 y = 365.242 d.

2.3 Average Value and Error

In general, the average value, the internal error and the external error are written as,

$$x = \frac{\Sigma\, x_i w_i}{\Sigma\, w_i} \tag{2.9}$$

$$\varepsilon_{int} = \frac{\sqrt{\Sigma\, \varepsilon_i^{\,2} w_i^{\,2}}}{\Sigma\, w_i} \tag{2.10}$$

$$\varepsilon_{ext} = \sqrt{\frac{\Sigma\, (x_i - x)^2 w_i}{(n-1)\Sigma w_i}} \tag{2.11}$$

where x_i, ε_i and w_i denote the observed value, its error and its weight, respectively, and n is the number of experimental values.

The experimental error ε_i is divided to three parts, which are the statistical error, the systematic error and the standard error. Estimation of the systematic error is difficult, and it depends on the individual experiment. The systematic error is often underestimated, though it is usually the largest. Unreasonably small error does not mean a good experiment, because the error sometimes includes only the statistical error without

estimate of the systematic error.

The weight w_i should be estimated as follows : after the calibration error which is common in most of experiments is removed from each experimental error and the systematic error is adjusted, the weight is obtained from this corrected error. However usually it is very difficult to estimate the systematic error in this way, when the author did not show details of the experiment. Then we used simple way for evaluation.

First, old data before 1970, 1960 and 1968 were rejected for strong gamma rays, weak gamma rays and half-lives, respectively, if new data are available. Some errors in remainders are corrected. A few groups performed series of measurements and reported gamma-ray intensities or half-lives for many nuclides. It is possible in such cases to correct their errors. If the corrected error is more than 3 times larger than the smallest error, this value is omitted. Then only one or a few data remained.

Two average values with the weights 1 and ε_i^{-2} and the internal and external errors are calculated by using following equations :

$$\bar{x} = \frac{1}{n} \Sigma\, x_i \tag{2.12}$$

$$\varepsilon_{int} = \frac{1}{n}\sqrt{\Sigma\, \varepsilon_i^{\,2}} \tag{2.13}$$

$$\varepsilon_{ext} = \sqrt{\frac{\Sigma (x_i - \bar{x})^2}{n(n-1)}} \tag{2.14}$$

for $w_i = 1$, and

$$\bar{x} = \frac{\Sigma\, x_i \varepsilon_i^{-2}}{\Sigma\, \varepsilon_i^{-2}} \tag{2.15}$$

$$\varepsilon_{int} = \frac{1}{\sqrt{\Sigma\, \varepsilon_i^{-2}}} \tag{2.16}$$

$$\varepsilon_{ext} = \sqrt{\frac{\Sigma (x_i - \bar{x})^2 \varepsilon_i^{-2}}{(n-1)\ \Sigma \varepsilon_i^{-2}}} \tag{2.17}$$

for $w_i = \varepsilon_i^{-2}$. When all of ε_i represent correct errors and are different each other, the weighted average is adopted. When the uncertainties of the selected values do not seem different each other, the unweighted average is adopted.

If the external error is larger than the internal error, usually one takes the external error as the error of the average value. The larger external error suggests two following cases. One is that the systematic errors are underestimated. Another case are that only two or three data are used for average and data accidentally scatter. Most of the intensity measurements and the half-life measurements are the first case. In this case one should adjust systematic errors. The intensity measurements of very weak gamma rays and the half-life measurements of very long-lived nuclides sometimes correspond to the second

case. Since data are carefully selected and some errors are corrected in our evaluation, the internal errors are generally larger than the external errors. Therefore the internal errors are adopted for our evaluated values.

2.4 Notations

Notations in chapters 3 and 4 are as follows :

γ_1, γ_2	Gamma-ray intensity per decay
$\gamma_1^\dagger$, $\gamma_2^\dagger$	Relative gamma-ray intensity
γ_1', γ_2'	Gamma-ray branching ratio
t_1, t_2	Transition intensity per decay. $t_1=\gamma_1(1+\alpha+\Gamma)$
β_1, β_2	Branching ratio of the beta-ray component
ε_1, ε_2	Branching ratio of the electron capture component
α_K	K-shell internal conversion coefficient
α_{LI}	L_I-shell internal conversion coefficient
α	Total internal conversion coefficient $\alpha=\alpha_K+\alpha_L+\cdots$
K/L	K to L ratio $K/L=\alpha_K/\alpha_L$
Γ	Internal pair formation coefficient
ε	Error
*	Adopted value
σ	Standard deviation
δ	Systematic error
chem	Chemical separation
ic	Ionization chamber
pc	Proportional counter
GM	Geiger-Muller counter
NaI	NaI(Tl) scintillator
Ge	Germanium detecter
$4\pi\gamma$ic	4π ionization chamber
4πpc	4π proportional counter
2πpc	2π proportional counter
$4\pi\beta\gamma$	4π proportional counter in coincidence with a gamma counter
electroscope	2π air ionization chamber
mag spect	Magnetic spectrometer
mass spect	Mass spectrometer

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3. Evaluation of Gamma-Ray Intensities

3.1 ^{22}Na

The radioactive nuclide ^{22}Na emits the 1275 keV gamma ray of almost 100 % per decay in the positron decay and the electron capture. The decay scheme is shown in Fig. 3.1.1. Intensities of the 1275 keV gamma ray and the annihilation radiation were evaluated.

a) ε/β^+. For the test of the beta decay theory, a lot of measurements of $\varepsilon_1/(\beta_1+\beta_2)$ were performed as shown in Table 3.1.1 and Fig. 3.1.2. Williams (64Wi04), Leutz and Wenninger (67Le07) and Vatai et al. (68Va13) obtained values with errors less than 1 % which were smaller than the theoretical value. After these measurements Merritt and Taylor (71Me) and MacMahon and Baery (76Ma38) precisely determined ε/β^+. Since Bosch et al. (77Bo10) measured with NaI(Tl) detectors, this value was not adopted. Though the error of MacMahon and Baery is smaller than that of Merritt and Taylor, reliabilities of two measurements are not essentially different. Therefore the unweighted averate (w_i=1) was adopted as shown in Table 3.1.2. This value agrees well with the theoretical value (70Wi) shown in Table 3.1.3.

b) Ground state transition of β^+. The positron intensity β_1 of the ground state transition was observed only by Write (53Wr13). The ratio of β_2/β_1 and the theoretical value of $\varepsilon_2/\varepsilon_1$ is given in Table 3.1.4. The branching ratio of $\beta_2+\varepsilon_2$ is used for evaluation of the gamma-ray intensity.

c) Internal conversion coefficient. Two experimental values of the total conversion coefficient are available as shown in Table 3.1.5. The theoretical conversion coefficients were obtained from Z^3 extrapolation of Hager and Seltzers' table. The experimental values are in good agreement with the theoretical value listed in Table 3.1.6. The internal pair formation coefficient is larger than the internal conversion coefficient for the 1275 keV transition. The average of the experimental values is adopted for the total internal conversion coefficient and the theoretical value with the error of 20 % is for the pair formation coefficient.

d) Evaluation of the 1275 keV gamma-ray intensity. The intensity per decay was obtained from Eq. (2.1), i.e. the relation $\gamma_1 = 1-(\beta_1+\varepsilon_1)-(\alpha_1+\Gamma_1)$. The evaluated value is shown in Table 3.1.7 and is almost independent of the gamma-ray intensity measurement.

e) Evaluation of the annihilation radiation intensity. If all positrons annihilate, the intensity of annihilation radiation is twice of the positron intensity. However, the intensity of the 511 keV radiation was obtained from subtraction of the three-quantum annihilation and the annihilation in flight. Probabilities of these effects depend on material of the positron stopper. The values in Table 3.1.7 are of the annihilation in copper. The error of the evaluated intensity of the 511 keV radiation is small, but there still remains ambiguity larger than the error because of ambiguity in the calculated probability of the three-quantum annihilation and the annihlation in flight. In addition, the 511 keV line is affected by the Dopplar broadening effect, and the cover of the gamma-ray source usually used is not thick enough to stop positrons. Therefore the 511 keV radiation is not a very good intensity calibration line.

Table 3.1.1 Experimental values of electron capture to positron emission ratio.

Authors	ε/β^+	K/β^+	Ref.
Sherr, Miller	0.110 ±0.006		54Sh
Kreger	0.124 ±0.011		54Kr
Allen et al.	0.122 ±0.010		55Al
Konijin et al.	0.109 ±0.008		58Ko
Ramaswamy	0.112 ±0.004		59Ra
Williams	0.1041±0.0007 a)		64Wi04
Leutz, Wenninger	0.1048±0.0007		67Le07
Vatai et al.	0.1042±0.0010		68Va13
McCann, Smith		0.105 ±0.009	69Mc
Merritt, Taylor	0.1082±0.0033*		71Me
MacMahon, Baerg	0.1077±0.0006*		76Ma38
Bosch et al.	0.1128±0.0057	0.1043±0.0052 b)	77Bo10

a) The error is a quadratic sum of statistical error (0.45%) and systematic error (0.5%).

b) The value was obtained from the experimental value of ε/β^+.

Table 3.1.2 Average values of electron capture to positron emission ratio.

$w=1/\varepsilon^2$			$w=1$		
Average value	Error Int.	Error Ext.	Average value	Error Int.	Error Ext.
0.1077	0.0006	0.0001	0.1080*	0.0017*	0.0003

Table 3.1.3 Theoretical values of electron capture to positron emission ratio.

Authors	ε/β^+	K/β^+	Ref.
Sherr, Miller	0.1135±0.003		54Sh
Zweifel	0.111		54Zw
Leutz, Wenninger	0.1138±0.0025 a)	0.1058±0.0015 a)	67Le07
	0.100 ±0.006 b)	0.090 ±0.005 b)	
Vatai et al.	0.1118±0.0025 a)		68Va13
	0.0974 b)		
Zyryanova, Suslov		0.1146±0.003	68Zr
Williams	0.1099±0.0027		70Wi
Fitzpatrik et al.		0.1073±0.0004	73Fi
Bosch et al.		0.1041±0.0005	77Bo10

a) Ommiting the electron exchange corrections.
b) Including the electron exchange corrections.

Table 3.1.4 Evaluation of beta branches.

Item	Value	Ref.
$\varepsilon_1/(\beta_1+\beta_2)$	0.1080±0.0017	
β_2/β_1	0.0006±0.0002	53Wr13
ε_2/β_2 (Theoretical)	0.0023	70MaB1
β_1	90.20±0.14 % a)	
β_2	0.05 ±0.02 %	
ε_1	9.75 ±0.15 %	
ε_2	0.0001 %	

a) Obtained from the equation $\beta_1+\beta_2+\varepsilon_1+\varepsilon_2=1$.

Table 3.1.5 Experimental values of internal conversion coefficient for the 1275 keV transition.

Authors	$\alpha \times 10^6$	Ref.
Leamer, Hinman	6.74±0.67	54Le
Nakayama, Hirata	6.77±0.45	63Na

Table 3.1.6 Theoretical values of internal conversion coefficients and internal pair formation coefficient.

Item		Value
Atomic number		10
Energy (keV)		1274.5
Multipolarity		E2
Conversion coeff coefficients	α_K	6.42(- 6)
	α_{L_1}	3.77(- 7)
	α_{L_2}	2.07(-10)
	α_{L_3}	3.39(-10)
	α_L	3.78(- 7)
	K/L	17
	α	6.80(- 6)
Pair formation coefficient	Γ	2.5(-5)
Gamma branch	$1/(1+\alpha+\Gamma)$	0.999968

Table 3.1.7 Evaluation of gamma-ray intensities per decay.

Item	Value	Ref.
$\beta_2+\varepsilon_2$	0.05±0.02 %	
α_1	(6.76±0.37) 10^{-6} a)	
Γ_1	2.5×10^{-5}	
γ_1	99.94±0.02 % b)	
$\beta_1+\beta_2$	90.25±0.14 %	
f_1 c)	0.27 %	49Or
f_2 d)	1.0 ±0.2 %	76Az
γ_a e)	178.0 ±0.5 %	

a) Weighted average of the two values in Table 3.1.5.
b) Obtained from the equation $\gamma_1(1+\alpha_1+\Gamma_1)+\beta_2+\varepsilon_2=1$.
c) Cross section ratio of 3γ to 2γ decay.
d) Ratio of positron annihilation in flight to total annihilation in aluminum.
e) Annihilation radiation intensity obtained from the equation $\gamma_a=2(\beta_1+\beta_2-f_1-f_2)$.

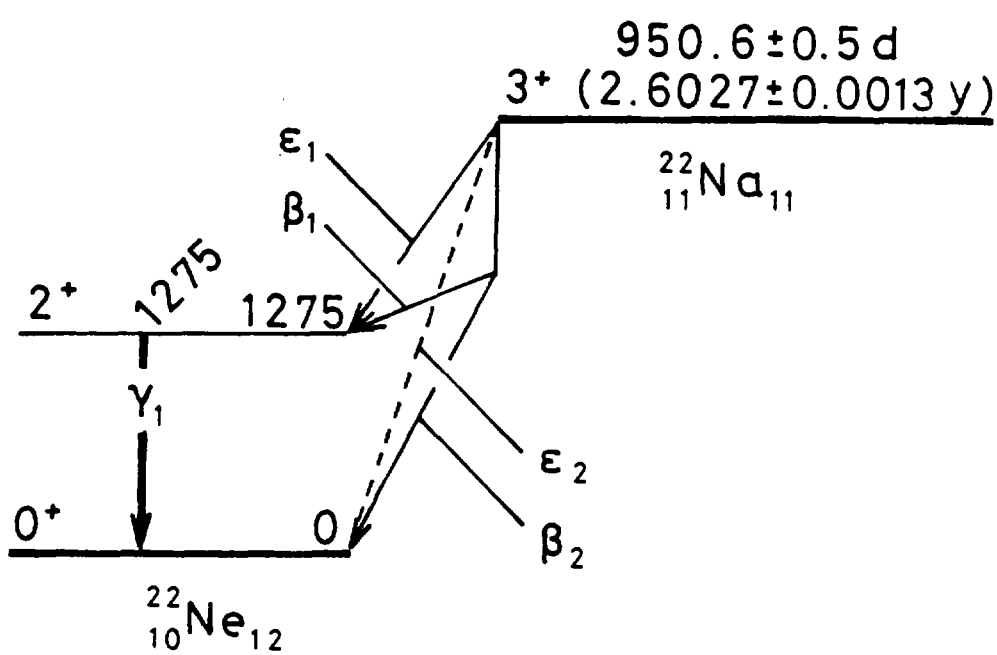

Fig. 3.1.1 Decay scheme of ^{22}Na

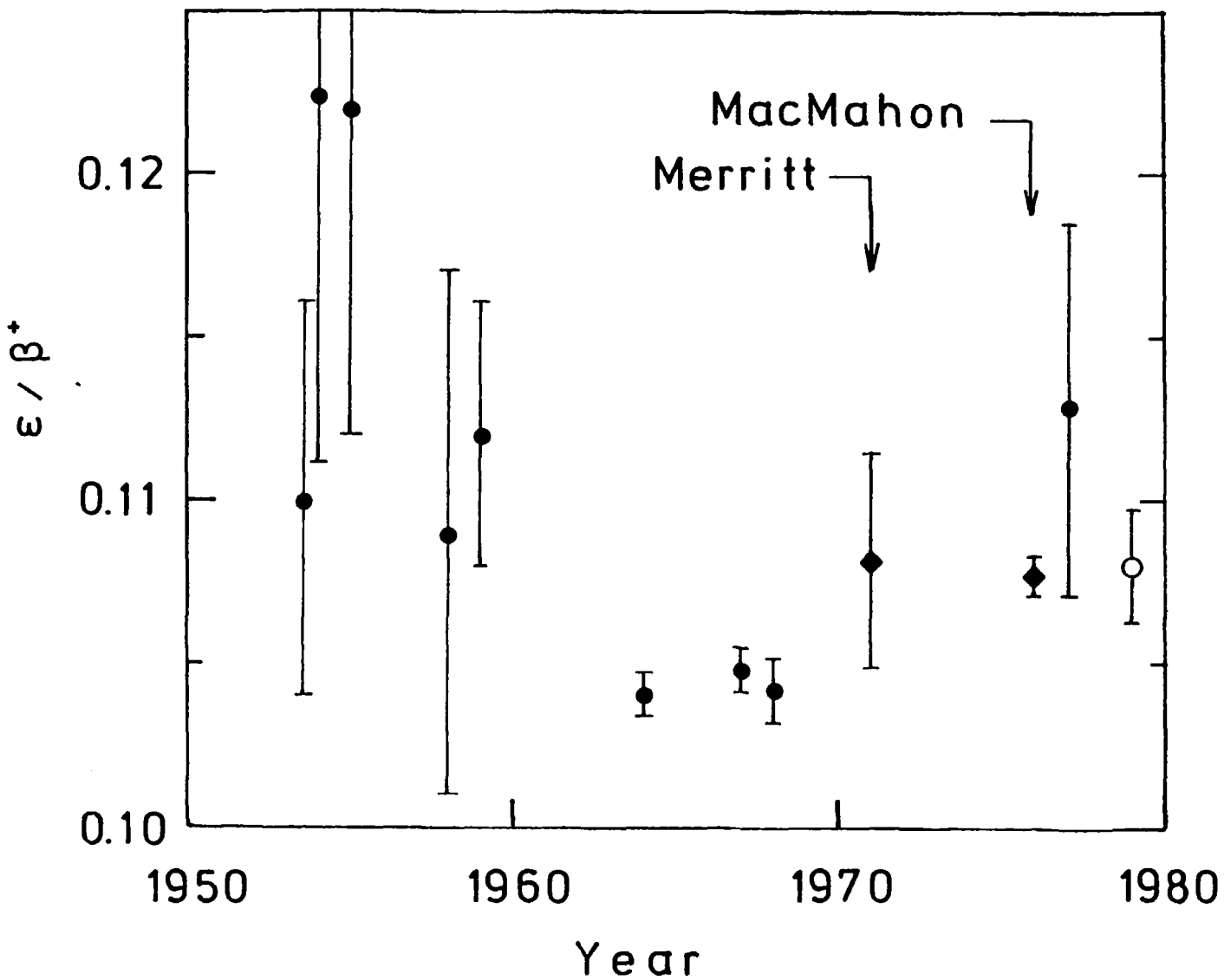

Fig. 3.1.2 Ratio of electron capture to positron decay.

3.2 ^{24}Na

The short-lived nuclide ^{24}Na decays to ^{24}Mg and emits the 1369 keV and 2754 keV gamma rays of almost 100 % per decay. The decay scheme is shown in Fig. 3.2.1. Relative intensities and intensities per decay of these strong gamma rays were evaluated.

a) Beta-decay branches. The main beta transition feeds to the second excited state (4+). A weak branch to the first excited state was observed by Turner and Cavanagh (51Tu). Their result is 3×10^{-5} for the ratio of this weak transition to the main transition, which was used for our evaluation.

b) Weak gamma rays. Two weak gamma rays of 3867 keV and 4239 keV were observed in the decay of ^{24}Na. These intensities are shown in Table 3.2.1. The values of Lebowitz et al. (70Le12) and Raman et al. (72Ra21) were adopted for relative intensities of the 3867 keV and the 4239 keV gamma rays, respectively. On the other hand, weak gamma rays emitted from the 4239 keV and the 5236 keV levels were measured in nuclear reactions such as ^{23}Na(p, γ)^{24}Mg. The branching ratios of gamma rays are listed in Table 3.2.2, and the values of Meyer et al. (72Me09) were adopted. The 997, 1113 and 5236 keV gamma rays emitted from the 5236 keV level were neglected.

c) Internal conversion and pair formation coefficients. Theoretical coefficients are shown in Table 3.2.3. The theoretical values were adopted for the total internal conversion coefficient. Many experimental values of the pair formation coefficients are available as shown in Table 3.2.4. We adopted Spring's values which are in agreement with the theoretical values in Table 3.2.3.

d) Evaluation of the strong gamma rays. Intensities per decay of two strong gamma rays at 1369 keV and 2754 keV were evaluated, as shown in Table 3.2.5, by using the three weak gamma rays and the pair formation coefficients, while the internal conversion coefficients are negligibly small. The final evaluated values are listed in Table 3.2.6.

Table 3.2.1 Experimental values of relative gamma-ray intensities.

Authors \ Number / Energy(keV)	1 1368	2 2754	6 3867	8 4239	9 5236	Ref.
Artamonova et al.	(100)	100	0.09 ±0.02	0.0015 ±0.0005	$<2\times10^{-5}$	60Ar
Monahan et al.	(100)	100	0.075 ±0.020	0.008 ±0.003[a]	$<7\times10^{-4}$	62Mo
Vanklinken et al.	(100)	100	0.063			68Va06
Lebowitz et al.	(100)	100	0.0489±0.0025	0.0033[a]		70Le12
Raman et al.	(100)	100		0.00084±0.00010*		72Ra21

a) Gamma rays of number 7 and 8 are not resolved.

Table 3.2.2 Experimental values of gamma-ray branching ratios in nuclear reactions and in the decay of ^{24}Na.

Authors \ Level energy	4239 keV		5236 keV				Ref.
Number	5	8	3	4	6	9	
Energy (keV)	2871	4239	996	1113	3867	5236	
Batchelor	1.0	2.9 ±0.5					60Ba
Cohen, Cookson	1.0	3.44±0.50	<3		92	<5	62Co
Meyer et al.*	23 ±2	77 ±2	1.0±0.5	<1	99.0±0.5	<8	72Me09
Detratz	1.4±0.4	3.6 ±0.4					72De28

Table 3.2.3 Theoretical values of internal conversion coefficients and internal pair formation coefficients.

Item		Value	
Atomic number		12	12
Energy (keV)		1368.6	2754.1
Multipolarity		E2	E2
Conversion coefficients	α_K	9.33(-6)	2.52(-6)
	α_{L_1}	6.12(-7)	1.76(-7)
	α_{L_2}	5.44(-10)	7.15(-11)
	α_{L_3}	8.83(-10)	1.70(-10)
	α_L	6.13(-7)	1.76(-7)
	K/L	15.2	14.3
	M/L	0.05	0.05
	α	9.97(-6)*	2.71(-4)*
Pair formation coefficient	Γ	0.3(-4)	6.9(-4)
Gamma branch	$1/(1+\alpha+\Gamma)$	0.99996	0.99931

Table 3.2.4 Experimental values of internal pair formation coefficients.

Authors	$\Gamma\times10^4$		Method	Ref.
	1369 keV	2754 keV		
Rae		11.6 ±1.0	e^+/β	49Ra
Mims et al.		7.6 ±1.9	Ann/decay	50Mi
		8.25±1.05	Ann/decay	50Mi
Cleland et al.		6.7 ±1.0	Ann/decay	51Cl
Slätis, Siegbahn	0.30	8.0 ±0.5	e^+/β	52Sl
Bloom	0.6 ±0.1	7.1 ±0.2	e^+/β	52Bl
Spring	0.4 ±0.3*	6.6 ±0.7*	Triple coinc.	65Sp08

Table 3.2.5 Evaluation of gamma-ray intensity per decay.

Item	Value	Remarks
β_4/β_3	0.003 ±0.001[a)]	51Tu
γ_6^+/γ_2^+	0.0489 ±0.0025	70Le12
γ_8^+/γ_2^+	0.00084±0.00010	72Ra21
γ_5^0/γ_8^0	29.9 ±2.7	72Me09
γ_2'	99.9470 ±0.0027	b)
γ_1'	99.99916±0.00010	$1-\gamma_2'(\gamma_8'/\gamma_2')$
γ_1	99.994 ±0.003	$\gamma_1'/(1+\alpha_1+\Gamma_1)$
γ_2	99.881 ±0.008	$\gamma_2'/(1+\alpha_2+\Gamma_2)$

a) The error is estimated by us.

b) $[1+\frac{\beta_4}{\beta_3}+\frac{\gamma_6'}{\gamma_2'}+\frac{\gamma_8'}{\gamma_2'}(1+\frac{\gamma_5'}{\gamma_8'})]^{-1}$.

Table 3.2.6 Evaluated values.

Gamma ray		Intensity per decay (%)	Relative intensity (%)
Number	Energy (keV)		
1	1368.6	99.994±0.003	100.000±0.003
2	2754.1	99.881±0.008	99.887±0.008

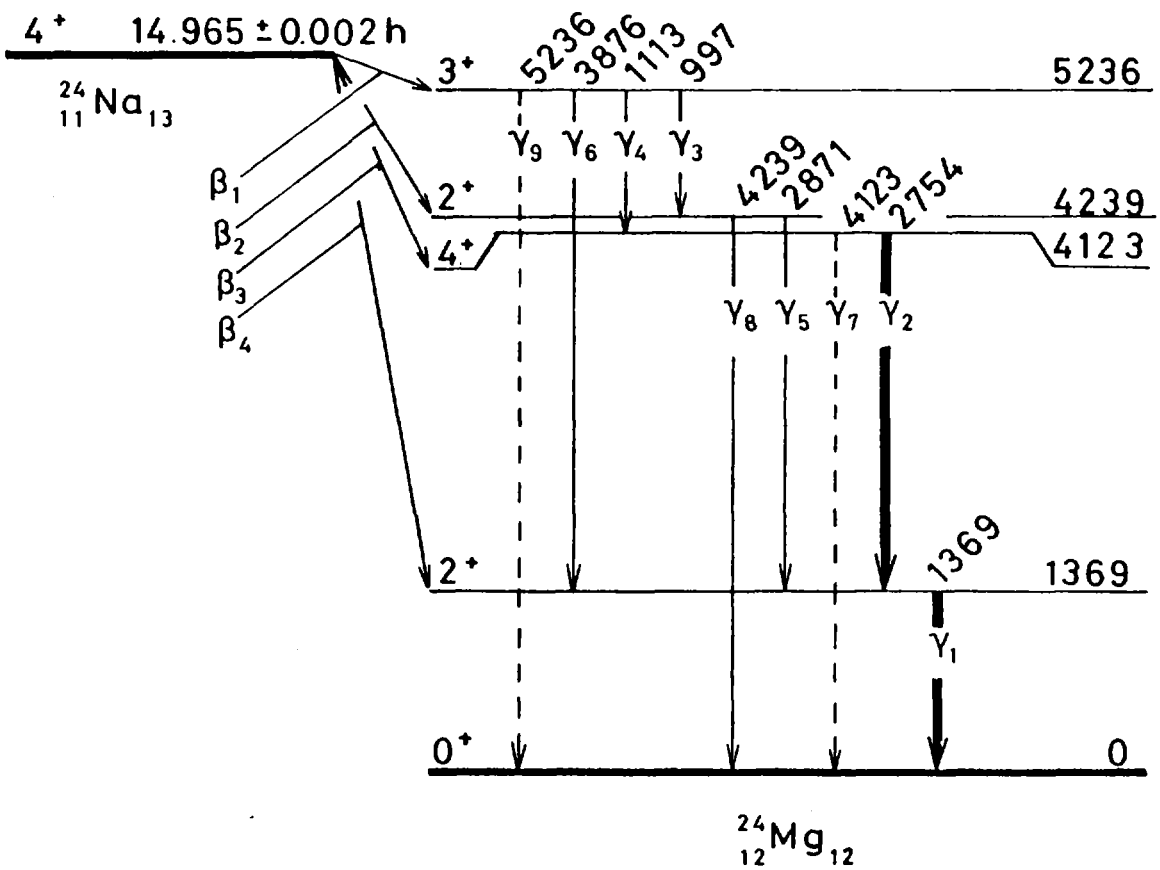

Fig. 3.2.1 Decay scheme of ^{24}Na.

3.3 ^{46}Sc

Two cascade gamma rays of 889 keV and 1120 keV are emitted in the decay of ^{46}Sc. The decay scheme is shown in Fig. 3.3.1. Intensities per decay and relative intensities of these gamma rays were evaluated.

a) Beta-decay branching. Main part of beta transitions feeds to the second excited state, while a small branch does to the first excited state. The upper limit of it was observed by several group as shown in Table 3.3.1. Since Wolfson's value (56Wo09) is consistent with other upper limits, this value is adopted. Then the log ft value becomes 12.94, which is suitable to the non-unique second forbidden transition. The beta transition to the ground state is the fourth forbidden $4^+ \rightarrow 0^+$. Hence this branching was neglected.

b) Weak gamma rays. Three groups observed the upper limits of weak gamma rays which are shown in Table 3.3.2. The upper limit of the cross over gamma ray at 2010 keV was obtained to be 1.2×10^{-5} from Fluharty and Deutsch (49Fl05). Recent Ge(Li) detector measurement by Iwata and Yoshizawa (80Iw) indicates that no effective weak gamma rays exist. The possibility of the existence of weak gamma rays is very small, because no other excited states lower than 2611.3 keV of ^{46}Ti have been found by nuclear reaction experiments.

c) Internal conversion coefficients. Experimental values of total internal conversion coefficients are shown in Table 3.3.3. The theoretical internal conversion coefficients of two gamma rays are listed in Table 3.3.4, which were obtained by extrapolation. The pair formation coefficient for the 1120 keV gamma ray was also estimated. The experimental values scatter each other, but roughly agree with the theoretical values, except values given with the Compton electron method by Sturcken et al (54St08). Since both transitions are pure E2, the theoretical values with 10 % errors were adopted.

d) Evaluation of intensities. The evaluation method of the intensities per decay are shown in Table 3.3.5. The error of the 889 keV gamma ray was obtained only from the error of α_1, while the error of the 1120 keV gamma ray was from the errors of β_2 and α_2. The error of the relative intensity is given by the root square sum of the errors of the two gamma rays. The final evaluated values are listed in Table 3.3.6.

Table 3.3.1 Experimental values of beta-ray branching ratio of the 1.47 MeV component (β_2).

Authors	Value (%)	Ref.
Moon et al.	≦0.06	50Mo62
Sorensen et al.	<0.05	50So57
Whalen et al.	≦0.1	53Wh06
Keister, Schmidt	0.096±0.001	54Ke04
Wolfson	0.0036±0.0007*	56Wo09

Table 3.3.2 Upper limit of weak gamma rays.

Authors	Gamma-ray energy (MeV)	Intensity (%)	Ref.
Fluharty, Deutsch	1.63∿2.68	1.2×10^{-5}	49Fl05
Bartlett et al.	0.05∿2.0	<2.2	63Ba40
Iwata, Yoshizawa	0.09∿1.116	<0.06	80Iw
	1.124∿2.400	<0.006	

Table 3.3.3 Experimental values of internal vonversion coefficients.

Gamma ray		$\alpha\times10^4$			
Number	Energy (keV)	Moon et al. 50Mo62	Whalen et al. 53Wh06	Strucken et al. 54St08	Keister 54Ke28
1	889.2	1.74±0.08	1.9	1.86±0.25 a) 2.60±0.50 b)	1.55±0.16
2	1120.5	0.98±0.05	0.88	1.00±0.06 a) 1.34±0.15 b)	0.82±0.08

a) Beta ray spectrometer.
b) Compton electron method.

Table 3.3.4 Theoretical values of internal conversion coefficients.

Item		Value	
Atomic number Z		22	22
Energy (keV)		889.2	1120.5
Multipolarity		E2	E2
Conversion coefficients	α_K	1.49(-4)	8.44(-5)
	α_{L_1}	1.32(-5)	7.47(-6)
	α_{L_2}	9.07(-8)	3.98(-8)
	α_{L_3}	1.11(-7)	5.12(-8)
	α_L	1.26(-5)	7.82(-6)
	K/L	11.12	11.16
	M/L	0.14	0.14
	α	1.64(-4)*	9.30(-5)*
Pair formation coefficient	Γ		0.4(-6)*
Gamma branch	$1/(1+\alpha+\Gamma)$	0.9994	0.99991

Table 3.3.5 Evaluation of intensity per decay.

Item	Value	Ref.
β_2	0.0036±0.0007 %	56Wo09
Cross-over gamma ray	Neglected	
α_1 (Theoretical)	1.64×10^{-4}	
α_2 (Theoretical)	9.30×10^{-5}	
Γ_2 (Theoretical)	0.4×10^{-6}	
γ_1	99.9836±0.0016 % a)	
γ_2	99.9871±0.0012 % a)	

a) Obtained from the equations $\gamma_2(1+\alpha_2+\Gamma_2)+\beta_2=1$ and $\gamma_1(1+\alpha_1)=1$.

Table 3.3.6 Evaluated values.

Gamma ray		Intensity per decay (%)	Relative intensity (%)
Number	Energy (keV)		
1	889.2	99.9836±0.0016	99.9965±0.0016
2	1120.5	99.9871±0.0012	100.0000±0.0012

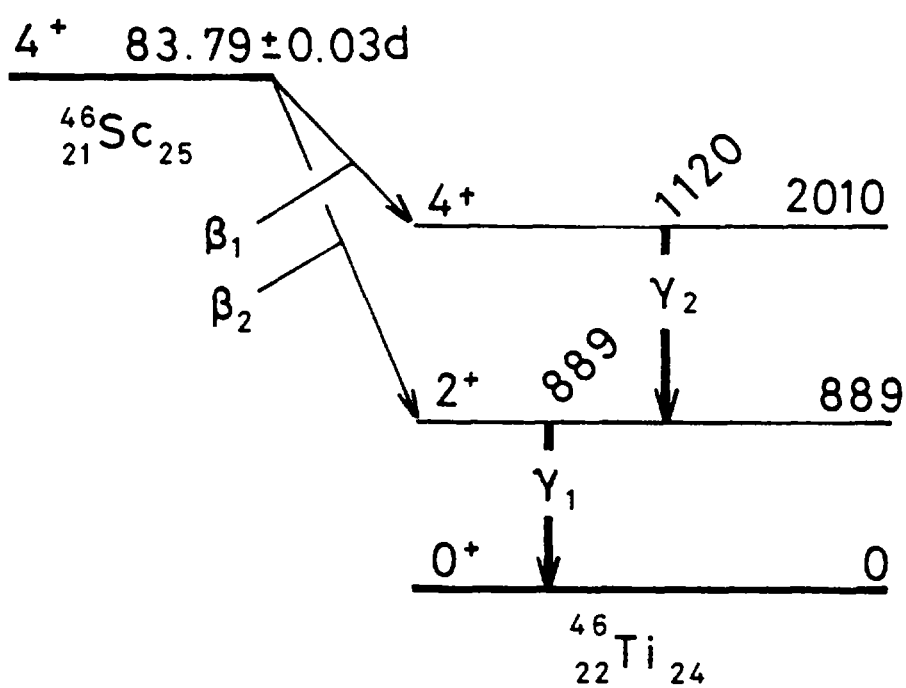

Fig. 3.3.1 Decay scheme of ^{46}Sc.

3.4 ^{54}Mn

The radioactive nuclide ^{54}Mn decays to ^{54}Cr by electron capture and emits the 835 keV gamma ray as shown in Fig. 3.4.1. No other gamma rays have been observed.

a) Ground state transition. The main electron capture transition feeds to the first excited state at 835 keV of ^{54}Cr. Since the Q value between ground states of ^{54}Mn and ^{54}Cr is 1375 keV as shown in Table 3.4.1, the weak positron emission is expected. Berenyi et al. (68Be01) observed upper limit of the β^+ transition, and gave a lower limit of the log ft value shown in Table 3.4.1. This value is reasonable for the unique second forbidden transition compared with log ft = 12 for ^{10}Be. From this limit the electron capture transition is expected to be $\varepsilon_2 < 1\times10^{-5}$. Therefore this branching ratio is assumed to be $\varepsilon_2 = (0.5\pm0.5)\times10^{-5}$.

b) Weak gamma rays. No one reported a weak gamma ray up to date. In addition, the second excited state was observed at 1824 keV which is higher than the ground state of ^{54}Mn and no level between 835 keV and 1824 keV has been observed by various kinds of nuclear reactions. Therefore, no weak gamma ray can be expected.

c) Internal conversion coefficient. A few measurements were reported for the internal conversion coefficient of the 835 keV transition shown in Table 3.4.2. In this region, deviations between experimental and theoretical coefficients are small and the 835 keV transition is a pure E2 transition. Therefore, the theoretical internal conversion coefficient given by Band et al. (76Ba) was adopted. The theoretical coefficients are listed in Table 3.4.3.

d) Evaluation of intensity. The 835 keV gamma-ray intensity was evaluated from the upper limit of the ground state electron capture transition and the theoretical total internal conversion coefficient as shown in Table 3.4.4.

Table 3.4.1 Beta transition to the ground state.

Authors	Q_ε (keV)	β_1^+	log *ft*	ε_2	Ref.
Berenyi et al.		$<8\times10^{-7}$	> 12.0	$<1\times10^{-5}$ *	68Be01
Wapstra, Gove	1374.9±3.6				71Wa

Table 3.4.2 Experimental values of internal conversion coefficients.

Authors	$\alpha_K\times10^5$	K/L	$\alpha\times10^5$	Ref.
Katoh et al.		8.5±0.7		58Ka34
Rao			20 ±5	63Ra21
Hamilton et al.	22.4±1.0		25.1±1.1	66Ha07

Table 3.4.3 Theoretical values of internal conversion coefficients.

Item		Value
Atomic number		24
Energy (keV)		834.8
Multipolarity		E2
Conversion coefficients	α_K	2.25(-4)
	α_{L_1}	2.04(-5)
	α_{L_2}	1.89(-7)
	α_{L_3}	2.21(-7)
	α_L	2.08(-5)
	K/L	1.08(+1)
	M/L	0.15
	α	2.49(-4)
Gamma branch	$1/(1+\alpha)$	0.999751

Table 3.4.4 Evaluation of the 835 keV gamma-ray intensity.

Item	Value
ε_2	$(0.5\pm0.5)\times10^{-5}$
α	$(24.9\pm2.5)\times10^{-5}$
$1/(1+\alpha)$	0.999751 ± 0.000025
γ_1	99.9746 ± 0.0025 %

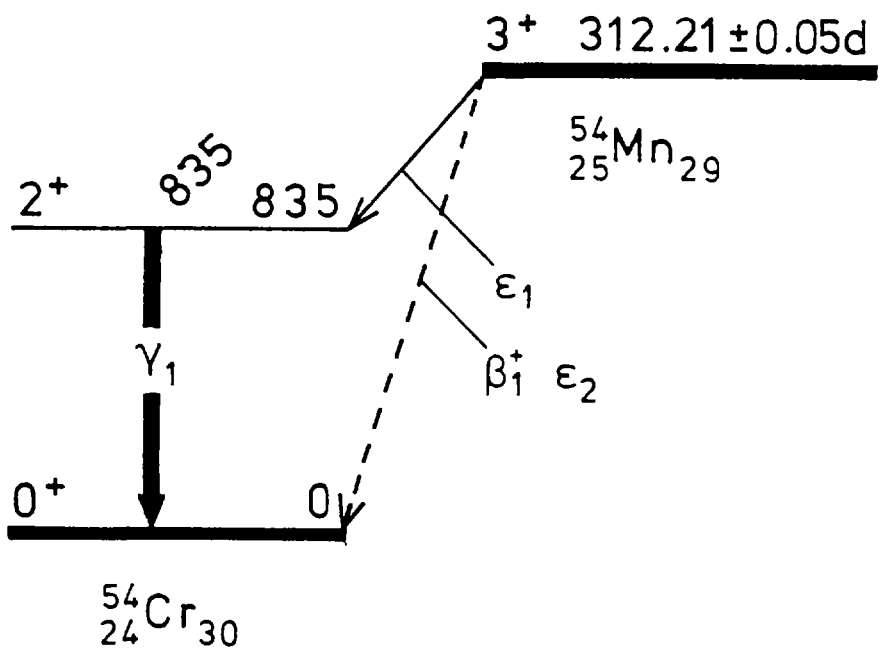

Fig. 3.4.1 Decay scheme of ^{54}Mn.

3.5 ^{60}Co

Two strong gamma rays of 1173 keV and 1333 keV and three weak gamma rays are emitted in the decay of ^{60}Co. The decay scheme is shown in Fig. 3.5.1. Intensities per decay and relative intensities of the two strong gamma rays were evaluated by using weak beta decay branching ratios, weak gamma ray intensities and internal conversion coefficients.

a) Beta decay branchings. Observed values of beta decay branching ratios are listed in Table 3.5.1. The main transition is the 316 keV component. The weak branch β_4 to the first excited state is important to evaluate the intensity of the 1173 keV gamma ray. Since Hansen (68Ha03) reported details of experiment and discussed the error, his value was adopted.

Other weak branches β_1 and β_3 can be estimated from weak gamma-ray intensities. Since the beta transition to the ground state is the unique fourth forbidden, this branching is completely negligible.

b) Weak gamma rays. Wolfson (55Wo44) observed internal conversion electrons of the weak gamma ray at 2159 keV. Measurements of weak gamma rays were performed by many groups by means of the coincidence method, the Compton suppression spectrometry and others. These results are listed in Table 3.5.2. The values of Camp and Van Hise (76Ca) were adopted for the 347 keV and 2159 keV gamma rays, because their measurement with a Compton suppression spectrometer is reliable and their values agree with some others. For the 2506 keV gamma ray the value of Fujishiro (76Fu) was adopted.

Unobserved weak gamma-ray intensities were estimated from gamma-ray branching ratio in the decay of ^{60}Cu. These values are shown in Table 3.5.3.

c) Internal conversion and pair formation coefficients. Experimental values of the internal conversion coefficients and the internal pair formation coefficients for two strong gamma rays are shown in Table 3.5.4. Experimental values were used for internal pair formation coefficients. Theoretical values of the internal conversion coefficients were used for evaluation. These values are listed in Table 3.5.5.

d) Evaluation of intensity. The branching ratios of the beta decays were evaluated from the experimental values of the beta branching ratios and the weak gamma-ray intensities (Table 3.5.6).

The evaluated values of weak gamma-ray intensities are summarized in Table 3.5.7. The 1173 keV and 1333 keV gamma-ray intensities were evaluated by using the beta-decay branching ratios, the weak gamma-ray intensities and the internal conversion coefficients. Equations for the evaluation are shown in remarks of Table 3.5.7. The final results in intensities per decay and relative intensities are summarized in Table 3.5.8.

Table 3.5.1 Experimental values of beta-ray branching ratios.

Authors \ Number	Brancing ratios (%) 1	2	3	4	Ref.
Maximum energy(keV)	196	316	663	1490	
Keister,Schmidt				0.15	54Ke04
Wolfson			<0.0105[a)]		55Wo44
Wolfson				0.010±0.002	56Wo09
Camp et al.				0.12	61Ca05
Hansen,Spernol		99.74±0.05	0.18±0.03	0.08 ±0.02*	68Ha03
Rauch et al.			<0.022		69Ra23
Van Hise,Camp	<0.0006	99.862	<0.0057		69Va20
Dixon,Storey	<0.01		<0.01		70Di01
Rice-Evans,Aung			<0.012		70Ri20
Legrand,Clement		99.92	∿0.0035	∿0.08	72Le

Table 3.5.2 Experimental values of gamma-ray intensities per decay.

Authors \ Number	Intensity per decay ×10^6 2	3	4	6	8	9	Ref.
Energy(keV)	346.8	467.3	826.4	1293.7	2158.9	2505.7	
Wolfson					12±2		55Wo44
Van Hise,Camp	78						69Va20
Legrand,Clement			30±20		5±2	non obs.	72Le
Fujishiro					20±13	0.09±0.07	73Fu
Camp,Van Hise	75.8±5.0	<2.3	76.2±8.0	<1.1	11.1±1.8*		76Ca
Logan et al.	69 ±10	<12					77Lo

Table 3.5.3 Branching ratios of transition intensities from the decay of ^{60}Cu.

Gamma ray		Gamma-ray Branching ratios	Branching ratios of transition intensities
Number	Energy (keV)	γ† 69Ra07	(%)
4	826.4	24.7 ± 1.2	86.7
8	2158.9	3.8 ± 0.2	13.3
1	120.5	0.22± 0.02	4.5
3	467.3	4.0 ± 0.2	62.6
6	1293.7	2.1 ± 0.2	32.9
10	2626.2	<0.02 a)	<0.31

a) Our estimation from F. Rauch et al. (69Ra07)

Table 3.5.4 Experimental values of conversion coefficients.

Gamma ray Number	Energy (keV)		Waggoner et al. 50W09	Fan 52F14	Kamada et al. 58K13	Camp et al. 61Ca5	Frey et al. 62Fr13	Spring 65Sp08
5	1173.3	$\alpha \times 10^4$	1.73±0.06	1.72±0.17		1.65	1.65±0.07	
		$\alpha_K \times 10^4$			1.50±0.06			
		$\Gamma \times 10^5$						1.5±0.5*
7	1332.5	$\alpha \times 10^4$	1.29±0.04	1.24±0.12				
		$\alpha_K \times 10^4$			1.16±0.06			
		$\Gamma \times 10^5$						4.7±0.7*

Table 3.5.5 Theoretical values of internal conversion coefficients and internal pair formation coefficients.

Item		Value	
Atomic number	Z	28	
Energy (keV)		1173.3	1332.5
Multipolarity		E2	E2
Conversion coefficients	α_K	1.50(-4)	1.13(-4)
	α_{L_1}	1.44(-5)	1.09(-5)
	α_{L_2}	1.55(-7)	1.18(-7)
	α_{L_3}	1.57(-7)	1.07(-7)
	α_L	1.47(-5)	1.11(-5)
	K/L	10.20	10.20
	M/L	0.16	0.16
Pair formation coefficients	α	1.67(-4)*	1.26(-4)*
	Γ	0.9(-5)	3.7(-5)
	$1/(1+\alpha+\Gamma)$	0.999824	0.999837

Table 3.5.6 Evaluated values of beta-ray branching ratios per decay.

Beta ray		Branching ratio (%)	Estimation
Number	Maximum energy(keV)		
1	196	<0.00037	$\gamma_1'+\gamma_3'+\gamma_6'+\gamma_{11}'$
2	316	99.91 ±0.03	$\gamma_5'+\gamma_2'+\gamma_{10}'-\gamma_1'$
3	663	0.0087±0.0009	$\gamma_4'+\gamma_8'$
4	1490	0.08 ±0.02*	

Table 3.5.7 Evaluated values of intensities per decay.

Gamma ray		Intensity per decay (%)	Remarks
Number	Energy (keV)		
1	120.5	$(8\pm8)\times10^{-6}$	$\beta_1\times\gamma_1'$
2	346.8	0.0076±0.0005	76Ca
3	467.3	0.00012±0.00012	76Ca
4	826.4	0.0076±0.0008	76Ca
5	1173.3	99.89±0.02	$(\gamma_7-\gamma_6-\gamma_4-\beta_4)/(1+\alpha+\Gamma)$
6	1293.7	0.00006±0.00006	76Ca
7	1332.5	99.9816±0.0015	$(100-\gamma_8-\gamma_{11}-\gamma_{10})/(1+\alpha+\Gamma)$
8	2158.9	0.00111±0.00018	76Ca
9	2505.7	$(9\pm7)\times10^{-6}$	73Fu
10	2626.2	$(6\pm6)\times10^{-6}$	$\gamma_1\times\gamma_{11}'$

Table 3.5.8 Evaluated values.

Gamma ray		Intensity per decay	Relative intensity	Remarks
Number	Energy (keV)	(%)	(%)	
5	1173.3	99.89 ±0.02	99.91 ±0.02	a)
7	1332.5	99.9816±0.0015	100.0000±0.0015	b)

a) These values are obtatned from intensities of three transitions to the first excited state (826 keV, 1173 keV and 1294 keV).

b) These values are evaluated from intensities of the 1332 keV and 2159keV transitions. Other gamma transitions to the ground state are neglected.

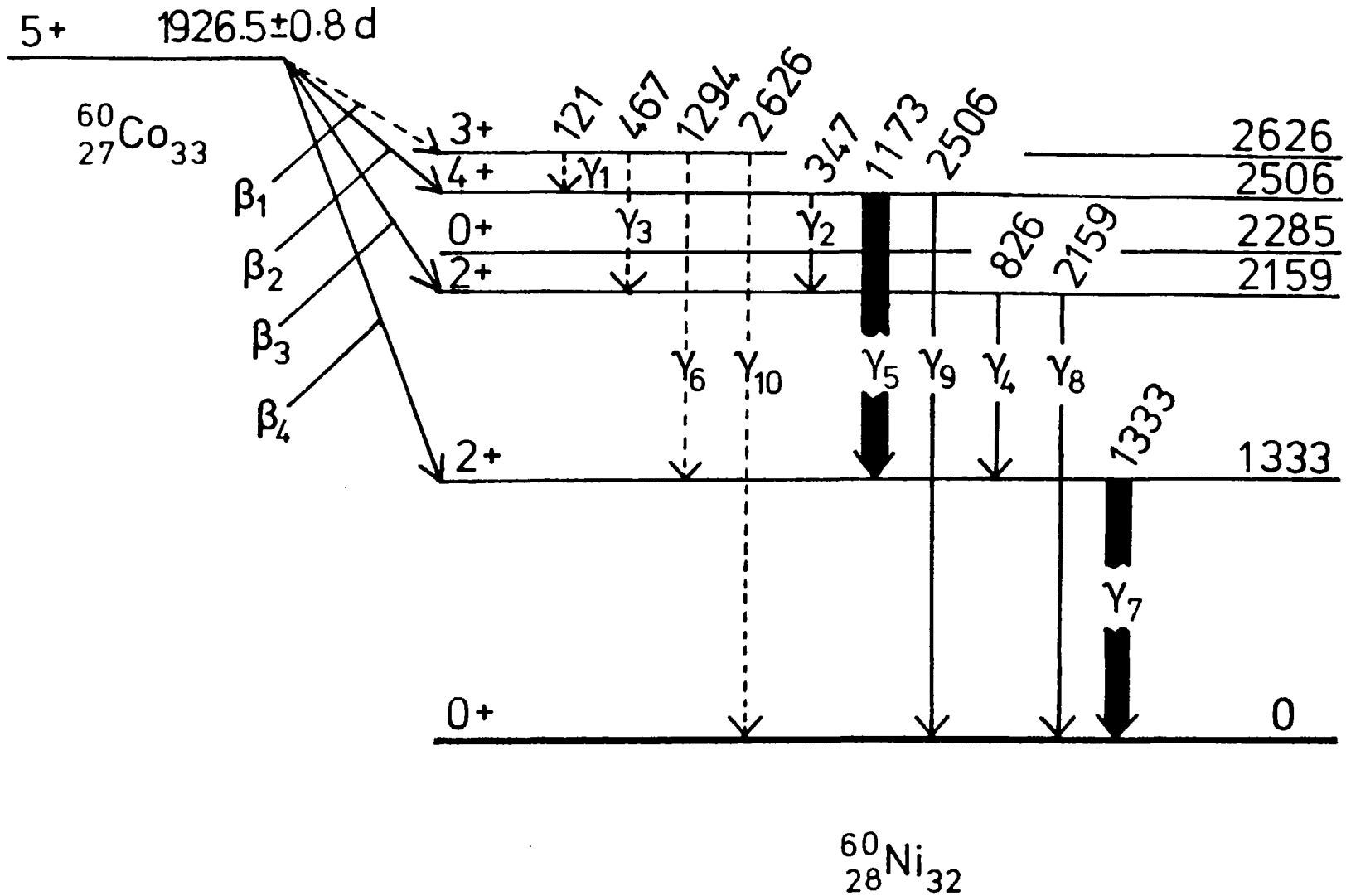

Fig. 3.5.1 Decay scheme of ^{60}Co.

3.6 ^{85}Sr

The radioactive nuclide ^{85}Sr decays to ^{85}Rb by electron capture and emits the 514 keV gamma ray. The decay scheme is shown in Fig. 3.6.1. The intensity per decay was evaluated for this gamma ray.

a) Electron capture transition to the ground state. No one observed the branching ratio of the ground state transition, and the measurement of this branching ratio is almost impossibly difficult. However, this ratio is the most important value to evaluate the gamma-ray intensity. Therefore we estimated it from the systematics of log ft values in neighbouring nuclei. This transition is a unique first forbidden one $9/2+ \rightarrow 5/2-$. Log f_1t values of the unique first forbidden transitions in neighbouring nuclei are listed in Table 3.6.1. The values except for ^{81}Kr and ^{86}Y are between 9.40 and 9.60. We adopted 9.47±0.17 as the unweighted average of seven values with uncertainty of 2 σ. This adopted value includes most of log f_1t values in neighbouring nuclei. Then the branching ratio was calculated as shown in Table 3.6.2. The half-life of ^{85}Sr was taken from the value in 4.6 and the Q_β value was from the mass table of Wapstra and Gove (71Wa). The adopted branching ratio of the ground state transition is obtained to be 0.8±0.4 %.

b) Weak gamma rays. Experimental values of relative intensities are listed in Table 3.6.3. Bubb et al. (71Bu08) reported that the 869 keV gamma ray decreased after chemical separation. The value given by Vatai et al. (74Va02) was adopted to evaluate the intensity of the 514 keV gamma ray.

c) Internal conversion coefficients. Experimental values and theoretical values of the internal conversion coefficients for the 514 keV transition are shown in Table 3.6.4 and Table 3.6.5, respectively. The experimental values are compatible with the theoretical values of M2 and E3 within the experimental errors. It is possible that the transition is M2 and E3 mixing. Therefore, the experimental value of α given by Sunyar et al. (52Su29) was adopted, though the error is large.

d) Evaluation of the intensity per decay. The 514 keV gamma-ray intensity was evaluated by using the estimated value of the electron capture transition to the ground state, the weak gamma-ray intensity and internal conversion coefficient, as shown in Table 3.6.6. The evaluated value is 98.4±0.4 %. The main part of the error is due to the electron capture transition to the ground state. If one neglects the electron capture branching to the ground state, a larger value is obtained as 99.2 %.

Table 3.6.1 Log *ft* values of the unique first forbidden transition for the neighbouring nuclei.

Nucleus		Spin-parity		log *ft*
Parent	Daughter	Initial	Final	
^{79}Se	^{79}Br	7/2+	3/2-	10.17
^{81}Kr	^{81}Br	7/2+	3/2-	11.05
^{85}Kr	^{85}Rb	9/2+	5/2-	9.45
^{89}Sr	^{89}Y	5/2+	1/2-	9.40
^{91}Y	^{91}Zr	1/2-	5/2+	9.59
^{84}Rb	^{84}Kr	2-	0+	9.60
^{84}Rb	^{84}Sr	2-	0+	9.44
^{86}Rb	^{86}Sr	2-	0+	9.43
^{86}Y	^{86}Sr	4-	2+	11.10
^{90}Y	^{90}Zr	2-	0+	9.40

Table 3.6.2 Estimation of the electron-capture transition intensity from ^{85}Sr to the ground state of ^{85}Rb.

Item	Value	Ref.
log *ft*	9.47±0.17	
Transition energy	1064 ±7 keV	71Wa
log *f*	0.61	71Go
$T_{1/2}$	64.93±0.24 day	
ε_3	0.8 ±0.4 %	

Table 3.6.3 Experimental values of relative gamma-ray intensities.

Gamma ray		Sattler	Vartanov et al.	Bubb et al.	Vatai et al.
Number	Energy (keV)	62Sai2	66Val6	71Bu08	74Va02
1	514.0	100	100	100	100
2	356	0.002		no	$<10^{-3}$
3	869	0.017	0.010±0.002	<0.006	0.014±0.002*

Table 3.6.4 Experimental values of internal conversion coefficients for the 514 keV transition.

Authors	$\alpha_K \times 10^3$	K/L	$\alpha \times 10^3$	Ref.
Emmerich, Kurbatov	7	12±3		52Em02
Sunyar et al.			8±1*	52Su29
Alvager et al.		8.4		62Al11

Table 3.6.5 Theoretical values of internal conversion coefficients.

Item		Value	
Atomic number		37	
Energy (keV)		514.0	
Multipolarity		M2	E3
Conversion coefficients	α_K	6.30(-3)	7.92(-3)
	α_{L_1}	6.73(-4)	8.02(-4)
	α_{L_2}	2.60(-5)	1.01(-4)
	α_{L_3}	9.85(-6)	6.66(-5)
	α_L	7.09(-4)	9.69(-4)
	K/L	8.88	8.17
	MN/L	0.18	0.18
	α	7.13(-3)	9.06(-3)
Gamma branch	$1/(1+\alpha)$	0.993	0.991

Table 3.6.6 Evaluation of intensity per decay.

Item	Value	Remarks
α_1 (Exp.)	0.008±0.001	52Su29
$\gamma_3^\dagger$	0.014±0.002 %	74Va02
ε_3 (Estimated)	0.8 ±0.4 %	
γ_1	98.4 ±0.4 %	$\gamma_1(1+\alpha_1)+\varepsilon_3+\gamma_3^\dagger=1$

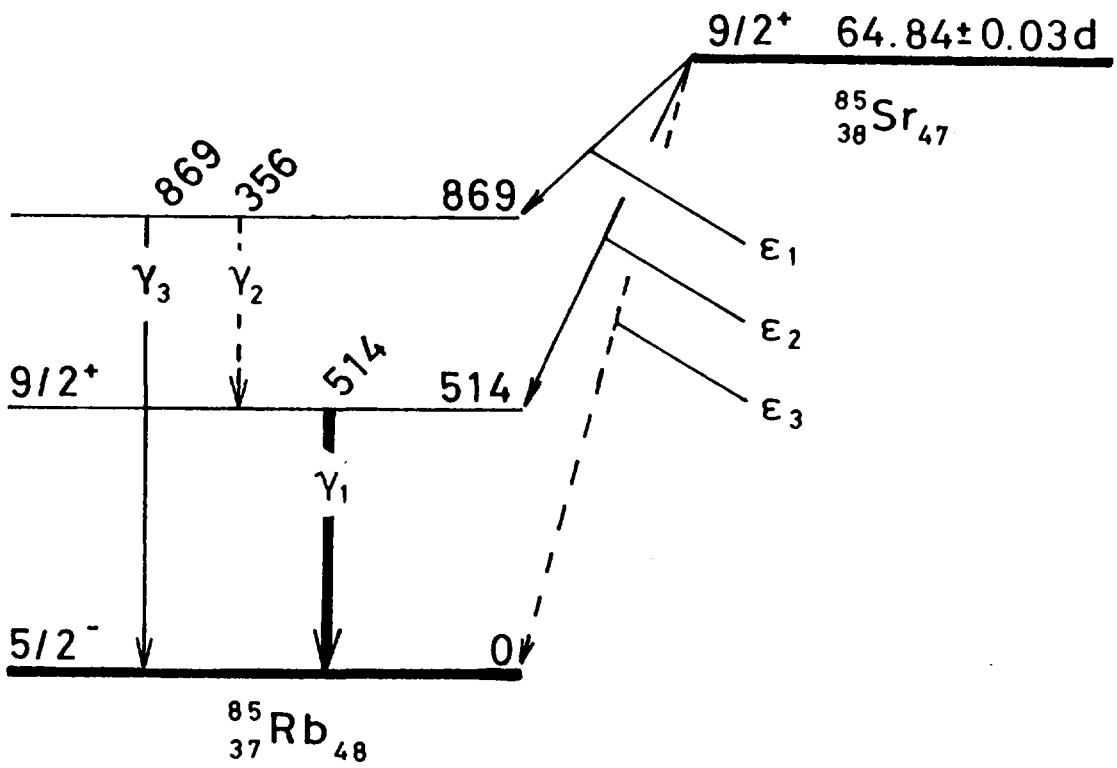

Fig. 3.6.1 Decay scheme of ^{85}Sr.

3.7 ^{88}Y

Two strong gamma rays of 898 keV and 1836 keV are emitted in the electron capture decay of ^{88}Y. The decay scheme is shown in Fig. 3.7.1. These gamma-ray intensities per decay were evaluated.

a) Electron capture transition to the ^{88}Sr ground state. This transition is not observed, and is a unique third forbidden transition 4- → 0+ . An example of the 4- → 0+ transition is ^{40}Kr, the log ft values of which are 18 and 21 for $^{40}Kr \rightarrow ^{40}Ca$ and $^{40}K \rightarrow ^{40}Ar$, respectively. Then the branching ratio of the transition to the ^{88}Sr ground state is estimated to be 10^{-9}. Therefore, this transition is neglected.

b) Gamma-ray intensities. Experimental values of relative intensities and intensities per decay are summarized in Table 3.7.1. Intensities of the 2734 keV and 3219 keV gamma rays are necessary to evaluate the intensity per decay of the 1836 keV gamma ray. The values given by Ardisson et al. (74Ar12) were adopted. The intensity ratio of the 898 keV gamma ray to the 1836 keV one was used for evaluation of the intensity of the 898 keV gamma ray.

c) Internal conversion coefficients and internal pair formation. Experimental and theoretical internal conversion coefficients are shown in Table 3.7.2 and Table 3.7.3, respectively. For the 1836 keV transition the theoretical value of α_K is obtained from interpolation of Trusov's values (72Tr) and the K/L ratio is from extrapolation of theoretical K/L ratio, because no theoretical values of α_K and α_L are available for this energy region. For the total internal conversion coefficients the experimental value is 17 % smaller than the theoretical value. The theoretical value of the internal pair formation coefficient is obtained from interpolation of the value of Lombard et al. (71Lo), and agrees with the experimental value of Allan. Therefore we adopted his experimental values for the total internal conversion coefficient and the internal pair formation coefficient.

d) Evaluation of gamma-ray intensities. The intensity per decay of the 1836 keV gamma ray was obtained from the total internal conversion coefficient, the internal pair formation coefficient and the intensities of the 2734 keV and 3219 keV gamma rays as shown in Table 3.7.4. The value of Yoshizawa et al. (79Yo) was adopted for the relative intensity of the 898 keV gamma ray. The intensity per decay of this gamma ray was obtained from this relative intensity and the intensity per decay of the 1836 keV gamma ray. The evaluated result of two strong gamma rays are shown in Table 3.7.5.

Table 3.7.1 Experimental values of gamma-ray intensities.

Gamma ray		Relative intensity					Intensity per decay	
Number	Energy (keV)	Pelle 60Pe23	Shastry et al. 64Sh16	Sakai et al. 66Sa08	Zarnowiki 67Za	Yoshizawa et al. 79Yo	Schotzig et al. 73Sc40	Ardisson et al. 74Ar12
1	898.0	94.0±0.7	91		92	94.4±0.3*	94.3±0.5	91.4±0.7[a)]
2	1836	100	100	100	100	100.0±0.3*	99.37±0.02	99.4±0.1[a)]
3	850.6							0.066±0.013
4	1328		3					0.021±0.006
5	2734		0.97	0.63±0.04	0.63±0.4			0.72 ±0.07*
6	3219		0.3	0.0095±0.003				0.0071±0.0020*

a) IAEA recommended value.

Table 3.7.2 Experimental values of internal conversion coefficients and internal pair formation coefficients.

Gamma ray			Peacock Jones Pe	Metzger Amacher 52Me50	Hamilton et al. 66Ha07	Allan 71A106
Number	Energy (keV)					
1	898.0	$\alpha_K \times 10^4$			3.01±0.21	2.5 ±0.3
		K/LMN			7.0 ±0.5	8.0 ±0.2
		$\alpha \times 10^4$	2.7	3.4±0.7	3.45±0.24	2.8 ±0.3
2	1836	$\alpha_K \times 10^4$				1.24±0.16
		K/LMN				7.8 ±0.3
		$\alpha \times 10^4$	1.3	1.7±0.4		1.40±0.16*
		$\Gamma \times 10^4$				2.3 ±0.3*
5	2734	$\Gamma \times 10^4$				3.3 ±0.5

Table 3.7.3 Theoretical values of internal conversion coefficients and internal pair formation coefficients.

Item		Value	
Atomic number		38	38
Energy (keV)		898.0	1836
Multipolarity		E1	E2
Conversion coefficients	α_K	2.73(-4)	1.45(-4)
	α_{L_1}	2.79(-5)	
	α_{L_2}	3.23(-7)	
	α_{L_3}	6.12(-7)	
	α_L	2.89(-5)	
	K/L	9.45	9.23
	MN/L	0.18	0.19
Pair formation coefficient	α	3.07(-4)	1.64(-4)
	Γ		2.28(-4)
Gamma branch	$1/(1+\alpha+\Gamma)$	0.99969	0.99961

Table 3.7.4 Evaluation of gamma-ray intensity per decay.

Item	Value	Ref.
γ_5	0.72 ±0.07%	74Ar12
γ_6	0.0071±0.0020%	74Ar12
$\alpha_2\times10^4$	1.40 ±0.16	71A106
$\Gamma_2\times10^4$	2.3 ±0.3	71A106
γ_2	99.24 ±0.07% a)	

a) Obtained from the equation $\gamma_2(1+\alpha_2+\Gamma_2)+\gamma_5+\gamma_6=1$.

Table 3.7.5 Evaluated values.

Gamma-ray energy (keV)	Relative intensity (%)	Intensity per decay (%)
898.0	94.4±0.3	93.7 ±0.4
1836	100.0±0.3	99.24±0.07

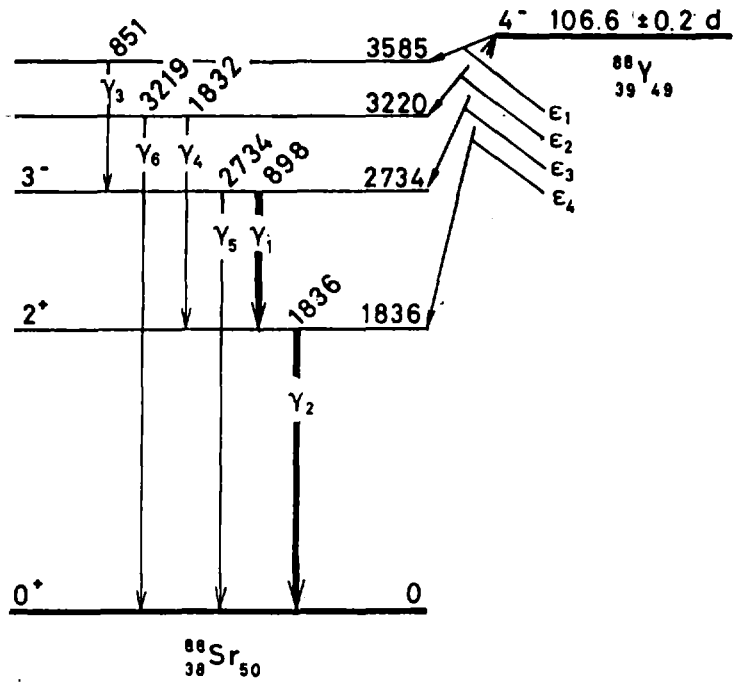

Fig. 3.7.1 Decay scheme of ^{88}Y.

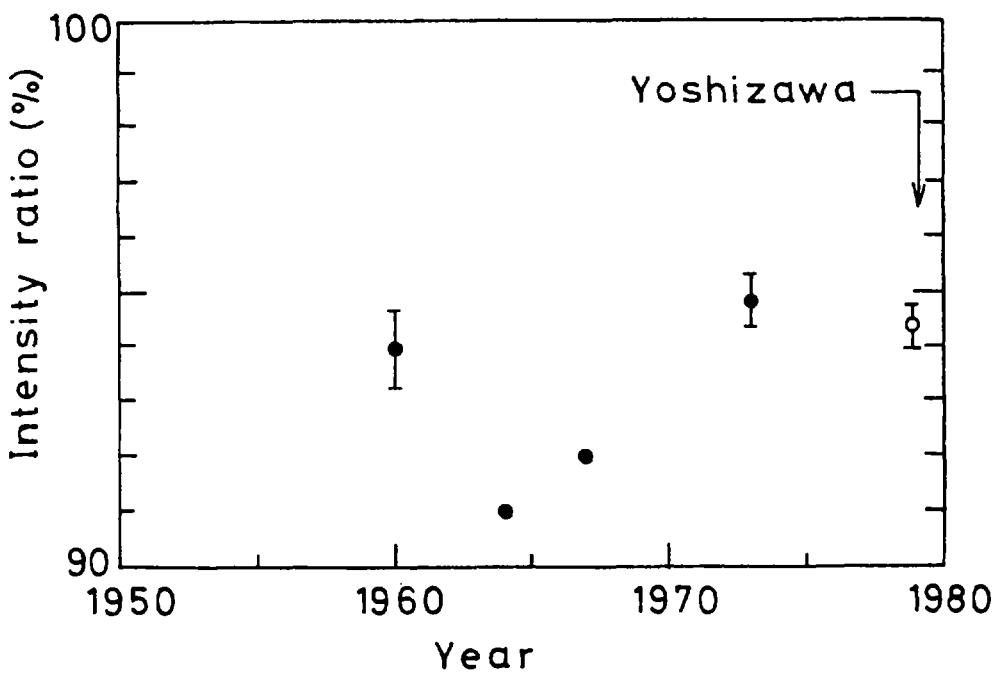

Fig. 3.7.2 Intensity ratio of the 898 keV gamma ray to the 1836 keV one in the decay of ^{88}Y.

3.8 ^{95}Nb

The radioactive nuclide ^{95}Nb emits a strong 766 keV gamma ray and weak gamma rays. The decay scheme is shown in Fig. 3.8.1. The intensity of the 766 keV gamma ray was evaluated.

a) Beta-decay branching. The main transition β_1 of 160 keV is more than 99.9 %. Branching ratios β_2 of the transition to the 204 keV level and β_3 to the ground state are shown in Table 3.8.1. The value β_3 given by Antoneva et al. (74An22) was adopted. The value β_2 was not used for evaluation.

b) Weak gamma rays. A weak gamma ray at 204 keV was observed by Antoneva et al. Their value shown in Table 3.8.2 was adopted.

c) Internal conversion coefficients. The E2/M1 mixing ratio of the 766 keV transition is shown in Table 3.8.3. The value of Cameron et al. (67Ca07) was adopted. Experimental values of the K conversion coefficient are listed in Table 3.8.4. Theoretical internal conversion coefficients are shown in Table 3.8.5. The experimental values except Langer and Wortman agree with the theoretical value within experimental errors. Since the K-shell and the total internal conversion coefficients of M1 is almost identical to those of E2 and the E2 component is very small, the theoretical coefficient of M1 was adopted.

d) Evaluation of intensity. The intensity per decay of the 766 keV gamma ray was evaluated as shown in Table 3.8.6 by using the branching ratio of the ground state transition β_3, the relative intensity of the 204 keV gamma ray $\gamma_2^{\dagger}$ and the total conversion coefficient of the 766 keV transition α_1. The internal conversion coefficients of the 204 keV transition (M1+E2) was neglected.

Table 3.8.1 Experimental values of beta-ray branching ratios.

Beta ray		Branching ratio (%)	
Number	Maximum energy (keV)	Langer Wortman 63La06	Antoneva et al. 74An22
1	160	>99.92	99.95
2	721		0.017±0.011
3	925	<0.075	0.030±0.005*

Table 3.8.2 Relative K conversion electron intensities and relative gamma-ray intensities.

Gamma ray		K conversion electron intensity [a] (%)	$\alpha_K \times 10^3$	Gamma-ray intensity [b]
Number	Energy (keV)			
1	765.8	100	1.28 [c]	100
2	204.1	1.0 ±0.3	46 [d]	0.028±0.008*
3	561.7	0.025±0.005		

a) 74An22.
b) Obtained from the K-conversion electron intensities and the internal conversion coefficients.
c) Theoretical value.
d) Obtained from the decay of ^{95}Tc (72MeHo).

Table 3.8.3 Experimental values of E2/M1 mixing ratio for the 766 keV gamma ray.

Authors	δ(E2/M1)	E2 (%)	Ref.
Collin	$-0.02^{+0.17}_{-0.23}$ or $-2.1^{+0.8}_{-1.5}$	$0.04^{+2.8}_{-7.4}$ or 82^{+39}_{-69}	65Co18
Cameron et al.	0.05±0.01	0.25±0.10*	67Ca07

Table 3.8.4 Experimental values of K conversion coefficient for the 766 keV transition.

Authors	α_K	Ref.
Langer, Wortman	0.0011 ±0.0001	63La06
Eissa et al.	0.00126±0.00025	67Ei03
Brahmava, Hamilton	0.00132±0.00013	69Br29

Table 3.8.5 Theoretical values of internal conversion coefficients.

Item		Value	
Atomic number		42	
Energy (keV)		765.8	
Multipolarity		M1	E2
Conversion coefficients	α_K	1.28(-3)	1.29(-3)
	α_{L_1}	1.38(-4)	1.36(-4)
	α_{L_2}	3.05(-6)	6.23(-6)
	α_{L_3}	1.32(-6)	5.20(-6)
	α_L	1.43(-4)	1.48(-4)
	K/L	8.97	8.73
	MN/L	0.21	0.21
	α	0.00145*	0.00147
Gamma branch	$1/(1+\alpha)$	0.999	0.999

Table 3.8.6 Evaluation of intensity per decay.

Item	Value	Ref.
β_3	0.030±0.005 %	74An22
$\gamma_2\dagger$	0.028±0.008 %	
α_1(Theoretical)	0.00145±0.00015	
γ_1	99.80 ±0.02 % a)	

a) Obtained from the equation $\beta_3+\gamma_1(1+\alpha_1+\gamma_2\dagger)=1$.

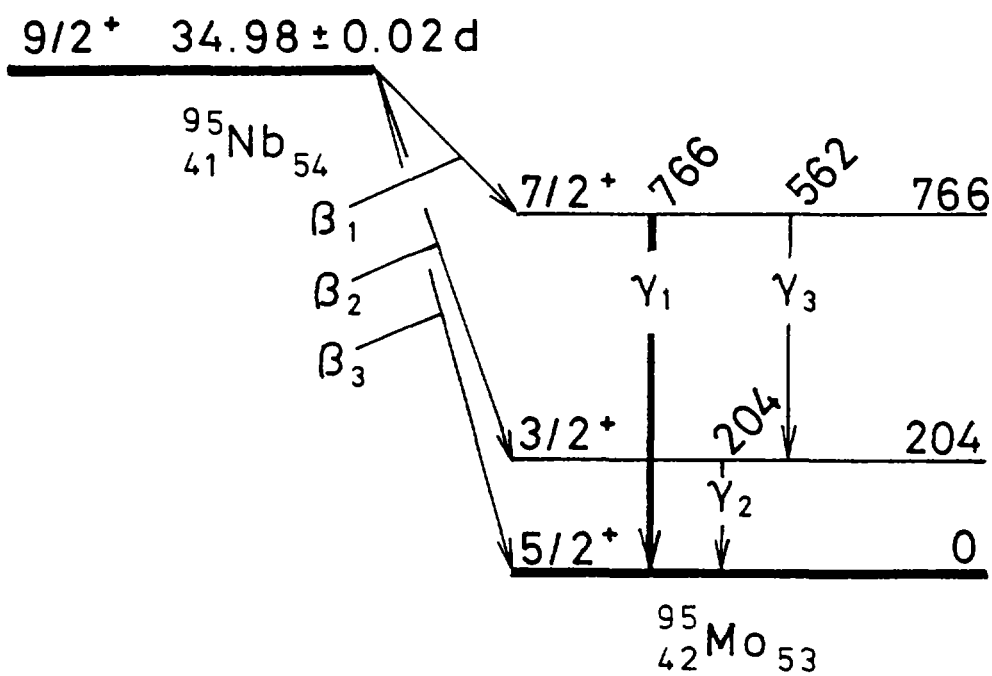

Fig. 3.8.1 Decay scheme of ^{95}Nb.

3.9 ^{108m}Ag

The long-lived isomer ^{108m}Ag mainly decays to ^{108}Pd by electron capture and emits three cascade gamma rays. The branching ratio of the isomeric transition to the ground state of ^{108}Ag is only 9 %. The decay scheme is shown in Fig. 3.9.1. Intensities of three strong cascade gamma rays were evaluated.

a) Electron capture. The isomeric state (6+) decays to the 1771 keV level (6+) in ^{108}Pd. Electron capture decay to the 1047 keV level (4+) has not been reported. But the branching of this non-unique second forbidden transition can not be neglected. This branching is estimated from log ft values of other non-unique second forbidden transitions in Table 3.9.1. The lower limit of the log ft value is about 12.0. If log ft is 12.0 or 12.3, the branching ratio ε_2 is 0.75 or 0.38, respectively. Therefore we adopted $\varepsilon_2 = 0.38 \pm 0.38$, as shown in Table 3.9.2.

b) Relative gamma-ray intensities. Experimental values of relative intensities are shown in Table 3.9.3. Errors of the 79 keV gamma ray following the isomeric transition are larger than 10 %. The relative intensity of the 79 keV gamma ray was evaluated by using values of Kistner and Sunyar (66Ki03), and of Kracikova and Kracik (68Kr04). That of the 633 keV gamma ray was by using two values of Hamilton et al. Average values of relative intensities are shown in Table 3.9.4.

c) Internal conversion coefficients. Experimental values of relative internal conversion electron intensities are listed in Table 3.9.5. Experimental and theoretical values of internal conversion coefficients are in Table 3.9.6 and Table 3.9.7, respectively. Internal conversion coefficients of the 79 keV transition are obtained from the experimental electron intensities of Kistner and Sunyar in Table 3.9.5 and the theoretical conversion coefficients of the 434 keV transition. The theoretical coefficients with 10 % errors was adopted for the 434 keV, 614 keV and 723 keV transitions. The evaluated values are shown in Table 3.9.8.

d) Decay of ^{108}Ag. The ground state of ^{108}Ag decays to both ^{108}Pd and ^{108}Cd. Decay data of the short lived ^{108}Ag are necessary to the evaluation of the ^{108m}Ag gamma rays. Experimental branching ratios of ^{108}Ag beta transitions are listed in Table 3.9.9. The new result of Frevert et al. (65Fr01) in this table was adopted. Relative gamma-ray intensities in the decay of ^{108}Ag are listed in Table 3.9.10, and the average values are in Table 3.9.11. Evaluated values of two gamma rays are shown in Table 3.9.12.

e) Branching ratio of isomeric transition. This ratio can be extracted from the intensity ratio of the 79 keV gamma ray to one of the cascade gamma rays and also from the intensity ratio of the 633 keV gamma ray to the 434 keV gamma ray. In Table 3.9.13, f_1 indicates the former and f_2 the latter. Relations used in extraction are in the foot notes, where $\gamma_4{}^{\dagger}$ means the relative intensity of the 434 keV gamma ray in the decay of ^{108m}Ag, $\hat{\gamma}_4$ means this gamma-ray intensity per decay of ^{108}Ag and $\gamma_8{}^{\dagger}$ and $\hat{\gamma}_8$ are similar ones for the 633 keV gamma ray.

f) Evaluation of three cascade gamma-ray intensities. The final evaluated result is given in Table 3.9.14. Since the 434 keV gamma-ray intensity per decay of ^{108}Ag is very

weak, intensity ratio of this gamma ray to the 614 keV gamma ray can be accurately evaluated. The branching ratio f_1 in Table 3.9.13 was used for the evaluation. Larger errors of intensities per decay are mainly due to the error of f_1.

Table 3.9.1 Log *ft* values of second forbidden transition for neighbouring nuclei.

Nucleus		Spin - parity		log *ft*
Parent	Daughter	Initial	Final	
^{94}Nb	^{94}Mo	6+	4+	12.0
^{98}Tc	^{98}Ru	(6)+	4+	14.1
^{110m}Ag	^{110}Cd	6+	4+	≳ 11.9
^{93}Mo	^{93}Nb	5/2+	9/2+	≳ 11.3
^{93}Zr	^{93}Nb	5/2+	9/2+	≳ 12.8
^{97}Tc	^{97}Mo	(9/2)+	5/2+	13.1
^{99}Tc	^{99}Ru	9/2+	5/2+	12.3
^{129}I	^{129}Xe	7/2+	3/2+	13.5
^{135}Cs	^{135}Ba	7/2+	3/2+	13.2
^{137}La	^{137}Ba	(7/2+)	3/2+	12.1
^{137}Cs	^{137}Ba	7/2+	3/2+	12.8

Table 3.9.2 Estimation of the electron capture transition intensity from ^{108m}Ag to the 1048.3 keV (4)+ state of ^{108}Pd.

Item	Value
log *ft*	12.3
log *f*	0.27
$T_{1/2}$ of ^{108m}Ag	127 ± 21
ε_2'	0.38 ± 0.38

Table 3.9.3 Experimental values of relative gamma-ray intensities in the decay of ^{108m}Ag.

Gamma ray		Wahlgren	Kistner	Kracikova	Hamilton et al.		Meyer
					71Ha17		
Number	Energy (keV)	Meinke 60Wa10	Sunyar 66Ki03	Kracik 68Kr04	Vanderbilt	ORNL	78Me
1	79.2	5.9	7.3±0.8*	8.3±0.9*			
	406			0.8±0.4	<0.012	<0.011	
4	434.0	100	100	100	100	100	991±3*
7	614.4	100	103± 3	105±10	98.8±2.8	99.3±2.0	997±3
8	632.9			0.18±0.07	0.16±0.02*	0.15±0.01*	1.51±0.008*
9	723.0	100	102± 3	102±10	97.8±2.8	100.4±2.0	1000±3
10	837			0.06±0.04	<0.01	0.005±0.003	
	1020			1.0±0.5	<0.004	<0.003	

Table 3.9.4 Average values of relative gamma-ray intensities in the decay of ^{108m}Ag.

Gamma ray		w = 1			w = $1/\varepsilon^2$		
Number	Energy (keV)	Average value	Error Int.	Error Ext.	Average value	Error Int.	Error Ext.
1	79.2	7.80*	0.60*	0.50	7.74	0.60	0.50
4	434.0	100.			100.		
8	633.0	0.154*	0.008*	0.003	0.152	0.006	0.002

Table 3.9.5 Experimental values of relative conversion electron intensities in the decay of ^{108m}Ag.

Gamma ray			Wahlgren Meinke 60Wal0	Kistner Sunyar 66Ki03
Number	Energy (keV)			
1	79.2	K		204 ±10*
		L		25 ± 2*
		M+N		6.1± 1.3*
4	434.0	K	100	100
		L+M		14.8± 2.3
6	614.4	K	41	37 ± 3
		L+M		5.1± 1.6
9	723.0	K	21	25.0± 1.2
		L+M		4.6± 0.8

Table 3.9.6 Experimental values of internal conversion coefficients

Gamma ray			Kracikova Kracik 68Kr04
Number	Energy (keV)		
1	79.2	α	0.25 ± 0.15
6	614.4	α_K	3.15 ± 0.30 (-3)
9	723.0	α_K	1.69 ± 0.30 (-3)

Table 3.9.7 Theoretical values of internal conversion coefficients.

Item		Value				
Atomic number		46	46	46	47	48
Energy (keV)		434.0	614.4	723.0	79.2	632.9
Multipolarity		E2	E2	E2	E1	E2
Conversion coefficients	α_K	7.87(-3)	2.92(-3)	1.91(-3)	0.271	3.01(-3)
	α_{L_1}	8.35(-4)	3.15(-4)	2.07(-4)	2.59(-2)	3.29(-4)
	α_{L_2}	9.94(-5)	2.47(-5)	1.33(-5)	3.08(-3)	2.84(-5)
	α_{L_3}	8.37(-5)	1.95(-5)	1.03(-5)	4.62(-3)	2.14(-5)
	α_L	1.02(-3)	3.59(-4)	2.30(-4)	3.36(-2)	3.79(-4)
	K/L	7.73	8.12	8.28	8.08	7.95
	MN/L	0.22	0.22	0.22	0.23	0.23
	α	9.11(-3)*	3.36(-3)*	2.19(-3)*	0.312	3.48(-3)*
Gamma branch	$1/(1+\alpha)$	0.99097	0.99665	0.99781	0.7622	0.99653

Table 3.9.8 Evaluated values of internal conversion coefficients.

Item	Value			
Atomic number	46	46	46	47
Energy (keV)	434.0	614.4	723.0	79.2
Multipolarity	E2	E2	E2	E1
α_K	7.87±0.79(-3)[a)]	2.91±0.37(-3)	1.97±0.22(-3)	0.206±0.028
K/LMN	6.8 ±1.1	7.3 ±2.4	5.4 ±1.0	6.56 ±0.60
α	9.03±0.92(-3)	3.31±0.45(-3)	2.33±0.27(-3)	0.237±0.032*
$1/(1+\alpha)$	0.99105±0.00090	0.99670±0.00045	0.99768±0.00027	0.808±0.021

a) Theoretical value.

Table 3.9.9 Experimental branching ratios of beta transitions in the decay of ^{108}Ag.

Beta decay or Electron capture		Perlman et al. 53Pe16	Wahlgren Meinke 60Wa10	Frevert 62Fr07	Frevert* 65Fr01
Symbol	Transition energy(keV)				
β_1	177			∿ 0.02	∿ 0.02
β_2	1018	0.8	1.90	1.73±0.10	1.75±0.10
β_3	1650	97.3	93.8	95.0 ±0.3	95.9 ±0.3
β_1^+	1921	0.14	0.36	0.28±0.02	0.28±0.02
ε_1	990	0.22	0.42	0.26±0.03	0.27±0.03
ε_3	1490	0.06	0.18	0.19±0.03	0.19±0.03
ε_4	1921	1.5	3.35	2.49±0.25	1.73±0.12

Table 3.9.10 Experimental values of relative intensities of gamma rays in the decay of ^{108}Ag.

Gamma ray Number	Energy (keV)	Johnson et al. 71Jo07	Okano et al.* 71Ok01	Singhal et al.* 73Si02
2	383			0.18 ±0.06
3	389		<0.2	0.37 ±0.12
4	434.0	100 ±2.3	100	100
5	497	0.26 ±0.15	0.25 ±0.09	0.45 ±0.11
7	618.9	54.9 ±1.5	54.1 ±2.4	52.4 ±2.6
8	633.0	375.9 ±8.5	355.1 ±14.9	349.6 ±17.5
11	841	≤0.15	<0.1	
12	880	0.45 ±0.08	0.65 ±0.03	0.64 ±0.05
13	931	0.094±0.045	0.091±0.016	0.11 ±0.01
14	1007	2.97 ±0.30	2.71 ±0.11	2.79 ±0.14
15	1106	0.49 ±0.04	0.26 ±0.02	0.33 ±0.03
16	1441	0.53 ±0.08	0.56 ±0.04	0.61 ±0.04
17	1540	0.15 ±0.06	0.20 ±0.02	0.21 ±0.02

a) Normalized at the 434 keV gamma-ray intensity.

Table 3.9.11 Average values of relative intensities of gamma rays in the decay of ^{108}Ag.

Gamma ray		w = 1			w = $1/\varepsilon^2$		
Number	Energy (keV)	Average value	Error Int.	Error Ext.	Average value	Error Int.	Error Ext.
4	434.0	100*			100		
5	497	0.32	0.07	0.07	0.32	0.06	0.07
7	618.9	53.8	1.3	0.7	54.2	1.1	0.7
8	632.9	360.2*	8.2*	8.0	367.6	6.8	7.9
12	880	0.580	0.033	0.065	0.629	0.024	0.041
13	931	0.098*	0.016*	0.006	0.104	0.008	0.006
14	1007	2.82	0.12	0.08	2.76	0.08	0.05
15	1106	0.360	0.018	0.068	0.312	0.015	0.056
16	1441	0.567*	0.033*	0.023	0.579	0.027	0.021
17	1540	0.187*	0.022*	0.019	0.204	0.014	0.009

Table 3.9.12 Evaluated values of the 434 keV and the 633 keV gamma-ray intensities per decay in the decay of ^{108}Ag.

Gamma ray		Intensity per decay
Number	Energy (keV)	(%)
4	434.0	0.48 ± 0.07
8	633.0	1.73 ± 0.23

Table 3.9.13 Evaluation of the isomeric transiton intensity.

Item		Value (%)	Remarks
Isomeric transition intensity	f_1	8.73 ± 0.65*	a)
	f_2	8.1 ± 1.1	b)

a) Obtained from the equation
$f_1 = \gamma_1^{\dagger}(1+\alpha_1)/\{\gamma_4^{\dagger}(1+\alpha_4)+\gamma_1^{\dagger}(1+\alpha_1)(1-\hat{\gamma}_4)\}$,
where $\hat{\gamma}_4$ means the gamma-ray intensity per decay of 2.4 min ^{108}Ag, while $\gamma_4^{\dagger}$ denotes the relative intensity in the decay of 127y ^{108m}Ag.

b) Obtained from the equation
$f_2 = [\gamma_8^{\dagger}(1+\alpha_8)/\hat{\gamma}_8]/[\gamma_4^{\dagger}(1+\alpha_4)+\{\gamma_8^{\dagger}(1+\alpha_8)/\hat{\gamma}_8\}(1-\hat{\gamma}_4)]$.

Table 3.9.14 Evaluation of intensities per decay and relative intensities of gamma rays in the decay of ^{108m}Ag.

Gamma ray		Intensity per decay (%)	Relative intensity (%)
Number	Energy (keV)		
4	434.0	90.5 ± 0.7 a)	99.476 ± 0.090 d)
6	614.4	91.0 ± 0.7 b)	100.000 ± 0.034
9	723.0	90.7 ± 0.8 c)	99.74 ± 0.38 e)

a) Obtained from the expression, $(1-f)/(1+\alpha_4)+f\hat{\gamma}_4$.
b) $(1-f)/(1+\alpha_6)$.
c) $(1-f-\varepsilon_2')/(1+\alpha_9)$.
d) $[1/(1+\alpha_4)+\frac{f}{1-f}\hat{\gamma}_4](1+\alpha_6)$.
e) $(1-\varepsilon_2')(1+\alpha_6)/(1+\alpha_9)$.

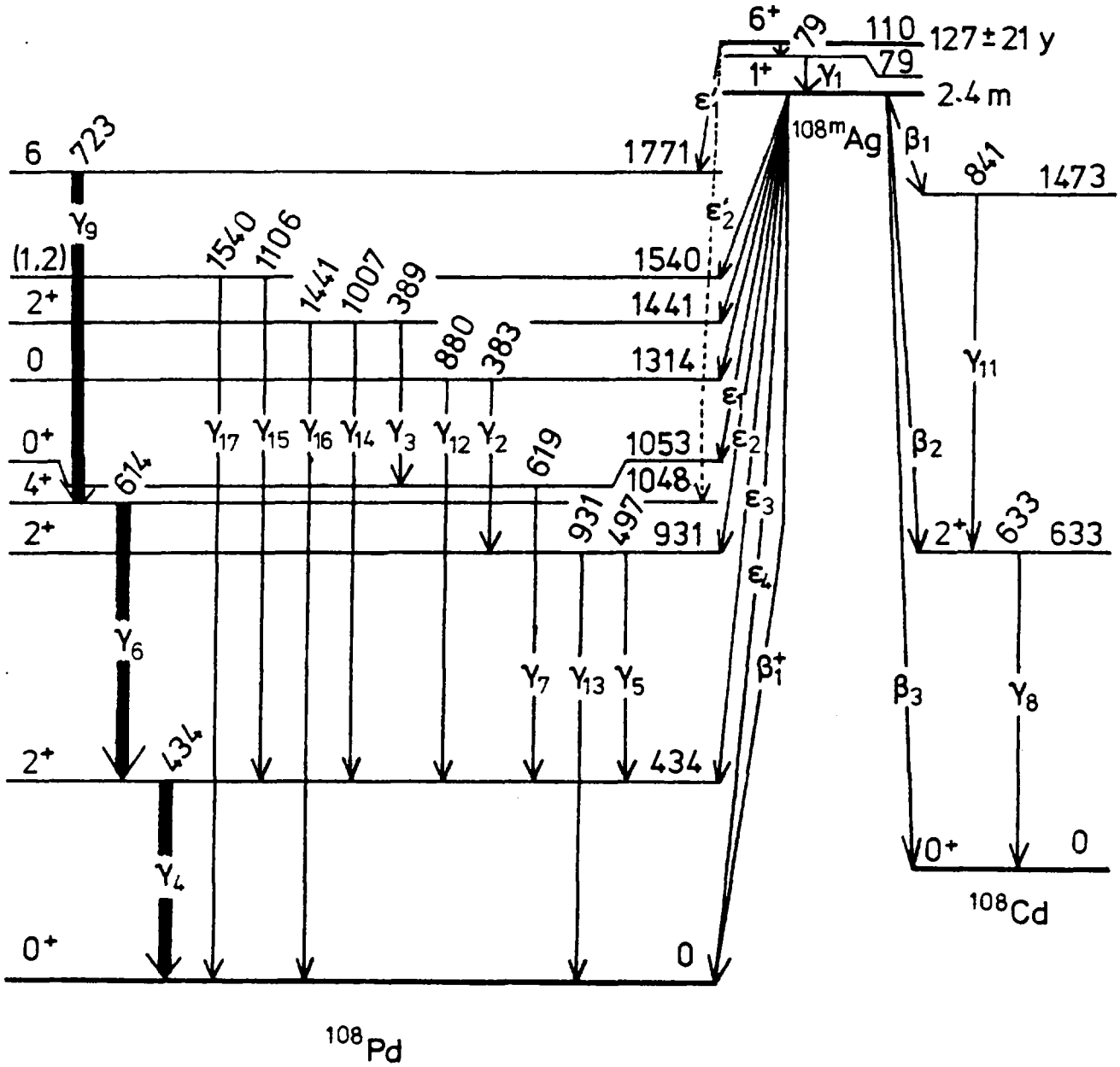

Fig. 3.9.1 Decay scheme of ^{108m}Ag

3.10 ^{134}Cs

Eleven gamma rays are emitted in the decay of ^{134}Cs. The decay scheme is shown in Fig. 3.10.1. Relative intensities and intensities per decay of gamma rays were evaluated by using relative gamma ray intensities.

a) Beta-ra branching ratios. Experimental branching ratios are shown in Table 3.10.1. For the weak transition β_5 to the 2+ state at 605 keV, we adopted the experimental value of Hsue et al. (68Hs01) which is necessary to evaluate the intensities per decay of the 796 keV gamma ray. Since the ground state beta transition is the fourth forbidden one ($4^+ \rightarrow 0^+$), the branching ratio of the ground state transition is about 10^{-8}.

b) Relative gamma-ray intensities. Many intensity measurements have been done with NaI detectors, Ge(Li) detectors and magnetic beta-ray spectrometers. Relative intensities and intensities per decay were listed in Table 3.10.2 and Table 3.10.3, respectively. Eight of them are measurements with Ge(Li) detectors. Experimental values of relative 1168 keV gamma-ray intensity are plotted in Fig. 3.10.2.

Fig. 3.10.3 shows deviations of intensities from values of Yoshizawa et al. (79Yo). In the 600~1000 keV region, larger deviations are seen in old measurements, and systematic deviations are much smaller between values of Yoshizawa et al. and Debertin et al. (77De) We adopted the values of Yoshizawa et al.

c) Internal conversion coefficients. Experimental values of K-shell internal conversion electron intensities are listed in Table 3.10.4, and adopted values are also in Table 3.10.5. The average values of K-shell electron intensities were obtained from these values as shown in Table 3.10.6. Theoretical values are listed in Table 3.10.7. The M1+E2 mixing is expected for the 475 keV and the 1038 keV transitions, and the E0+M1+E2 mixing is for the 563 keV and the 569 keV transitions. Adopted values of the K-shell conversion coefficients are shown in Table 3.10.8 with five other transitions. Values for the four transitions are obtained from the average values with the weight $w=1/\varepsilon^2$ which are normalized at the 605 keV transition, and values for five other transitions are the theoretical values. The total internal conversion coefficients in Table 3.10.8 are obtained from the adopted values of α_K and theoretical values of K/L and MNO/L in Table 3.10.7.

The M1/E2 ratios for the 569 keV transition given by gamma-gamma angular correlation experiments are summarized in Table 3.10.9. These values are consistent with the adopted internal conversion coefficients of α_K and α.

d) Evaluation of gamma-ray intensities. Evaluated values of gamma-ray intensities are shown in Table 3.10.10. Relative intensities are cited from the adopted values in Table 3.10.3. The intensity per decay of the 605 keV gamma ray γ_6 is obtained from the intensity balance of two transitions of 605 keV and 1165 keV. Since the relative intensity $\gamma_{10}^{\dagger} = \gamma_{10}/\gamma_6$ is only 1.8 %, the intensity per decay γ_6 was accurately evaluated. The intensity per decay of the 796 keV gamma ray γ_7 was also evaluated from the intensity balance at the 605 keV level, and is satisfactorily accurate. Other values for intensities per decay were obtained from the relative intensities. Final evaluated values for two

gamma rays are listed in Table 3.10.11, where relative intensities were obtained from the evaluated intensities per decay.

Table 3.10.1 Experimental values of beta-ray branching ratios.

Beta ray		Trehan et al. 63Tr05 (%)	Van Wijngaarden Connor 64Va06 (%)	Hsue et al. 68Hs01 (%)
Number	Maximum energy (keV)			
1	89	26	28	27 ±2
2	416	2.1 ±0.2	1	3.0 ±0.5
3	658	71 ±3	71	70 ±2*
4	891	0.7 ±0.08	<0.045	0.045±0.015
5	1454	0.13±0.02	<0.005	0.008±0.004*

Table 3.10.2 Experimental values of relative gamma-ray intensities.

Gamma ray		Verhaeghe et al.	Keister et al.	Girgis et al.	Yamamoto	Segaert et al.	Brown Ewan	Bashaindy Abd El-Hariem	Nagpal	Yoshizawa Iwata*
Number	Energy (keV)	54Ve09	55Ke04	59Gi49	60Ya03	63Se09	65Br20	66Ba57	68Na11	79Yo
3	475.4	4	1.8±0.4	1.3±0.4	1.72	1.4±0.04	1.54±0.8	0.31±0.05	1.67±0.11	
4	563.3	15	9±2		12.2		8.5 ±0.8	8.86±0.83	8.83±0.46	8.57 ±0.03
5	569.3	20	13±2	24±4	26.3	20±5	14.6 ±1.4	14.18±1.12	13.61±0.70	15.78 ±0.06
6	604.7	100	100	100	100	100	100 ±5	100	100 ±3	100.0 ±0.4
7	795.8	100	91±4	92±7	46.55	91±10	90 ±9	48.08±3.55	89.25±4.47	87.5 ±0.3
8	801.8	15	18±4		4.85		9.0 ±1.5	1.43±0.25	8.12±0.42	8.89 ±0.03
9	1038.5	4	0.9±0.2	1.5±0.3	0.36	1.5±0.3	1.06±0.10	1.55±0.21	1.06±0.06	1.008±0.005
10	1167.9	4	3.0±0.4	2.2±0.3	0.44	2.4±0.5	1.99±0.17	2.31±0.30	2.06±0.14	1.827±0.008
11	1365.1	4	4.6±0.3	3.3±0.5	0.57	3.5±0.7	3.46±0.30	4.76±0.52	3.55±0.19	3.074±0.013

Table 3.10.3 Experimental values of intensities per decay.

Gamma ray		Brown Ewan	Raeside et al.	Nagpal	Abdul-Malek	Hofmann et al.	Stelson et al.	Hise et al.	Debertin et al.	Yoshizawa Iwata*
Number	Energy (keV)	65Br20	67Ra10	68Na11	68Ab01	70Ho06	73St	75Hi	77De	79Yo
	233						<0.0005	<0.0002		
1	242.9		0.02±0.01[a)]			<0.08	0.022±0.002	0.0210±0.0008*		
2	326.5		0.02±0.01[a)]			<0.08	0.014±0.002	0.0144±0.0006*		
3	475.4	1.5 ±0.15	1.51±0.16	1.62±0.11	1.4±0.2	1.57±0.08	1.50±0.03	1.465±0.040*	1.51 ±0.03*	
4	563.3	8.3 ±0.8	8.96±0.84	8.60±0.46	8.7±1.0	8.86±0.45	8.47±0.17	8.38 ±0.05	8.34 ±0.12*	8.37 ±0.05
5	569.3	14.2 ±1.4	15.81±1.1	13.30±0.70	15.0±1.6	16.0 ±1.0	15.36±0.31	15.43 ±0.11	15.38 ±0.22	15.40 ±0.08
6	604.7	97.5	98.04	97.50±3.0	98.0	98.1 ±6.0	98.2 ±1.0	97.56 ±0.32	97.6 ±0.1	97.64 ±0.06
7	795.8	87.8 ±9	87.79±6.6	87.00±4.47	88.4±9.1	86.0 ±4.3	84.9 ±2.2	85.44 ±0.38	85.3 ±0.9	85.52 ±0.05
8	801.8	8.8 ±1.5	8.94±0.8	7.90±0.42	9.2±1.0	8.70±0.44	8.61±0.22	8.73 ±0.04	8.64 ±0.12	8.68 ±0.04
9	1038.5	1.03±0.1	1.02±0.08	1.04±0.06	1.1±0.6	0.99±0.06	1.01±0.02	1.00 ±0.01	0.998±0.013	0.984±0.006
10	1167.9	1.94±0.15	1.96±0.22	2.01±0.14	1.9±0.2	1.86±0.10	1.84±0.04	1.805±0.026	1.800±0.020	1.783±0.010
11	1365.1	3.37±0.30	3.25±0.32	3.47±0.19	3.3±0.3	3.23±0.17	3.11±0.08	3.04 ±0.04	3.02 ±0.03	3.001±0.017

a) Intensities were measured with the bend-cristal spectrometer.

Table 3.10.4 Experimental values of K-shell internal conversion electron intensities.

Gamma ray		Relative intensity			Intensity per decay × 10^5		
Number	Energy (keV)	Keister et al. 55Ke04	Trehan et al. 65Tr05	Abdul-Malek Naumann 68Ab01	Van Wijngaarden Connor 64Va06	Brown Ewan 65Br20	Nagpal 68Na11
3	475.4	3 ±1	1.2 ±0.2			14.1 ±0.6	15.97± 3.2
4	563.3	11.9 ±0.6		10.5±0.7		46.5 ±2	55.00± 5.50
5	569.3	26 ±1	20 ±2	22.4±1.2		116.2 ±5	117.00±11.70
6	604.7	100	100 ±10	98.0	469	473 ±10	494.00±49.40
7	795.8	44 ±1		51.4±2.0		216 ±8	252.10±25.21
8	801.8	3.9 ±0.5	94 ±9	5.6±1.0		22.6 ±1	21.90± 4.4
9	1038.5	0.43±0.08	1.14±0.15		1.82±0.18	1.67±0.09	1.75± 0.18
10	1167.9	0.49±0.08	3.0 ±0.3		1.82±0.18	2.04±0.10	2.11± 0.20
11	1365.1	0.49±0.08	3.6 ±0.4		2.30±0.20	2.41±0.10	2.75± 0.27

Table 3.10.5 Experimental values of relative K-shell internal conversion electron intensities.

Gamma ray		Keister * et al.	Brown * Ewan	Abdul-Malek * Naumann	Nagpal *
Number	Energy(keV)	55Ke04	65Br20	68Ab01	68Na11
3	475.4	3 ±1	2.98 ±0.13		3.23±0.65
4	563.3	11.9 ±0.6	9.83 ±0.42	10.71±0.71	11.1 ±1.1
5	569.3	26 ±1	24.6 ±1.1	22.9 ±1.2	23.7 ±2.4
6	604.7	100 ±4	100 ±2.1	100 ±4 a)	100 ±10
7	795.8	44 ±1	45.7 ±1.7	52.5 ±2.0	51.0 ±5.1
8	801.8	3.9 ±0.5	4.78 ±0.21	4.6 ±1.0	4.43±0.89
9	1038.5	0.43±0.08	0.353±0.019		0.35±0.0036
10	1167.9	0.49±0.08	0.431±0.021		0.43±0.041
11	1365.1	0.49±0.08	0.510±0.021		0.56±0.055

a) Errors are our estimation.

Table 3.10.6 Average values of relative K-shell internal conversion electron intensities.

Gamma ray		$w = 1/\varepsilon^2$			$w = 1$		
Number	Energy (keV)	Average value *	Error Int.*	Error Ext.	Average value	Error Int.	Error Ext.
3	475.4	2.99	0.12	0.034	3.07	0.40	0.081
4	563.3	10.59	0.30	0.50	10.89	0.38	0.43
5	569.3	24.61	0.60	0.71	24.28	0.76	0.67
6	604.7	100	1.7	0	100	2.9	0
7	795.8	45.77	0.78	1.75	48.3	1.5	2.0
8	801.8	4.64	0.19	0.18	4.43	0.37	0.19
9	1038.5	0.356	0.017	0.011	0.379	0.030	0.026
10	1167.9	0.433	0.018	0.009	0.449	0.031	0.020
11	1365.1	0.515	0.019	0.012	0.519	0.033	0.020

Table 3.10.7 Theoretical values of internal conversion coefficients.

Gamma ray		E2 conversion coefficients					M1 conversion coefficients				
Number	Energy (keV)	α_K $\times 10^3$	α_L $\times 10^3$	K/L	MNO/L	α $\times 10^3$	α_K $\times 10^3$	α_L $\times 10^3$	K/L	MNO/L	α $\times 10^3$
3	475.4	9.52	1.45	6.54	0.25	11.3	13.0	1.67	7.77	0.26	15.1
4	563.3	6.04	0.88	6.86	0.25	7.14	8.54	1.09	7.83	0.26	9.91
5	569.3	5.88	0.85	6.88	0.25	6.94	8.32	1.06	7.83	0.26	9.65
6	604.7	5.03	0.72	6.98	0.25	5.93					
7	795.8	2.58	0.35	7.38	0.25	3.02					
8	801.8	2.54	0.34	7.39	0.25	2.97					
9	1038.5	1.43	0.19	7.69	0.25	1.67	2.00	0.25	7.97	0.26	2.32
10	1167.9	1.12	0.14	7.80	0.25	1.30					
11	1365.1	0.819	0.104	7.91	0.25	0.949					

Table 3.10.8 Adopted values of the internal conversion coefficients.

Gamma ray		Conversion coefficienrs		
Number	Energy (keV)	$\alpha_K \times 10^3$	$\alpha \times 10^3$ *	Remarks
3	475.4	9.7 ±0.5	11.4 ±0.6	a)
4	563.3	6.7 ±0.4	7.9 ±0.4	a)
5	569.3	7.9 ±0.3	9.2 ±0.4	a)
6	604.7	5.03±0.50	5.93±0.59	b)
7	795.8	2.58±0.26	3.02±0.30	b)
8	801.8	2.54±0.25	2.97±0.30	b)
9	1038.5	1.73±0.10	2.01±0.12	a)
10	1167.9	1.12±0.11	1.30±0.13	b)
11	1365.1	8.19±0.82	0.949±0.95	b)

a) These values are experimental values and are normalized to the theoretical values of 5.03×10^{-2} at 604.7 keV.

b) Theoretical values.

Table 3.10.9 Experimental values of the E2/M1 mixing ratio of the 563.3 keV and 569.3 keV gamma rays.

Gamma ray		Begzhanov et al. (1972)	
Number	Energy (keV)	δ(E2/M1)	E2(%)
4	563.3	7.5±0.9	$98.3^{+0.3}_{-0.5}$
5	569.3	-0.29±0.02	$7.8^{+0.8}_{-1.1}$

Table 3.10.10 Evaluated values of gamma-ray intensities.

Gamma ray		Relative intensity (%)	Intensity per decay (%)
Number	Energy (keV)		
1	242.9	0.0222±0.0012	0.0217±0.0012
2	326.5	0.0153±0.0009	0.0149±0.0008
3	475.4	1.55 ±0.04	1.52 ±0.04
4	563.3	8.57 ±0.03	8.37 ±0.05
5	569.3	15.78 ±0.06	15.40 ±0.08
6	604.7	100.0 ±0.4	97.64 ±0.06
7	795.8	87.5 ±0.3	85.52 ±0.05
8	801.8	8.89 ±0.03	8.68 ±0.04
9	1038.5	1.008 ±0.005	0.984 ±0.006
10	1167.9	1.827 ±0.008	1.783 ±0.010
11	1365.1	3.074 ±0.013	3.001 ±0.017

Table 3.10.11 Evaluated values for primary standard.

Gamma ray		Intensity per decay (%)	Relative intensity (%)	Estimation
Number	Energy (keV)			
6	604.7	97.64±0.06	100.00±0.06	a)
7	795.8	85.52±0.05	87.59±0.05	b)

a) Beta transition to the first excited state is neglected. These values are obtained from the 604.7 keV and 1167.9 keV gamma-ray intensities.

b) These values are obtained from the four gamma transition intensities to the first excited state such as the 563.3 keV, 795.8 keV, 1038.5 keV and 1365.1 keV gamma rays. In the error estimation of the relative intensity the error of the 1167.9 keV gamma ray is not included.

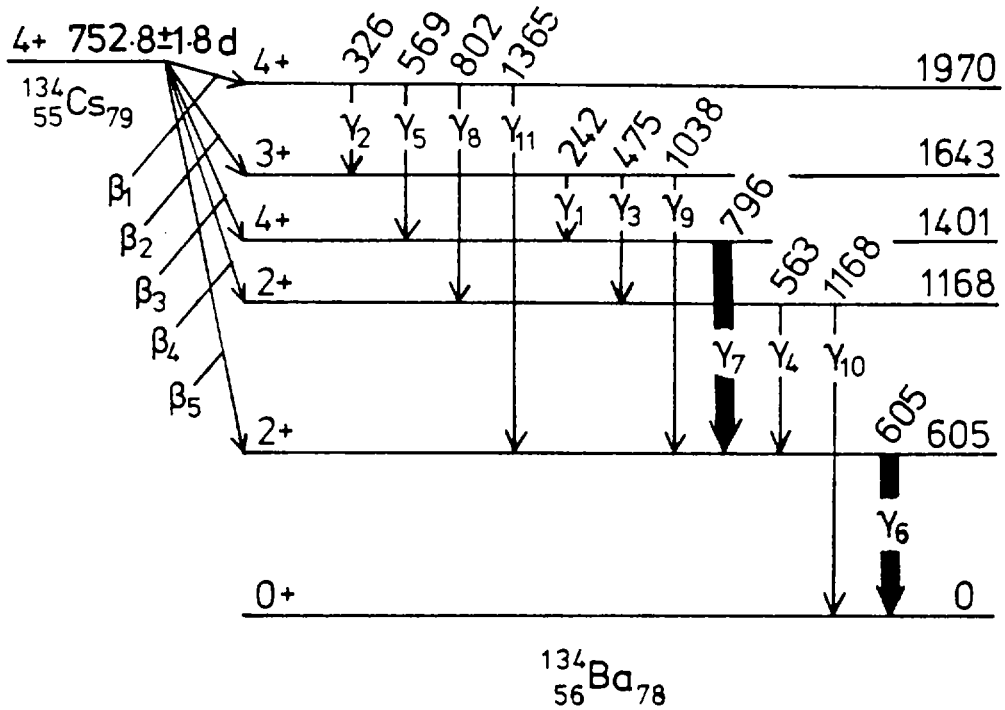

Fig. 3.10.1 Decay scheme of ^{134}Cs.

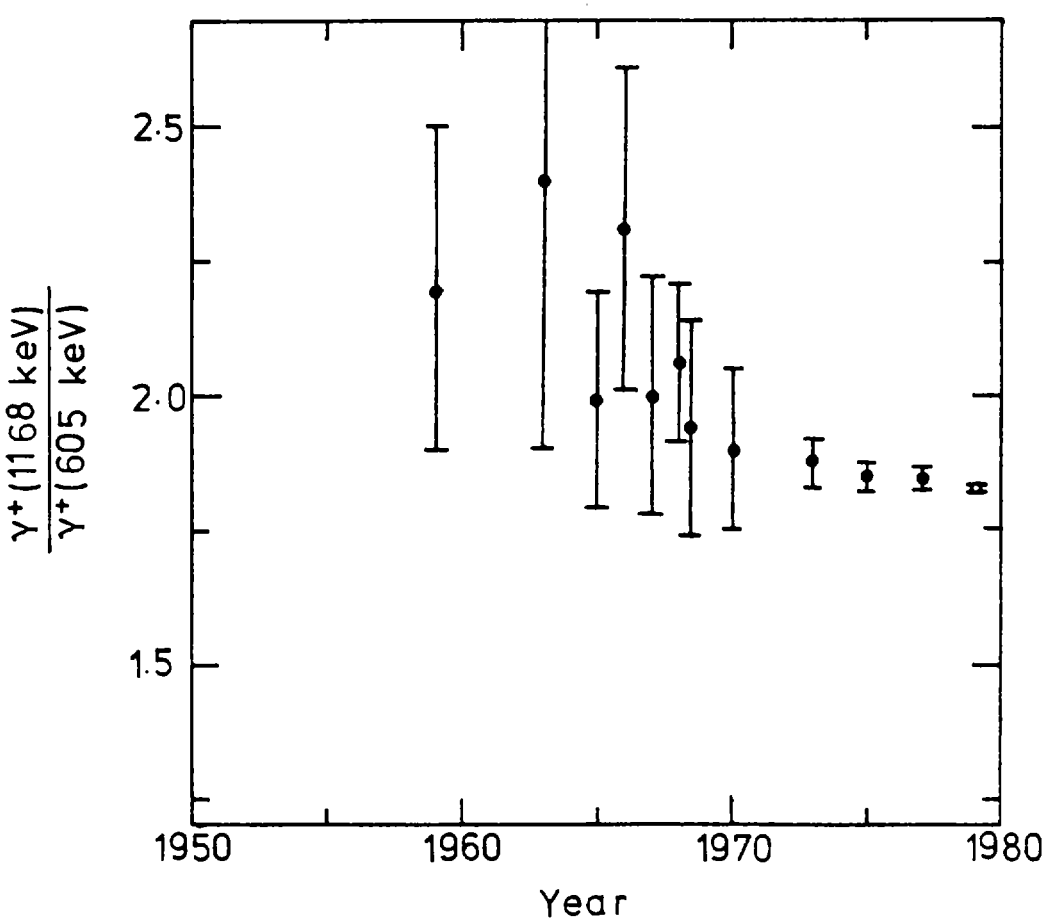

Fig. 3.10.2 Intensity ratio of the 1168 keV gamma ray to the 605 keV one in the decay of ^{134}Cs.

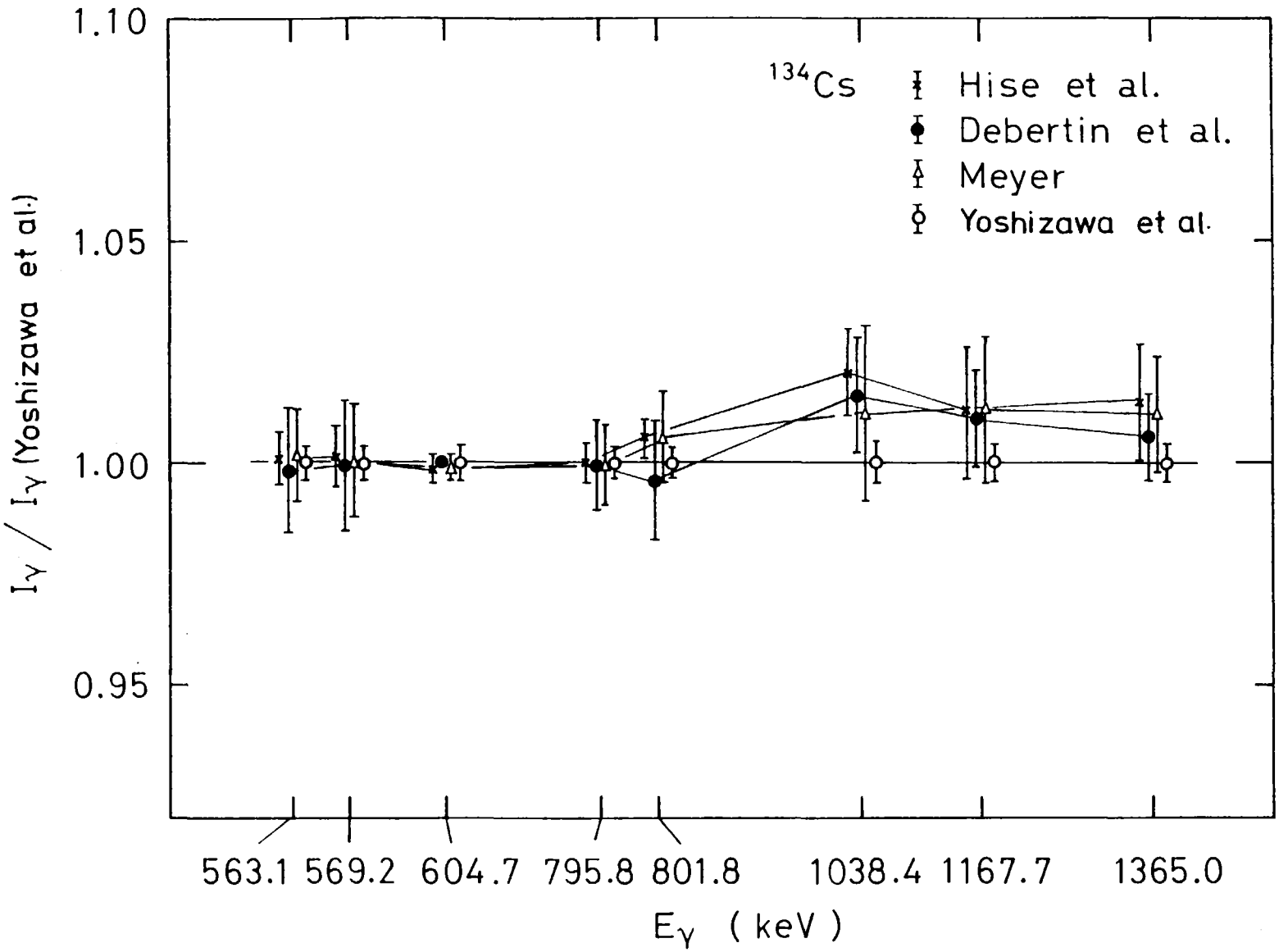

Fig. 3.10.3 Comparison of relative intensities of strong gamma rays in the decay of ^{134}Cs.

3.11 ^{133}Ba

The long-lived nuclide ^{133}Ba decays to ^{133}Cs by electron capture and emits 9 low energy gamma rays. The decay scheme is shown in Fig. 3.11.1. Intensities of the 276, 303, 356 and 384 keV gamma rays were evaluated.

a) Relative intensities. Many observed values have been reported as shown in Table 3.11.1. Fig. 3.11.2 shows experimental values of the relative intensity of the 303 keV gamma ray. Deviations of three recent accurate values of Schötzig et al. (77Sc31), Gehrke et al. (77Ge) and Meyer (78Me) from those of Yoshizawa et al. (79Yo) are plotted in Fig. 3.11.3. This figure indicates that four measurements agree each other within their experimental errors. Therefore, the most accurate values of Yoshizawa et al. are adopted for four gamma rays and the average value of Schötzig et al., Gehrke et al. and Meyer shown in Table 3.11.2 is adopted for the 223 keV gamma ray.

b) Electron capture. Branching ratios of electron capture transitions which are obtained from gamma ray intensities are shown in Table 3.11.3. Branching ratios ε_3 and ε_4 correspond to the second forbidden transition (1/2+→5/2+). Since the experimental values scattered each other and are not reliable, the branching ratios are estimated from log ft values of non-unique second forbidden transitions at neighbouring nuclei shown in Table 3.9.1. Assuming log ft = 12.4 for both transitions, one obtains branching ratios ε_3 and ε_4 shown in Table 3.11.4. The transitions to the ground state is an unique second forbidden one, the log ft value of which is about 13~14, for example, ^{10}Be and ^{26}Al. Assuming log ft = 13.4, one obtains the ratio in Table 3.11.4. These ratios are very small, but the values $\varepsilon_5 \pm \varepsilon_5$ were used for evaluation.

c) Internal conversion coefficients. Experimental values of K-shell coefficients and conversion ratios are summarized in Table 3.11.5 and 3.11.6, respectively. Theoretical ones are also in Table 3.11.7. The penetration effect for conversion electrons and the E2 mixings are not negligible for M1 transitions. In addition, many conversion electron measurements are available. Therefore experimental values are adopted. The adopted values of α_K shown in the table were measured with Ge(Li) and Si(Li) detectors, and those of conversion ratios were with high resolution magnetic spectrometers. The average values of them are shown in Table 3.11.8 and Table 3.11.9. The final evaluated values of the conversion coefficients and the ratios are summarized in Table 3.11.10.

d) Evaluation of gamma-ray intensities. Sum of the 223, 276, 303, 356 and 384 keV transition intensities and the electron capture branching ratios of ε_1, ε_2 and ε_3 is normalized to 100 % per decay. One can obtain gamma-ray intensities per decay from this condition, the evaluated values of the relative gamma-ray intensities and the total internal conversion coefficients α. The final results are listed in Table 3.11.11.

Table 3.11.1 Experimental values of relative gamma-ray intensities in the decay of ^{133}Ba.

Authors \ Number	1	2	3	4	5	6	7	8	9	Ref.
Energy (keV)	53.2	79.6	81.0	160.6	223.1	276.4	302.9	356.0	383.9	
	Relative intensities (%)									
Hayward et al.	1.45		31.9				44.9	100		54Ha
Craseman et al.	weak		48	0.1		weak	34	100		57Cr
Gupta et al.	7.3		45.5	0.4		3.3	22	100		58Gu
Koicki et al.						10	38.4	100	20	58Ko
Ramaswamy et al.	2.4	7	35			38		100	14	60Ra
Stewart, Lu					∿0.3	8	27	100	10	60St
Mann, Chaturvedi	2.5 ±1.0		52.0±2.0			10.0 ±1.0	21.0 ±2.0	100	11.0 ±3.0	63Ma
Thun et al.						11.0	25.8	100.0	14.7	66Th09
Blasi et al.	3.8 ±0.8	3.8 ±0.4	53 ±4	1.1 ±0.3	0.7 ±0.3	11.0 ±0.7	30 ±2	100	14.5 ±1.0	67Bl
Gurfinkel, Notea	3.7 ±0.09		64.7±4.2	1.2 ±0.05	0.80 ±0.42	11.6 ±0.17	29.7 ±0.29	100	14.1 ±0.26	67Gu
Alexander, Lau	3.3 ±0.5		65.9±3.9	1.20±0.06	0.74 ±0.06	12.0 ±0.4	30.6 ±0.9	100	14.2 ±0.5	68Al16
Bosch et al.	4.2 ±0.2	4.0 ±0.4	58.2±1.5	1.07±0.05	0.78 ±0.06	11.8 ±0.3	29.8 ±0.8	100	14.3 ±0.3	68Bo04
Donnelly et al.	3.16±0.39	5.48±0.71	52.0±6.8	0.99±0.10	0.72 ±0.08	11.62±0.82	29.4 ±2.1	100	14.3 ±1.0	68Do10
Notea, Gurfinkel	3.78±0.09	4.90±0.59	59.8±7.2	1.21±0.05	0.803±0.042	11.61±0.17	29.75±0.29	100	14.18±0.26	68No01
Schmidt et al.	3.54±0.05	3.9 ±0.2	52.[illegible]±1.0	1.16±0.05	0.74 ±0.04	11.4 ±0.3	30.2 ±0.6	100	14.4 ±0.3	72Sc08
Inoue et al.				0.98±0.07	0.76 ±0.05	11.6 ±0.5	29.6 ±1.1	100.0	14.9 ±0.6	73In06
Legrand	3.2	3.7 ±0.4	56.1±5.7	1.4 ±0.2	0.66 ±0.02	11.35±0.25	29.4 ±0.6	100	14.3 ±0.3	73Le
McNelles, Campbell						11.43±0.23	29.29±0.59	100	14.47±0.32	73Mc18
Schötzig et al.	3.49±0.06	4.29±0.10	55.8±1.3	0.97±0.02	0.73 ±0.02*	11.41±0.14	29.43±0.33	100.0 ±0.9	14.33±0.13	77Sc31
Gehrke et al.	3.54±0.18	3.1 ±0.3	49.2±2.6	1.08±0.04	0.745±0.024*	11.7 ±0.4	29.76±0.30	100.0 ±1.0	14.36±0.14	77Ge
Meyer	3.48±0.07	3.77±0.09	51.2±0.4	1.05±0.03	0.71 ±0.02*	11.3 ±0.2	29.2 ±0.3	100.0 ±0.3	14.5 ±0.2	78Me
Yoshizawa et al.						11.53±0.06*	29.48±0.14*	100.0 ±0.4*	14.39±0.06*	79Yo

Table 3.11.2 Average values of relative intensities of 223.1 keV gamma ray.

W=1			$W=1/\varepsilon^2$		
Value	Error		Value	Error	
	Int.	Ext.		Int.	Ext.
0.728*	0.012*	0.010	0.726	0.012	0.010

Table 3.11.3 Experimental values of electron capture branches in the decay of ^{133}Ba.

	Electron capture branches (%)				
Authors \ Number	1	2	3	4	Ref.
Energy	48 keV	101 keV	324 keV	403 keV	
Stewart, Lu	76	11	13		60St
Blasi et al.	86 ± 4	14 ±6	<1.5		67Bl
Hennecke et al.	80 ± 3	20 ±3	≦3	≦6.5	67He09
Alexander, Lau	88.8	6.5	4.7	∿0	68Al16
Bosch et al.	82 ± 3	11 ±2	≦3	7 ± 3	68Bo10
Donnelly et al.	86 ±14	14 ±7	<14	<12	68Do10
Notea, Gurfinkel	71.6± 8.6	22.0±2.4	0.58±0.70	5.8±11.0	68No01
Schmidt, Fink	85.5± 1.5	14.5±0.5	<1	<2	72Sc08
Awwad et al.	85 ± 5	6.5±0.4	0.9 ±1.2	8.2± 5.9	74Aw02
Schötzig et al.	86.5± 2.7	13.6±2.5	-0.3 ±0.3	0.2± 1.3	77Sc31

Table 3.11.4 Estimation of electron capture branches.

	Electron capture branches (%)		
Item \ Energy	324 keV	403 keV	484 keV
log *ft*	12.4	12.4	13.4
log *f*	-0.429	-0.223	-0.0512
$T_{1/2}$	10.71 y	10.71 y	10.71 y
branch	0.005 %	0.008 %	0.0012 %

Table 3.11.5 Experimental values of K-shell internal conversion coefficients.

Gamma ray		K-shell conversion coefficients						
Number	Energy (keV)	Mann, Chaturvedi 63Ma	Thun et al. 66Th09	Bosch et al. 68Bo04	Avignone et al. 70Av01	Avignone, Trueblood 71Av01	Freund 73Fr15	Ramaniah 75Ra17
1	53.2			4.7 ±0.4				
2	79.6		1.36 ±0.10	1.7 ±0.4				
3	81.0		1.36 ±0.05	1.34 ±0.08	1.46 ±0.05[a)]			
4	160.6		0.39 ±0.13	0.19 ±0.02	0.21 ±0.02		0.205 ±0.007	
5	223.1			0.06 ±0.02		0.082±0.004	0.0743±0.0043*	0.092±0.01
6	276.4	0.047	0.050±0.008	0.046±0.003				
7	302.9	0.036±0.004	0.037±0.005	0.038±0.004[b)]*	0.039±0.004[b)]*			
8	356.0	0.021±0.002		0.023±0.002*	0.020±0.002[b)]*			
9	383.9	0.020±0.013	0.017±0.004	0.028±0.010*				

a) Obtained from the decay of ^{133}Xe.

b) Errors are estimated by us.

Table 3.11.6 Experimental values of K/L,K/LM and L/MN ratios.

Gamma-ray energy (keV)		Mann, Chaturvedi[a)] 63Ma	Nieschmidt et al. 64Ni04	Hennecke et al. 67He09	Hendric, Avignone 67He10	Bosch et al. 68Bo04	Avignone et al. 70Av01	Törnkvist et al. 70To01	Awwad et al. 74Aw02
53.2	L/MN			3.1 ±0.3					
79.6	K/L			6.4 ±1.2					
81.0	K/L			5.72±0.73					6.0 ±0.6
	K/LM		4.79±0.09		5.4±0.5	5.4±0.5			
	L/MN			3.6 ±0.4					
160.6	K/L			4.80±0.54				5.13±0.27	4.8 ±0.6
	K/LM					4.4±0.8	3.75±0.25		
	L/MN			4.5 ±0.5					
223.1	K/LM		7.4 ±0.7	7.82±0.81					
276.4	K/L			5.63±0.37*					5.5 ±0.5*
	K/LM	4.7±0.8				3.9	4.75±0.15		
	L/MN			3.8 ±0.4*					
302.9	K/L			6.95±0.56*					
	K/LM	5.3±2.0				6.1±0.2			
	L/MN			4.0 ±0.4*					
356.0	K/L			6.06±0.34*					6.29±0.24*
	K/LM	7.0±4.2			4.27±0.13	5.0±0.5			
	L/MN			3.9 ±0.4*					
383.9	K/L			6.05±0.43*					
	K/LM	6.0±5.0				5.0±1.0			
	L/MN			4.3 ±0.4*					

a) Values deduced from α_K and α_{LM}.

Table 3.11.7 Theoretical values of internal conversion coefficients.

Item		Values						
Atomic number		55						
Energy (keV)		223.1		276.4	302.9		356.0	383.9
Multipolarity		E2	M1	E2	E2	M1	E2	E2
Conversion coefficients	α_K	9.18(-2)	8.44(-2)	4.62(-2)	3.47(-2)	3.77(-2)	2.11(-2)	1.68(-2)
	α_{L_1}	9.49(-3)	1.03(-2)	4.93(-3)	3.74(-3)	4.56(-3)	2.32(-3)	1.87(-3)
	α_{L_2}	4.93(-3)	6.33(-4)	1.93(-3)	1.30(-3)	2.57(-4)	6.55(-4)	4.79(-4)
	α_{L_3}	3.81(-3)	1.44(-4)	1.53(-3)	1.05(-3)	5.92(-5)	5.10(-4)	3.60(-4)
	α_L	1.82(-2)	1.11(-2)	8.39(-3)	6.09(-3)	4.88(-3)	3.48(-3)	2.70(-3)
	K/L	5.03	7.62	5.51	5.70	7.72	6.06	6.23
	MNO/L	0.25	0.26	0.25	0.25	0.26	0.25	0.25
	α	1.10(-1)	9.55(-2)	5.46(-2)	4.08(-2)	4.25(-2)	2.46(-2)	1.95(-2)
Gamma branch	$1/(1+\alpha)$	0.901	0.913	0.948	0.961	0.959	0.976	0.981

Table 3.11.8 Average values of K-shell internal conversion coefficients.

Gamma-ray energy (keV)	W=1			$W=1/\varepsilon^2$		
	Value	Error		Value	Error	
		Int.	Ext.		Int.	Ext.
302.9	0.0385*	0.0028*	0.0005	0.0385	0.0028	0.0005
356.0	0.0215*	0.0015*	0.0015	0.0215	0.0015	0.0015

Table 3.11.9 Average values of K/L ratios.

Gamma-ray energy (keV)	W=1			$W=1/\varepsilon^2$		
	Value	Error		Value	Error	
		Int.	Ext.		Int.	Ext.
276.4	5.59*	0.31*	0.04	5.60	0.29	0.03
356.0	6.18*	0.20*	0.12	6.21	0.19	0.10

Table 3.11.10 Evaluated values of internal conversion coefficients.

Gamma-ray energy (keV)	α_K	K/L	K/LM	L/MN	α
223.1	0.074 ±0.004		7.8±0.8		0.084 ±0.005
276.4	0.046 ±0.003	5.6 ±0.3		3.8±0.4	0.056 ±0.004
302.9	0.0385±0.0028	7.0 ±0.6		4.0±0.4	0.045 ±0.003
356.0	0.0215±0.0015	6.18±0.21		3.9±0.4	0.0259±0.0018
383.9	0.028 ±0.010	6.1 ±0.4		4.3±0.4	0.0337±0.0012

Table 3.11.11 Evaluated gamma-ray intensities.

Gamma ray Number	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
6	276.4	11.53±0.06	7.15±0.03
7	302.9	29.48±0.14	18.28±0.08
8	356.0	100.0 ±0.4	62.00±0.14
9	383.9	14.39±0.06	8.92±0.04

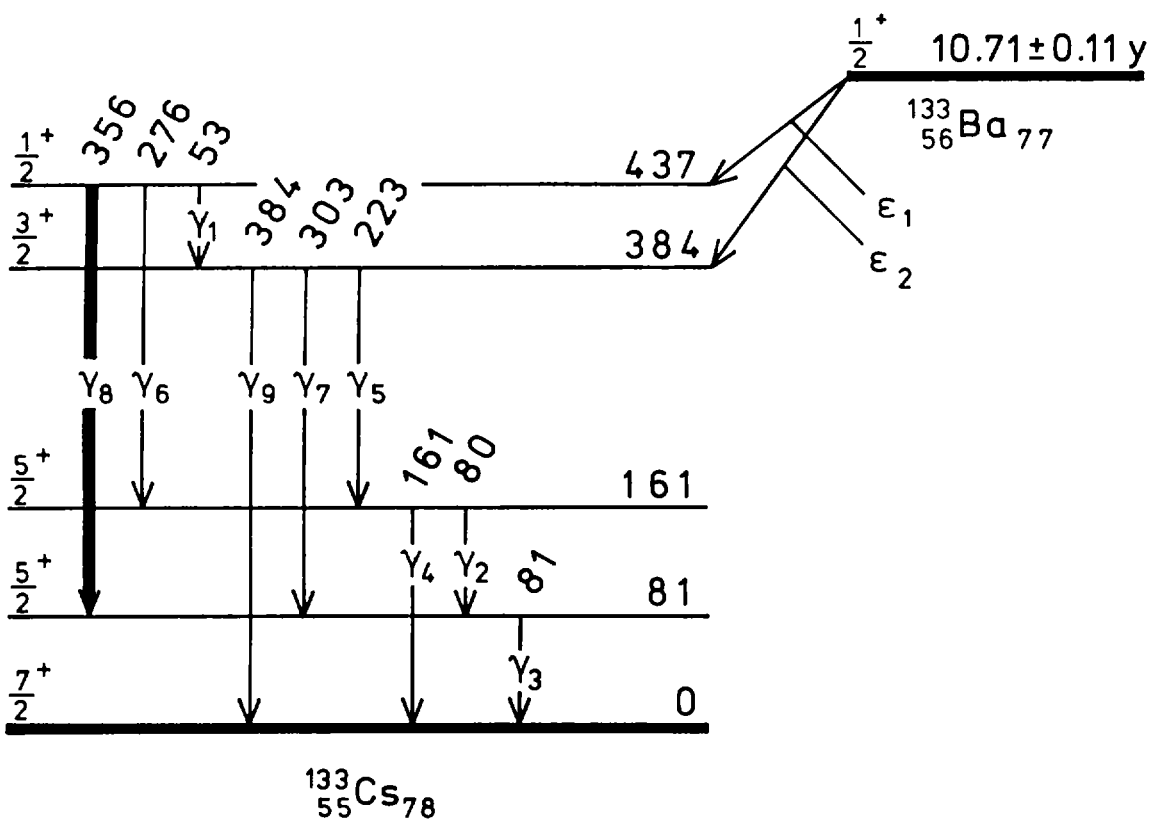

Fig. 3.11.1 Decay scheme of ^{133}Ba .

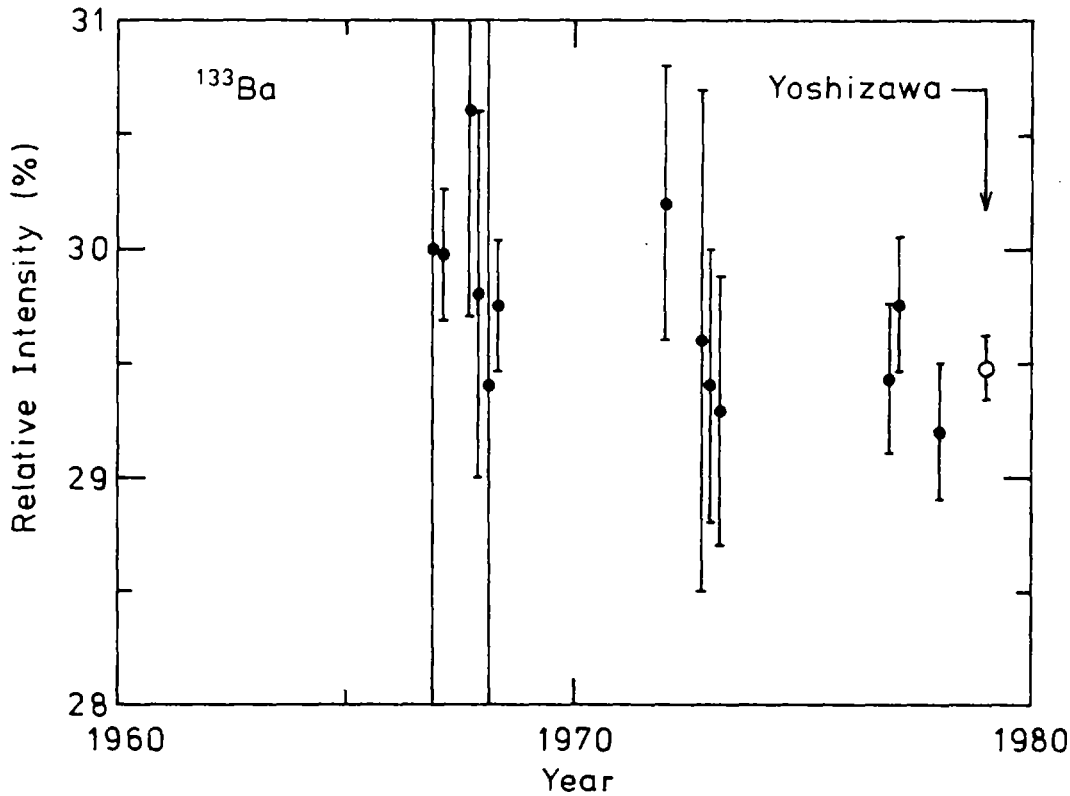

Fig. 3.11.2 Relative intensity of the 303 keV gamma ray to the 356 keV one in the decay of ^{133}Ba.

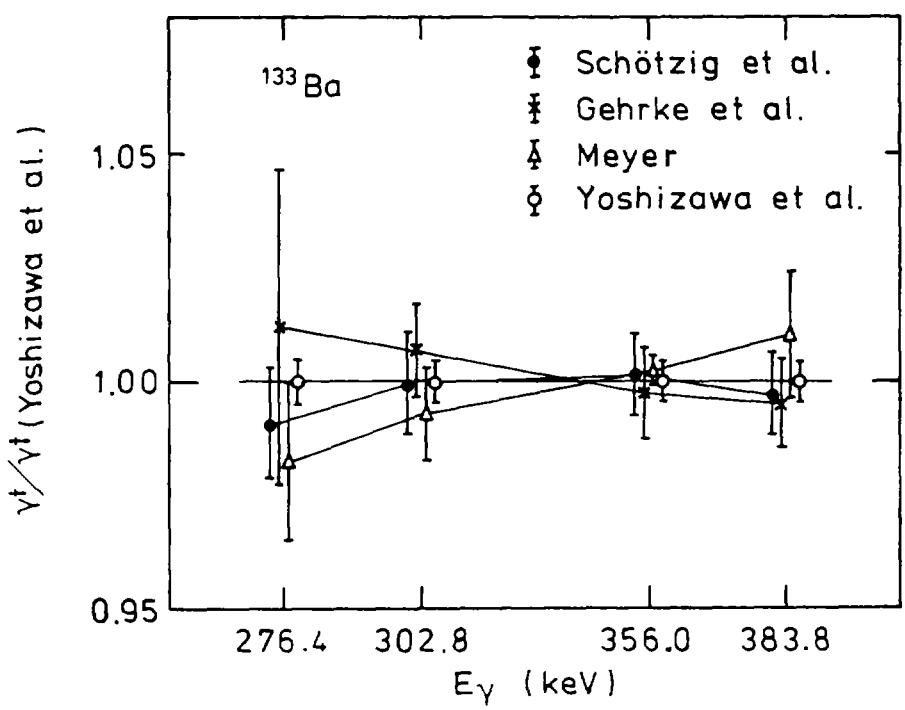

Fig. 3.11.3 Comparison of relative intensities of strong gamma rays in the decay of ^{133}Ba.

3.12 ^{139}Ce

The radioactive nuclide ^{139}Ce decays to ^{139}La and emits the 166 keV gamma ray. The decay scheme is simple as shown in Fig. 3.12.1. This gamma-ray intensity per decay was evaluated.

a) Electron capture transition to the ground state. Spins and parities are $3/2^+$ and $7/2^+$ for the ground states of ^{139}Ce and ^{139}La, respectively. This transition is a second forbidden one, and log ft values of second forbidden transitions are seen in Table 3.9.1. If one assums that the log ft value is the same to that of the transition ^{137}Cs $(7/2^+) \rightarrow {}^{137}$Ba $(3/2^+)$, i.e. log ft=12.5, the branching ratio ε_2 is 4×10^{-6}. Therefore, this transition is negligible.

b) Internal conversion coefficient. Many experimental values of α_k and α are available as shown in Table 3.12.1 and Fig. 3.12.2. All the values of α_k and α after 1960 agree each other within experimental errors except both α_k and α values of Legrand et al. The value of Rytz is the result of international intercomparison measurements of 23 institutions. Therefore this value is adopted for the total internal conversion coefricients.

The theoretical values are listed in Table 3.12.2. The ratio E2/M1 is shown in Table 3.12.3 and the E2 component is very small. Therefore the experimental value of α is 6 %, smaller than the theoretical M1 value.

c) Evaluation of the 166 keV gamma ray intensity. The evaluated value of the intensity per decay was obtained from the experimental total internal conversion coefficients as shown in Table 3.12.4.

Table 3.12.1 Experimental values of conversion coefficients of the 166 keV gamma ray.

Author	$\alpha_K \times 10^3$	K/LMN	$\alpha \times 10^3$	Ref.
Pruett, Wilkinson	0.20 ±0.05	6.6 ±0.3		54Pr31
Mitchell, Hebb	0.22	7.0 ±0.3		54Mi56
Nussbaum, Van Lieshout	0.20 ±0.01			54Nu12
Kettelle et al.	0.22 ±0.01	5.7 ±0.3		56Ke23
Dzhelepov et al.		8.1 ±0.5		58Dz10
Jastrzebski		6.7		60Ja02
Taylor, Merritt			0.2514±0.0011	62Ta03
Geiger et al.		5.85±0.13		65Ge04
Hansen, Delabaye	0.209 ±0.027			67Ha45
Aristov, Bazhenov			0.254 ±0.006	71Ar43
Legrand et al.	0.2111±0.0026	6.30±0.30	0.2446±0.0012	73Le27
Morinaga, Hisatake	0.207 ±0.009			75Mo12
Hansen, Mouchel	0.2152±0.0033	5.84±0.17	0.2520±0.0050	75Ha
Plch et al.	0.214 ±0.002		0.251 ±0.002	75Pl
Rytz			0.2502±0.0025*	77Ry

Table 3.12.2 Theoretical values of internal conversion coefficients.

Item		Value	
Atomic number		57	
Energy (keV)		165.85	
Multipolarity		M1	E2
Conversion coefficients	α_K	2.26(-1)	2.51(-1)
	α_{L_1}	2.79(-2)	2.48(-2)
	α_{L_2}	1.93(-3)	2.30(-2)
	α_{L_3}	4.10(-4)	2.21(-2)
	α_L	3.03(-2)	6.98(-2)
	K/L	7.46	3.60
	MNO/L	0.26	0.26
	α	0.264	0.339
Gamma branch	$1/(1+\alpha)$	0.791	0.747

Table 3.12.3 Experimental values of the E2/M1 mixing ratio.

Author	(E2/M1)	E2(%)	Ref.
Knipper	-0.06	0.36	61Kn02
Grace et al.	<0.02	<0.040	62Gr17
Haag et al.	0.34±0.34	0.12±0.02	63Ha07,64Ha20

Table 3.12.4 Evaluation of the intensity per decay for the 166 keV gamma ray.

Item	Value
ε_2	neglect
α	0.2502±0.0025
γ_1	79.99 ±0.16 %

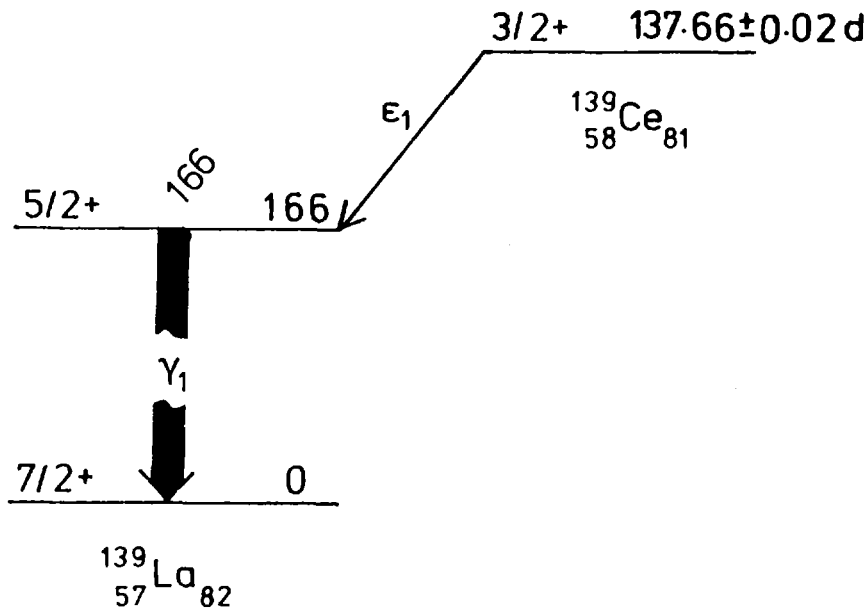

Fig. 3.12.1 Decay scheme of ^{139}Ce.

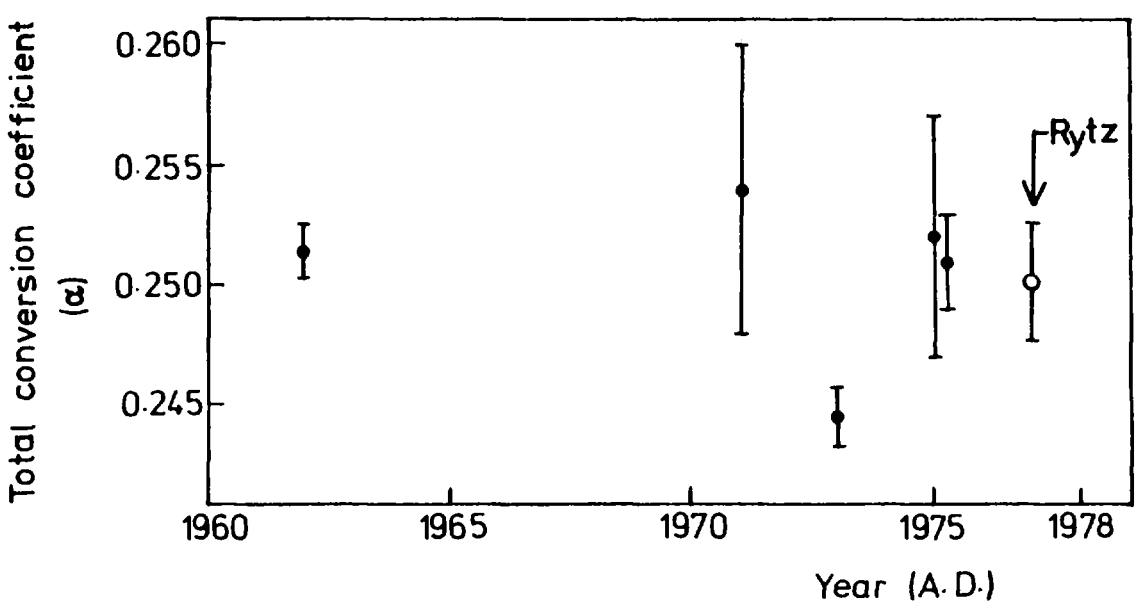

Fig. 3.12.2 Total conversion coefficient of the 166 keV transition in the decay of ^{139}Ce.

3.13 ^{180m}Hf

The short-lived isomer ^{180m}Hf with half-life of 5.5 hr emits 6 gamma rays. The decay scheme is shown in Fig. 3.13.1. Intensities of three cascade gamma rays of 215 keV, 332 keV and 443 keV were evaluated.

a) Relative gamma-ray intensities. Experimental values are listed in Table 3.13.1. Jardine and Geyrathi and D'auria measured them with Ge(Li) detectors. Other three measurements were performed with curved crystal spectrometers.

b) Internal conversion coefficients. Experimental and theoretical values of internal conversion coefficients are summarized in Table 3.13.2 and Table 3.13.3. Only a few experimental values are available, and these α_K values are about 5~10 % smaller than the theoretical values. The gamma rays of 93, 215, 332 and 443 keV are E2 transition, but the 501 keV gamma ray is a E3/M2 mixing transition. Experimental mixing ratios are shown in Table 3.13.4. Theoretical total conversion coefficients with 10 % errors are adopted. For the 501 keV gamma ray the adopted value was obtained from the theoretical E3 and M2 coefficient and the experimental mixing ratio given by Krame et al. One experiment pointed out a E2 mixing of E2/M2 = 0.038+0.004 (71Kr) for the 501 keV transition, but this mixing is negligible for the internal conversion coefficient. Since the conversion coefficient is too large for the 93 keV gamma ray, we did not evaluate the intensity.

c) Evaluation of gamma-ray intensities. The unweighted average value of two Ge(Li) measurements is adopted for intensity ratio of the 501 keV gamma ray to 443 keV one. Intensities per decay of the 215 keV and 332 keV gamma rays are obtained from the total internal conversion coefficients.

Table 3.13.1 Experimental values of relative gamma-ray intensities.

Gamma ray		Relative intensities				
Number	Energy (keV)	Edwards, Boehm 61Ed01	Reirson et al. 70Re08,67Ne07	Jardine 71Ja21	Gujrathi, D'auria 71Gu	Gehrke 72Ge24
1	57.5	51.3±1.2	51.3±2.0		47.5±3.4	∿49
2	93.3	17.6±0.4	18.0±0.5		19.5±1.7	15.5±0.8
3	215.3	88.2±2.5	86.5±2.0		85.9±2.5	86.2±2.5
4	332.3	100.0±4.2	100.0±2.5		100.0±4.2	100
5	443.2	86.6±4.6	90.4±3.0	570±15*	84.7*	86.4±2.5
6	500.7		13.6±1.2	100*	15.7±1.7*	15.1±0.8

Table 3.13.2 Experimental values of internal conversion coefficients.

Authors	Gamma-ray energy (keV)	Conversion coefficients					Ref.
		$\alpha_K \times 100$	$\alpha_L \times 100$	K/L	MNO/L	$\alpha \times 100$	
Edwards, Boehm	93.3	110 ±9	313 ±19	0.325±0.025	0.29±0.03		61Ed01
Gvozdev et al.			272				70Gv01
Edwards, Boehm	215.3	12.3 ±0.9		1.59 ±0.14			61Ed01
Gvozdev et al.				1.8 ±0.1			68Gv01
El-Nesr, El-Sayad		13.1 ±0.2					68E102
Edwards, Boehm	332.3	3.8 ±0.3		2.60 ±0.23			61Ed01
Gvozdev et al.				3.1 ±0.2			68Gv01
Edwards, Boehm	443.2	1.89±0.17		4.3 ±0.6	0.39±0.09	2.49±0.22	61Ed01
Gvozdev et al.				3.8 ±0.2			68Gv01
El-Nesr, El-Sayad		2.4 ±0.4					68E102
Edwards, Boehm	500.7	3.7 ±1.2					61Ed01
Gizon, Gizon		3.83±0.12	1.68±0.11	2.28 ±0.07			67Gi11
Goldhaber, McKeown		4.5 ±0.4		2.50 ±0.45			67Sc19
Gvozdev et al.				2.70 ±0.10			68Gv01
El-Nesr, El-Sayad		9.5 ±2.5					68E102

Table 3.13.3 Theoretical values of internal conversion coefficients.

Item		Values					
Atomic number		72					
Energy (keV)		93.3	215.3	332.3	443.2	500.7	
Multipolarity		E2	E2	E2	E2	E3	M2
Conversion coefficients	α_K	1.10(+0)	1.37(-1)	4.20(-2)	2.01(-2)	3.80(-2)	1.23(-1)
	α_{L_1}	1.13(-1)	1.56(-2)	5.16(-3)	2.57(-3)	5.55(-3)	1.93(-2)
	α_{L_2}	1.35(+0)	3.14(-2)	4.96(-3)	1.55(-3)	7.45(-3)	2.24(-3)
	α_{L_3}	1.26(+0)	2.16(-2)	2.82(-3)	7.72(-4)	2.45(-3)	6.43(-4)
	α_L	2.73(+0)	6.85(-2)	1.29(-2)	4.89(-3)	1.55(-2)	2.22(-2)
	K/L	0.404	2.01	3.24	4.11	2.46	5.53
	MNO/L	0.30	0.30	0.30	0.30	0.30	0.29
	α	4.65(+0)	2.27(-1)	5.88(-2)	2.65(-2)	5.81(-2)	1.52(-1)
Gamma branch	$1/(1+\alpha)$	0.177	0.815	0.944	0.974	0.945	0.868

Table 3.13.4 Experimental values of E3/M2 mixing ratio for the 500.7 keV gamma ray.

Authors	δ(E3/M2)	E3	Ref.
Bodenstedt et al.	5.3±0.4	96.5±0.5 %	61Bo25
Krane et al.	5.3±0.3	96.6±0.4 %	71Kr

Table 3.13.5 Evaluation of the intensities per decay.

Item	Value
γ_6/γ_5	0.180 ±0.010
α_3 (theoretical)	0.227 ±0.023
α_4 (theoretical)	0.059 ±0.006
α_5 (theoretical)	0.0265±0.0027
α_6 (theoretical)	0.061 ±0.006
γ_3	81.5±1.5 %
γ_4	94.4±0.5 %
γ_5	82.1±0.7 %

Table 3.13.6 Evaluated values of gamma-ray intensities.

Gamma ray		Intensity per decay	Relative intensity
Number	Energy (keV)	(%)	(%)
3	215.3	81.5±1.5	86.3±1.6
4	332.3	94.4±0.5	100.0±0.6
5	443.2	82.1±0.7	87.0±0.8

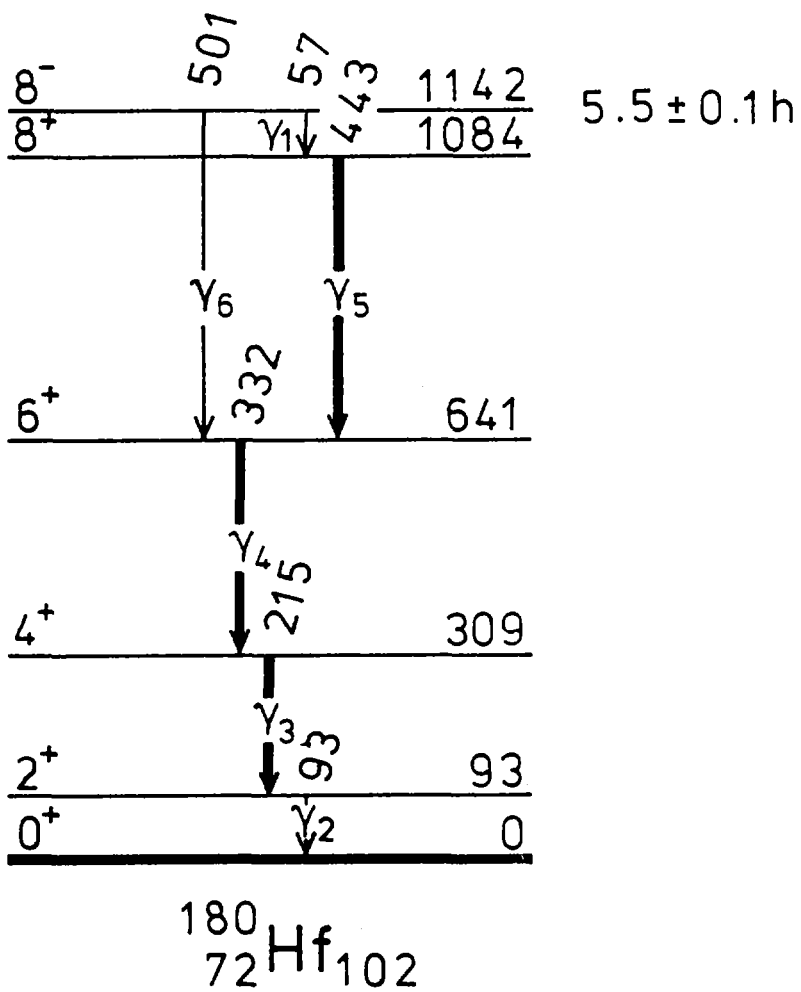

Fig. 3.13.1 Decay scheme of ^{180m}Hf

3.14 ^{198}Au

The ^{198}Au nuclide emits a strong 412 keV gamma ray and two weak gamma rays. The decay scheme is shown in Fig. 3.14.1. The intensity per decay of the strong gamma ray was evaluated.

a) Beta-decay branches. The radioactive nuclide ^{198}Au decays mainly to the 412 keV excited state and weakly to the 1088 keV one in ^{198}Hg. In addition, the transitions to the ground states of ^{198}Pt and ^{198}Hg were reported as shown in Table 3.14.1. Since the log f_1t value of the unique first forbidden transition is usually about 9.88 as mentioned in Table 3.14.2, the electron capture transition to the ^{198}Pt ground state is estimated to be about 1.73×10^{-3} % as shown in Table 3.14.3. Therefore this transition is neglected.

b) Relative gamma-ray intensities. Experimental values of relative intensities are summarized in Table 3.14.4. All the values except Iwata and Yoshizawa were measured with NaI(Tl) detectors. Since these values scatter beyond experimental errors, the best values observed with a Ge(Li) detectors by Iwata and Yoshizawa were adopted.

c) Internal conversion coefficients. Experimental values of internal conversion coefficients and ratios are listed in Table 3.14.5. Experimental values of the K-shell conversion coefficient are plotted in Fig. 3.14.2. Since the beta transition is a non-unique first forbidden transition, beta-ray spectrometer measurements of e_K/β^- ratio have some ambiguity from the shape factor of the beta-ray spectrum. Therefore we adopted values of β-γ coincidence measurements given by Petterson et al. and an internal-external conversion measurement by Bergkvist and Hullberg. The average values are shown in Table 3.14.6. These values are in good agreement with theoretical values given in Table 3.14.7.

d) Evaluation of the intensity per decay. The total internal conversion coefficient is obtained from the adopted value α_K and K/L and the theoretical value of MNO/L. The final evaluated value of the 412 keV gamma-ray intensity is obtained from the total conversion coefficient α, the relative intensity γ_3^t and the branching ratio of the weak beta transition β_3.

Table 3.14.1 Experimental values of beta and electron capture branches.

Authors	Transition	Branch (%)	log *ft*	Ref.
Elliott et al.	β_3	0.025±0.005	12.3	54E104
Bashilov	ε_1	<0.01	>9.1	56Ba90

Table 3.14.2 Log *ft* values of the unique first forbidden transitions for neighbouring nuclei.

Nucleus		Spin-parity		log *ft*
Parent	Daughter	Initial	Final	
^{172}Tm	^{172}Yb	2-	0+	9.8
^{200}Tl	^{200}Hg	2-	0+	9.8
^{202}Tl	^{202}Hg	2-	0+	9.9
^{204}Tl	^{204}Pb	2-	0+	10.1
^{205}Pb	^{205}Tl	5/2-	1/2+	11.8
^{207}Bi	^{207}Pb	9/2-	13/2+	10.6
^{208}Bi	^{208}Pb	5+	3-	12.5

Table 3.14.3 Estimation of the electron capture transition intensity from ^{198}Au to ^{198}Pt.

Item	Value
log *ft*	9.9
Q_ε	330 keV
log *f*	-0.25
t	1.55×10^5 day
$T_{1/2}$	2.6973 day
ε_1	1.73×10^{-3} %

Table 3.14.4 Experimental values of relative gamma-ray intensities.

Authors \ Number	Relative intensities (%) 1	2	3	Ref.
Energy (keV)	411.8	675.9	1087.7	
Cavanagh	100	1.43 ±0.10	0.33 ±0.07	51Ca24
Hubet	100	1.4 ±0.1	0.25 ±0.05	51Hu18
Elliot et al.	100	0.84 ±0.06	0.170 ±0.012	54El04
Maeder et al.	100	1.3 ±0.2	0.25 ±0.02	54Ma19
Dzhelepov et al.	100	1.11 ±0.05	0.26 ±0.02	55Dz41
Volpe, Hinman	100	0.97 ±0.11	0.156 ±0.014	56Vo20
Wapstra et al.	100	0.83 ±0.08		59Wa17
Keeler, Connor	100	1.0	0.28	65Ke04
Iwata, Yoshizawa	100.0±0.4*	0.841±0.003*	0.1664±0.0021*	80Iw

Table 3.14.5 Experimental values of conversion coefficients of the 412 keV transition.

Authors	$\alpha_K \times 10^4$	$\alpha_L \times 10^4$	$\alpha_M \times 10^4$	K/L	MNO/L	Ref.
Steffen et al.	280 ±70	125±30	30±20			49St
Hubert	300 ±10					51Hu18
Huber et al.	275 ±30					52Hu
Simons	307 ± 3	103± 1	31± 1			52Si25
Connors et al.	250 ±50	120±20				56Co
Kel'Man, Metskhvarishvili				2.69±0.02	0.347±0.006 a)	59Ke20
Wapstra et al.	281 ± 5	97± 4	31± 4			59Wa17
Hamilton et al.	244 ± 8					60Ha
Vries et al.	241 ± 9			2.91±0.10*	0.323±0.016*	60Vr
	252 ±13					
Hultberg et al.	280 ±15					61Hu
Petterson et al.	305 ±10*					61Pe07
Wolfson	278 ±19					61Wo
Hamilton et al.	282 ±10					62Ha25
Lewin et al.	303.5± 4.5					63Le11
	298.5± 4.5					
Herrlande, Graham				2.79±0.07* c)		64He19
Parsignault	283 ±10	111± 6	$\alpha_{MN} \times 10^4 = 31 \pm 3$			64Pa20
Bergkvist, Hultberg	302 ± 4*					65Be07
Keeler, Connor	299 ± 4	$\alpha_{LM} \times 10^4 = 145 \pm 3$				65Ke04
Newbolt, Hamilton	286 ±10					65Ne
Paul	299 ± 2					65Pa08
Petterson et al.	308 ± 9					65Pe
Dragoun et al.					O/N=0.21±0.03	72Dr02
Sahota	305 ±15					72Sa34
El-Nesr, Mousa	303.5± 4.5					73El10
Rao et al.	300 ± 3					75Ra09

a) Obtained from the ratio L:M:N:O=1:(0.252±0.004):(0.077±0.004):(0.018±0.002).
b) These values vary with shape factor.
c) Obtained from the ratio $K:L_1:L_2:L_3=(6.87\pm0.07):(1.00\pm0.01):(1.01\pm0.01):(0.45\pm0.01)$.

Table 3.14.6 Average values of conversion coefficients of 412 keV transition.

Item	W=1			$W=1/\varepsilon^2$		
	Average value	Error Int.	Error Ext.	Average value	Error Int.	Error Ext.
$\alpha_K \times 10^4$	303.5*	5.3*	1.5	302.4	3.7	1.0
K/L	2.85	0.06	0.06	2.83*	0.06*	0.06

Table 3.14.7 Theoretical values of internal conversion coefficients.

Item		Value
Atomic number		80
Energy (keV)		411.80
Multipolarity		E2
Conversion coefficients	α_K	3.01(-2)
	α_{L_1}	4.26(-3)
	α_{L_2}	4.49(-3)
	α_{L_3}	1.93(-3)
	α_L	1.07(-2)
	K/L	2.82
	MNO/L	0.32
	α	4.42(-2)
Gamma branch	$1/(1+\alpha)$	0.958

Table 3.14.8 Evaluation of the 412 keV gamma-ray intensity per decay.

Item	Value (%)	Ref.
α_1	4.45 ±0.09	
γ_3 †	0.1668±0.0021	80Iw
β_3	0.025 ±0.005	54Blo4
γ_1	95.56 ±0.08	

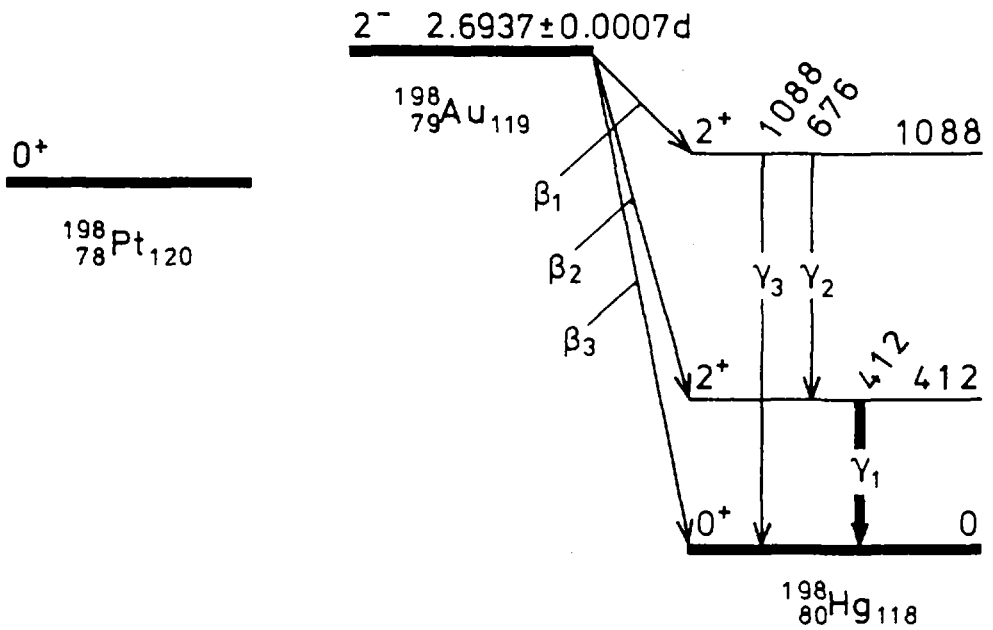

Fig. 3.14.1 Decay scheme of ^{198}Au.

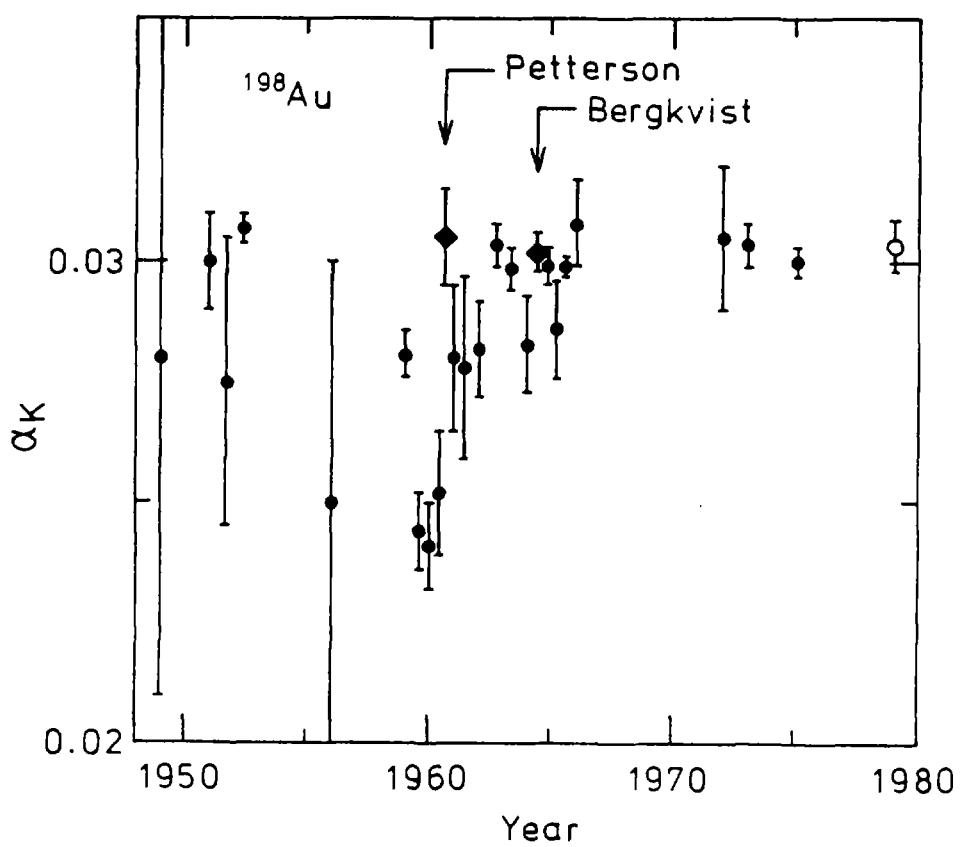

Fig. 3.14.2 K-shell internal conversion coefficient of the 412 keV transition in the decay of ^{198}Au.

3.15 ^{203}Hg

A single gamma ray at 279 keV is emitted in the decay of ^{203}Hg. Fig. 3.15.1 shows the decay scheme of this nuclide. The intensity per decay of the 279 keV gamma ray was evaluated.

a) Beta decay to the ground state. Upper limits of the ground state transition were reported as shown in Table 3.15.1. Since this transition is an unique first forbidden transition, the log ft value (> 12) is larger compared with usual unique first forbidden transitions. The large log ft value is found to be log ft = 11.2 for ^{198}Au.

b) Weak gamma rays. The second excited state of ^{203}Tl is at 680 keV. The decay energy of ^{203}Hg is Q_β = 491 keV. Since no excited state below 680 keV was observed by nuclear reaction experiments, no weak gamma ray is expected in the decay of ^{203}Hg.

c) Internal conversion coefficients. A lot of measurements for the conversion coefficients have been reported as shown in Table 3.15.2. Experimental values of the K-shell conversion coefficient are plotted in Fig. 3.13.2. Theoretical conversion coefficients are listed in Table 3.15.3. The experimental values cannot be accounted for by the M1+E2 multipole mixing, but these are explained by the penetration effect and the multipole mixing. The mixing ratio is determined to be E2/M1=1.32±0.11 (E2=57±2 %).

Experimental values were obtained from three kinds of measurements; gamma-ray intensity measurement, beta-ray spectrum measurement and beta-gamma coincidence measurement. Since there is no good intensity standards in this 279 keV region, the first one cannot expect reliable results. Accurate intensity determination of the continuous beta-ray spectrum is difficult with the beta-ray spectrometer. Therefore, we adopted three accurate experimental values observed by third method. The evaluated value of the total conversion coefficients is obtained from the unweighted mean of these values in Table 3.15.4.

d) Evaluation of gamma-ray intensity per decay. The beta decay branching to the ground state is neglected and no weak gamma ray is expected. Therefore, the evaluated value of the intensity per decay for the 279 keV gamma ray is obtained from the evaluated value of the total internal conversion coefficient as shown in Table 3.15.5.

Table 3.15.1 Beta transition to the ground state.
(Unique 1st forbidden)

Author	Branch	Intensity (%)	log *ft*	Ref.
Marty	β_2	$< 4 \times 10^{-3}$	> 12	55Ma40
Wolfson	β_2	$< 3 \times 10^{-2}$		56Wo09

Table 3.15.2 Experimental values of internal conversion coefficients for the 279 keV transition.

Author	α_K $\times 10^3$	K/L	K/LMN	L/MNO	α $\times 10^3$	Ref.
Saxon	180	3		>12		48Sa30
Slätis, Siegbahn		3		≪12	247	49Sl16
Wilson, Curran	185		3.71			51Wi22
Heath, Bell	230 ±10					52He18
Johansson	210 ±10					52Jo23
Burford	158 ± 3		2.59±0.04		(219 ±4)	53Bu79
Metzger	163 ± 6	3.5		3.2		54Me08
Thulin, Nybö	154 ±15		2.78±0.20			54Th17
Wapstra et al.	141 ±15	3.34±0.10	2.55±0.05	3.5 ±0.3		54Wa12
Marty	205 ±20	3.15±0.15		4.5 ±1.5		55Ma40
Azuma	160			2.80		55Az54
Doerner, Weber	147 ± 2	3.29				55Do12
Bell, Skarsgard	140					56Be97
Nordling et al.	159 ± 4	3.24±0.05				56No26
O'Friel, Weber	150 ±10	3.2				56Of03
Wapstra, Nijgh	164 ± 5	3.35±0.05				56Wa
Wolfson	130 ±10		2.75			56Wo09
Nijgh et al.	163 ± 3	3.39±0.06	2.60±0.06	3.28±0.10	(226 ±4)	58Ni28
Peele	163 ± 6					60Pe22
Ramaswamy, Jastram	195 ±14					60Ra04
Stockendal	160 ±15					60St21
Hurley, Ferguson	175 ± 4					61Hu15
Subba Rao	150 ±20	3.1				61Su05
Sujkowski	164 ± 4	3.65±0.26	2.75±0.19	3.09±0.21	(224 ±4)	61Su10
Taylor	163.3± 1.7				(226.2±1.9)	62Ta06
Burmeister er al.	168 ± 8					63Bu09
Croft et al.	162 ± 3					63Cr14
Herrlander et al.	163 ± 3	3.37±0.08	2.56±0.06	3.16±0.08	(226.7±3)*	64He19
Taylor	164.2± 2.1				227.3±2.3*	64He19
Walther et al.					222 ±15	65Wa13
Rao Hnanonanda	158 ±24					65Ra12
Bosch et al.	140 ±30		2.4 ±0.3			67Bo
Andersen	127	3.28±0.13		3.26±0.26		69An
Walz et al.					226.7±0.7*	71Wa
Walz et al.					224.0±0.9	71Wa
Sahota	295 ±15					72Sa34
	305 ±15					
Hansen, Mouchel	165.3± 1.7	3.48±0.12	2.64±0.03	3.14±0.12	227.9±2.4*	74Ha29

Table 3.15.3 Theoretical values of internal conversion coefficients.

Item		Value	
Atomic number		81	
Energy (keV)		279.19	
Multipolarity		M1	E2
Conversion coefficients	α_K	4.06(-1)	7.67(-2)
	α_{L_1}	6.21(-2)	1.07(-2)
	α_{L_2}	6.21(-3)	2.40(-2)
	α_{L_3}	4.68(-4)	1.23(-2)
	α_L	6.88(-2)	4.70(-2)
	K/L	5.91	1.63
	MNO/L	0.31	0.32
	α	0.497	0.139
Gamma branch	$1/(1+\alpha)$	0.668	0.878

Table 3.15.4 Average values of the total internal conversion coefficient.

w = 1			w = $1/\varepsilon^2$		
α	Error		α	Error	
	Int.	Ext.		Int.	Ext.
0.2273*	0.0012*	0.0003	0.2268	0.0006	0.0002

Table 3.15.5 Evaluation of gamma-ray intensity per decay.

Item	Value
β_2	Neglect
Other gamma ray	Neglect
Adopted value of α	0.2273±0.0012
Adopted value of γ_1	81.48 ±0.08

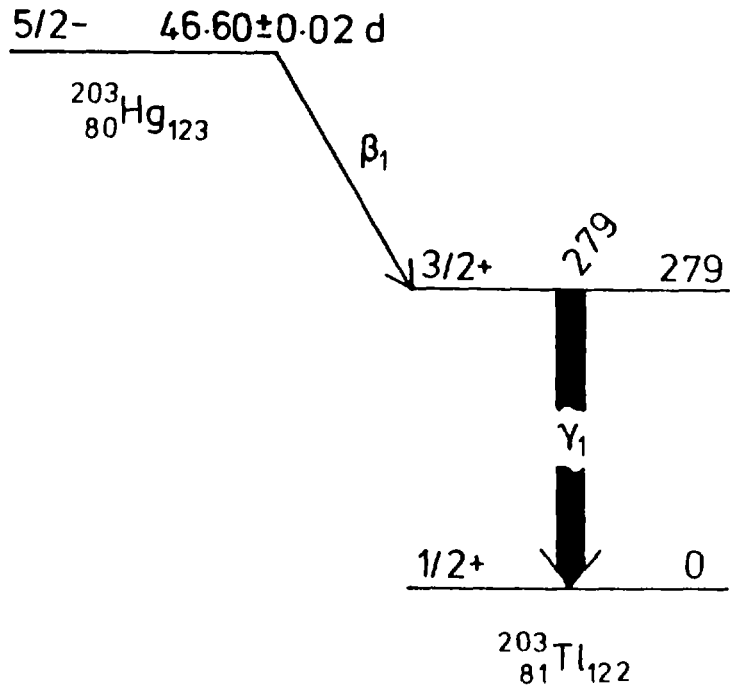

Fig. 3.15.1 Decay scheme of ^{203}Hg.

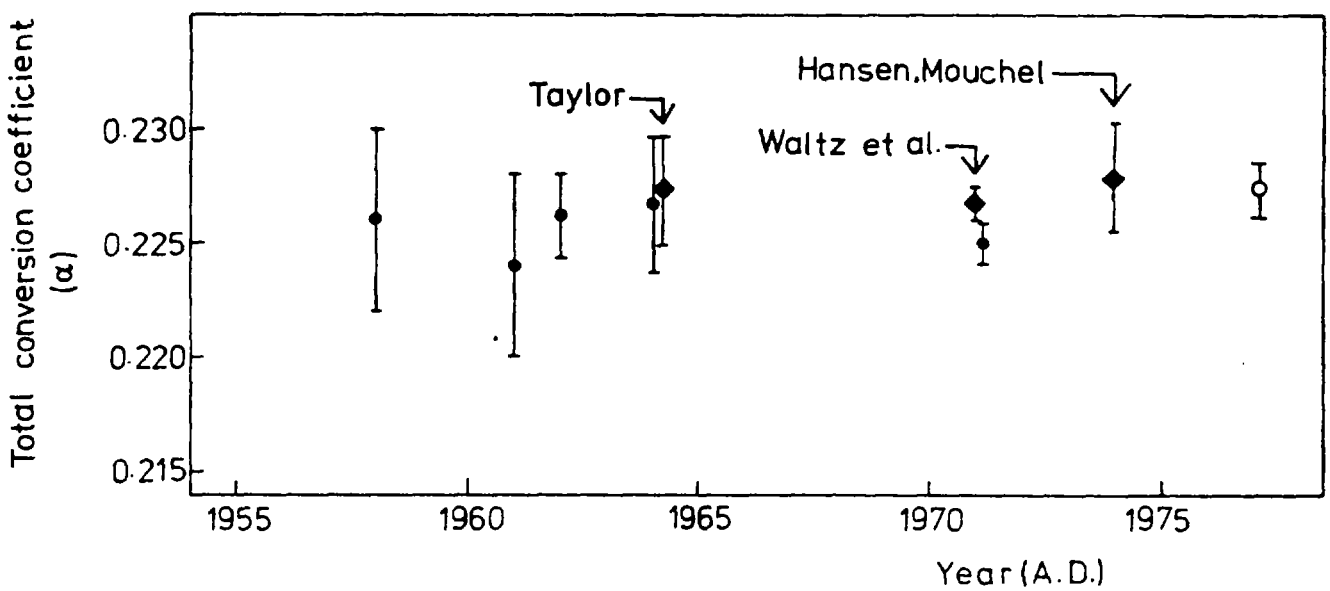

Fig. 3.15.2 Total internal conversion coefficient of the 279 keV transition in the decay of ^{203}Hg.

3.16 ^{207}Bi

The long-lived nuclide ^{207}Bi decays to ^{207}Pb by electron capture and emitts five gamma rays. The decay scheme is shown in Fig. 3.16.1. Intensities per decay of the 570 keV and 1064 keV gamma rays were evaluated.

a) Electron capture and positron decay. This nuclide decays mainly to the 1633 keV excited state of ^{207}Pb, and weakly to the 569 keV and 2339 keV states. Since the electron capture transition to the ground state is a 4th forbidden transition, this transition is neglected. Upper limit of positron decay was observed to be 0.5 % by Miller et al (59Mil9).

b) Relative intensities of gamma rays. Experimental values are listed in Table 3.16.1. The most accurate value of Yoshizawa et al. is adopted for the 1064 keV gamma ray.

c) Internal conversion coefficients. Experimental and theoretical conversion coefficients are shown in Table 3.16.2 and Table 3.16.3, respectively. The experimental values are in good agreement with the theoretical values. We adopted the experimental values of the 570 keV transition.

d) Evaluation of intensities per decay. The intensity per decay of the 570 keV gamma ray is obtained from the total internal conversion coefficient of this transition and the relative intensity of the 897 keV gamma ray as shown in Table 3.16.4. The intensity per decay of the 1064 keV gamma ray is given by the relative intensity ratio of the 1064 keV to the 570 keV gamma rays.

Table 3.16.1 Experimental values of relative gamma-ray intensities.

Authors \ Number	1	2	3	4	5	Ref.
Energy (keV)	569.7	897.3	1064	1442	1770	
Alburger, Sunyar	100	0.16	87	0.16	8	55A126
Monahan	100		76 ±6			61Mo09
Donnely et al.	100		78.4 ±2.4			67Do09
Hedin, Backlin	100 ±2.0		74.0 ±2.0			69He19
Rao et al.	100	0.150±0.015	78.7 ±4.0	0.150±0.015	7.5 ±0.4	69Ra13
Jardin	100	0.14 ±0.02	75.5 ±2.3	0.15 ±0.02	6.95 ±0.20	74Ja28
Yoshizawa et al.*	100.0±0.4	0.122±0.013	75.79±0.25	0.132±0.005	7.026±0.029	79Yo

Table 3.16.2 Experimental values of internal conversion coefficients.

Gamma ray			Kleinheinz et al. 67K102	Nooijien Krugten 67Va25	Sen Rizvi 67Se15	Anderson Christensen 68An04	Baldinger Hallen 69Ba53	Redin Backlin 69He19
Number	Energy (keV)							
1	569.7	$\alpha_K \times 10^2$	1.56±0.07	1.59±0.06	1.6 ±0.1	1.56±0.05	1.5 ±0.3	1.55±0.05
		K/L			3.26±0.09	3.45±0.35	3.00±0.15	
		$\alpha \times 10^2$				2.19±0.03*		
2	1064	$\alpha_K \times 10^2$	9.0 ±0.9		8.5 ±0.5	8.4	9.5 ±1.4	9.6 ±0.3
		K/L			3.64±0.10		3.20±0.15	
		$\alpha \times 10^2$				10.85		

Table 3.16.3 Theoretical values of internal conversion coefficients.

Item		Value	
Atomic number		82	82
Energy (keV)		569.7	1063.6
Multipolarity		E2	M4
Conversion coefficients	α_K	1.58(-2)	9.70(-2)
	α_{L_1}	2.34(-3)	1.89(-2)
	α_{L_2}	1.57(-3)	3.84(-3)
	α_{L_3}	5.42(-4)	1.72(-3)
	α_L	4.45(-3)	2.45(-2)
	K/L	3.55	3.96
	MNO/L	0.33	0.33
	α	2.17(-2)	1.30(-1)
Gamma branch	$1/(1+\alpha)$	0.979	0.885

Table 3.16.4 Evaluation of intensities per decay.

Item	Value	Ref.
γ_2†	0.122 ±0.013 %	79Yo
γ_3†	75.79 ±0.25 %	79Yo
γ_5†	7.026 ±0.029 %	79Yo
α_1	0.0219±0.003	68An04
γ_1	97.74 ±0.03 % a)	
γ_3	74.0 ±0.3 % b)	
γ_5	6.87 ±0.04 % c)	

a) Obtained from $\gamma_1 = 1/(1+\alpha_1+\gamma_2\dagger)$.
b) Obtained from the relative intensity $\gamma_3\dagger$.
c) Obtained from the relative intensity $\gamma_5\dagger$.

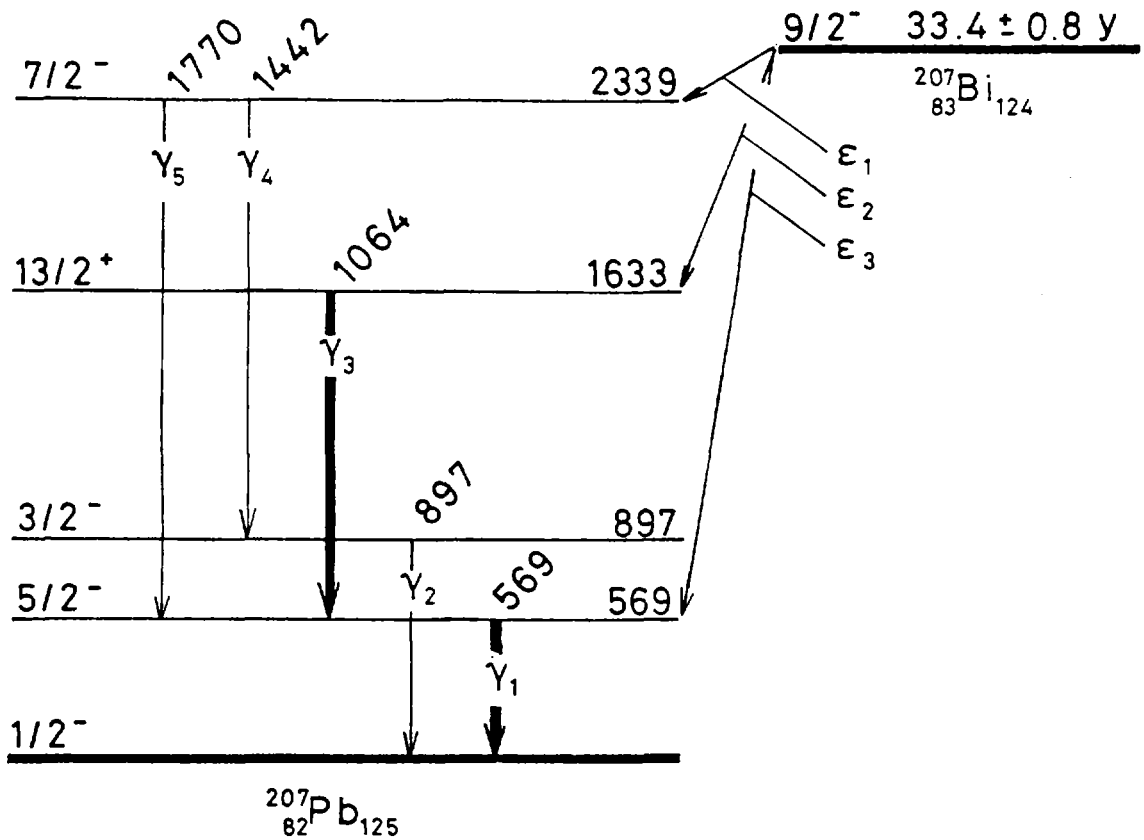

Fig. 3.16.1 Decay scheme of ^{207}Bi.

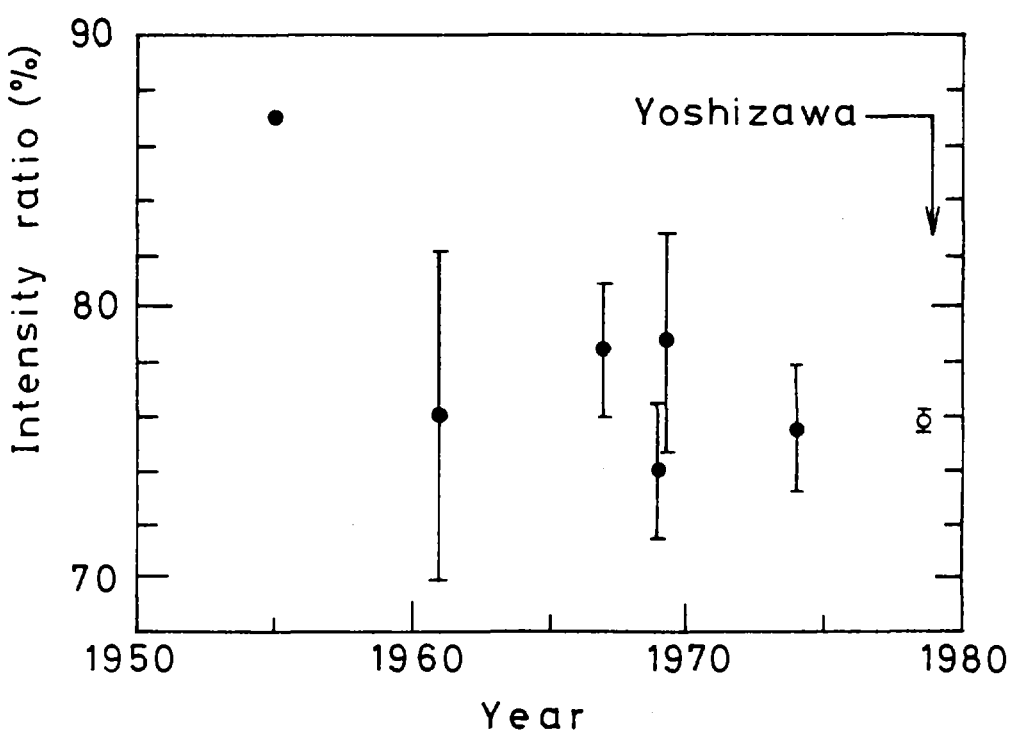

Fig. 3.16.2 Intensity ratio of the 1064 keV gamma ray to the 570 keV one in the decay of ^{207}Bi.

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- 3.1 ^{22}Na -

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4. Evaluation of Half-lives

4.1 ^{22}Na

Experimental values are summarized in Table 4.1.1 and Fig. 4.1.1. Values before 1965 are rejected. Five values given by Anspach et al. (65An07, 68An01) scatter beyond their experimental errors. Merritt and Taylor (73Me) examined impurity. Their errors are three times of the standard deviations, though they did not estimate systematic errors. Since they continue the measurement, their newest value 950.63±0.48 d (2.6027± 0.0013 y) is adopted for the evaluated value.

4.2 ^{24}Na

Experimental values are shown in Table 4.2.1 and Fig. 4.2.1. Values before 1968 are omitted. Since the errors of Lagoutine et al. (68La10) and Gentz et al. (76Ge06) are larger, their values are rejected. The difference between the values of Emery et al. (72Em01) and Merritt (78Me) are more than 20 times of their errors. The systematic error of Emery et al. seems to be underestimated. Therefore the value of Merritt, 14.965±0.002 h, is adopted.

4.3 ^{46}Sc

Nine experimental values are available, and these values are shown in Table 4.3.1 and Fig. 4.3.1. The values before 1963 are omitted because of old experimental technique and ambiguity of error estimation. Though the error of Anspach et al. (65An07) is very small, they did not estimate the systematic error. The errors of Hontzeas and Yaffe (63Ho17), Walker and Easterday (67Wa29) and Cressy (74Cr05) are more than four times larger compared with the error of Merritt (78Me). Therefore the value of Merritt, 84.79±0.03 d, is adopted for the evaluated value.

4.4 ^{54}Mn

Half-life of ^{54}Mn has been reported by many authors as shown in Table 4.4.1 and Fig. 4.4.1. Experimental value before 1965 are rejected for evaluation. Since Anspach et al. (68An01) reported their fourth value in 1968 and Merritt (78Me) gave new result in 1978, their values in 1965 and 1973 are omitted. The value given by Salisbury and Chalmers (65Sa09) has no error and the values by Fabry and Deworm (66Fa08) and by Hammer (68Ha17) have very large errors. The average value of Zimmer and Dahl (68Zi01) is 312.99±0.10 d which is larger than other remainders beyond the error. Therefore these values are also omitted. The unweighted average of six remainders is 312.3±0.2 d. Larger values among them were given by Vaninbroukx and Grosse (66Va26) and by Cressy (74Cr05), but these values agree with others within their experimental errors. Four other values converge in 312.1~ 312.21 d. Therefore, we adopt the value of Merritt (78Me) 312.21±0.05 d for the evaluated value.

4.5 ^{60}Co

Experimental values are listed in Table 4.5.1 and plotted in Fig. 4.5.1. The values before 1965 are rejected, because experimental errors are large and reliabilities are not good enough. Though the errors of Anspach et al. (65An07, 68An01) are small, their values are far from five other values except Harbottle et al. (73Ha60) whose value has a large error. Purpose of Harbottle et al. is to show possibility to determine a half-life from decay rate. Therefore both values of Anspach et al. and the value of Harbottle et al. are omitted. Since Merritt gave a new value (78Me), the old value (71MeB) is also rejected.

In the review article of Grinberg et al. (74Gr), the value of Lagoutine et al. (68La10) was rewritten as 5.272±0.007 with the error of σ. Vaninbroukx and Grosse (76Va30) carefully measured and estimated the systematic error. Since their value deviates from other remainders beyond their error, their value is not adopted. The unweighted average of the corrected value of Lagoutine et al. and the values of Walz and Weiss (70Wa19) Rytz (73Ry) and two values of Merritt (78Me) is 1925.0±0.6 d (5.2705±0.0016 y). The errors of Lagoutine et al., Walz and Weiss, and Rytz are larger and followed periods are shorter compared with those of Merritt. Therefore the unweighted mean of two Merritt's values, 1924.6±0.3 d (5.2694±0.0008 y), is adopted for the final evaluated value. This value slightly deviates from the evaluated value of Grinberg et al. beyond their error.

4.6 ^{85}Sr

Experimental values of half-life are shown in Table 4.6.1 and Fig. 4.6.1. Values before 1962 are rejected for evaluation. Since Anspach et al. (65An07) do not seem to estimate the systematic error, their error is multiplied by 5. Emery et al. (72Em01) included the systematic error and Lagoutine et al. (72La14) took three times of the standard deviation. The error of Grotheer et al. (69Gr12) is about three times larger than three other values mentioned above, and his value deviates from other values beyond the error. Therefore, Grotheer's value is rejected. The unweighted mean of three values Emery et al., Lagoutine et al. and Merritt and Gibson (75MeA) is 64.82±0.11 d. Finally the most accurate value of Merritt and Gibson, 64.84±0.03 d, is adopted for the evaluated value. This value agrees with the evaluate value of Martin and Blichert Toft (70Ma) within their error.

4.7 ^{88}Y

Experimental values are listed in Table 4.7.1 and plotted in Fig. 4.7.1. These values are separated into two groups. One is the values of Wyatt et al. (61Wy01) and Grotheer et al. (69Gr12) and the other is the values of Anspach et al. (65An07, 68An01), Lagoutine et al. (75La16) and Bormann (76Bo19). The value of Wyatt et al. is rejected because the value is old. Three values of Anspach et al. are scattered beyond their error. Their two old values are rejected. Since their error does not include the systematic one, we multiply their error by a factor 5. Then the corrected value is 106.61±0.10 d. The errors

of Grotheer et al. and Bormann et al. are much larger than the error of Anspach. Hence. their values are not adopted. The unweighted average of the new corrected value of Anspach et al. and the value of Lagoutine et al., 106.6 ±0.2 d, is adopted.

4.8 ^{95}Nb

Nine experimental values are summarized in Table 4.8.1 and Fig. 4.8.1. The values of earlier works before 1968 are rejected because of large errors. Since the difference between two values of Anspach et al. (65An07, 68An01) is about 4 times of their error, their old value is rejected. The error of the new value is multiplied by a factor 5. because their errors might not include systematic errors. Their value becomes 35.04±0.20 d. Since the error of this value and the error of Lagoutine et al. (68La10) are more than six times larger than the errors of three remainders the values of Anspach et al. and Lagoutine et al. are not adopted. Estimation of the systematic error is not clear for Reynolds et al. (68Re04) and their value largely deviates from the values of Merritt and Taylor (70Me31) and Hansen et al. (76Ha51). Therefore, the unweighted average of Merritt and Taylor and Hansen et al., 34.98±0.02 d was taken for the evaluated value.

4.9 ^{108m}Ag

Four experimental values shown in Table 4.9.1 and Fig. 4.9.1 are available. Kistner and Sunyar (66Ki03) and Emery et al. (72Em01) determined the lower limit of the half-life. Vonach et al. (69Vo11) obtained the half-life from the (n, 2n) reaction cross section and the strength of the produced ^{108m}Ag isomer. The error of this measurement is more than 40 %.

Harbottle (70Ha32) measured the half life with a proportional counter for 5 years. The error of the computer fitting is 5 %. but he did not consider the systematic error. For example, impurity such as ^{110m}Ag was not reported. About 0.1 % impurity of ^{110m}Ag may give the systematic error of 3 % for the half-life of ^{108m}Ag. The systematic error is not only the impurity of ^{110m}Ag. Therefore we adopted Harbottle's value 127±21 y with three times error.

4.10 ^{134}Cs

Experimental values of the half-life are listed in Table 4.10.1 and plotted in Fig. 4.10.1. The values before 1965 are rejected. The errors of Flynn et al. (65Fl02) and Lagoutine et al. (72La14) are a few times larger than that of Dietz and Pachucki (73Di01). Hence these values are not used. The value of Merritt (78Me) agrees with that of Dietz and Packucki within the error. Therefore we adopted the unweighted average of these two values 754.1±1.4 d (2.065±0.004 y).

4.11 ^{133}Ba

Experimental values are listed in Table 4.11.1 and illustrated in Fig. 4.11.1. These values are divided into two groups of 7.2~7.8 y and 10.3~11.3 y. Values before 1968 are

omitted. Lagoutine et al. (68La10) reported a new result (74La). The same members of Reynolds et al. (68Re04) also gave a new result as Emery et al. (72Em01). Walz and Weiss (70Wa19) continued their experiment and a new result was given by Schötzig et al. (77Sc31). The error of Lloyd and Mays (73Ll01) is large. Therefore these four values are rejected. The error of Schötzig et al. is small but it does not seem to include the systematic error. Hence we rewrite their value as 10.74±0.15 y with 3 σ. The unweighted average of four remainders are 10.67±0.12 y where the external error is larger than the internal error. These two values of Emery et al. and Lagoutine et al. deviate from two other values beyond their errors. Finally we adopted the unweighted average of two new values of Merritt and Gibson (76Me) and Schötzig et al., 10.71±0.11 y (3912±40 d).

4.12 ^{139}Ce

Six available experimental values are shown in Table 4.12.1 and Fig. 4.12.1. Four earlier values are rejected because of large errors. The error of Merritt et al. (75MeB) does not include the systematic error, but is three times of the standard deviation. The corresponding value of Vaninbroukx and Grosse (76Va03) is 137.66±0.06 d with the standard deviation 0.02, plus the systematic error 0.04, which agrees well with the value of Merritt et al. The unweighted average of two values 137.66±0.05 d is adopted for the evaluated value.

4.13 ^{180m}Hf

Only two experimental values are available as shown in Table 4.13.1. Both values are 5.5±0.1 hr. Burson et al. (51Bu50) measured chemically separated sample with a GM counter using separate isotope. Rao and Yaffe (63Ra14) measured chemically separated sample with a NaI(Tl) detector. The effect of impurities of hafnium isotopes was not examined. Reliabilities of two experimental results are not so different. However, the result of Rao and Yaffe is adopted, because the result of Burson et al. is too old.

4.14 ^{198}Au

Many experimental values are reported upto date as shown in Table 4.14.1 and Fig. 4.14.1. Most of experimental errors are as small as 0.2 %, and deviations of these values from the average are less than 0.3 %. Values before 1969 are rejected. The values of Cabell and Wilkins (69Ca23) are omitted, because their new result (70Ca09) is published. The error of Cabell and Wilkins (70Ca09) is estimated to be the standard deviation and might not include the systematic error. Therefore, their error should be multiplied by a factor of 3, that is 2.6946±0.0030 d. The error of Merritt and Gibson (77Me) is very small, and their error is the standard deviation and does not include the systematic error. They reported that the error given by impurity ^{199}Au was ±0.0001 d. Therefore, we rewrite their value as 2.6937±0.0007, where the error is three times of the standard deviation plus 0.0001 d. The unweighted average of four values is 2.6948±0.0014. Since the errors of

three values except Merritt and Gibson are more than three times larger than the corrected error of Merritt and Gibson, the value of Merritt and Gibson, 2.6937±0.0007 d, is adopted for the final evaluated value. This value agrees with the average of four values within the error and also with three other values.

4.15 ^{203}Hg

Experimental values of the half-life are shown in Table 4.15.1 and Fig. 4.15.1. First the values before 1965 are rejected. Since the new value is reported (68An01), two old values of Anspach et al. (65An07) are also rejected. Since the error of Anspach et al. may be the standard deviation, their error is multiplied by a factor of 5. Then their value is rewritten as 46.60±0.05 d. The errors of Vaninbroukx and Grosse (66Va26) and Gleason (67Gl05) are more than ten times and Lagoutine et al. (68La10) is five times larger than that of Merritt and Taylor (72MeZQ). The value of Lagoutine et al. largely deviates from other six values. Therefore, these values are rejected. Merritt and Taylor (72MeZQ) observed impurities of ^{60}Co and ^{110m}Ag and corrected their value. Their error does not include the systematic error, but they use three times of the standard deviation. The unweighted average of three values Anspach et al., Merritt and Taylor and one of Emery et al. is 46.65±0.04 d. Two values of Emery et al. (72Em01) deviate from the value of Merritt and Taylor beyond their errors. Their errors are larger than the error of Merritt and Taylor. Finally, the value of Merritt and Taylor is adopted. This value agrees well with the evaluated value of Martin and Blichert-Toft (70MaB1).

4.16 ^{207}Bi

Only six experimental values are available. These values are shown in Table 4.16.1 and Fig. 4.16.1. The values scatter from 28 y to 50 y. Harbottle (59Ha20) and Rupnik (72Ru10) followed the decay of ^{207}Bi with radiation detectors. Measuring the alpha decay of ^{211}At, Neumann and Perlman (51Ne02) and Appelman (61Ap01) obtained the half-life of ^{207}Bi from the half-life of ^{211}At (7.2 h) and the genetic relation. Measuring the beta decay of ^{207}Po, Sonsniak and Bell (59So12) obtained the half-life of ^{207}Bi from the half-life of ^{207}Po (5.8 h). The errors except for Harbottle and Yanokura et al. (78Ya) are large. The error of Harbottle seems too small considering his followed period. Yanokura et al. measured both decays of ^{211}At and ^{207}Po. and determined the half-life of ^{211}At as 7.23±0.02 h. Their results are 33.4±0.8 y and 31.7±3.7 y which were obtained from the decays of ^{211}At and ^{207}Po, respectively. Since both values are consistent, the better value of 33.4±0.8 y are adopted.

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Table 4.1.1 Half-life of ^{22}Na

Authors	Half-life (y)	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Merritt et al.	2.58 ±0.03			0.8		4πpc	57Me47
Wyatt et al.	2.62 ±0.02		σ	1.5	Mg(n,α) chem	4πγic	61Wy01
Anspach et al.	2.591 ±0.03		σ	2.6	Mg(p,2pn) chem	4πγic	65An07
	2.613 ±0.011		σ	0.5	Mg(p,2pn) chem	4πγic	
	2.603 ±0.001		σ	1.2	Mg(p,2pn) chem	4πγic	
	2.602 ±0.011		σ	0.5	Mg(p,2pn) chem	4πγic	
Anspach et al.	2.600 ±0.002		σ	1.2	Mg(p,2pn) chem	4πγic	68An01
Merritt, Taylor	(2.603 ±0.004)	950.7 ±1.3	3σ	1.4		4πγic	73Me
Merritt	(2.6027±0.0013)	950.63±0.48*	3σ			4πγic	78Me
Martin,Blichert-Toft	2.60 ±0.01	950 ±4	57Me47, 61Wy01, 65An07, 68An01				70MaB1
Evaluated value	2.6027±0.0013	950.6 ±0.5	78Me				

Table 4.2.1 Half-life of ^{24}Na

Authors	Half-life (h)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Cobble, Atteberry	15.10 ±0.04			$^{23}Na(n,\gamma)$ chem	4πic	50Co69
Solomon	15.04 ±0.06		13	$^{23}Na(n,\gamma)$ chem	pc	50So55
Sreb	15.06 ±0.039					51Sr14
Lockett, Thomas	14.97 ±0.02		> 5	$^{23}Na(n,\gamma)$	electroscope	53Lo09
Tobailem	14.90 ±0.05		0.7	$^{23}Na(n,\gamma)$	ic	55To07
Campion, Merritt	14.959±0.010		3∿8	$^{23}Na(n,\gamma)$ chem	4πpc	58Ca20
Poularikas, Fink	15.00 ±0.06			$^{27}Al(n,\alpha)$	pc	59Po64
Wolf	14.953±0.013		4	$^{23}Na(n,\gamma)$	pc	60Wo07
Jozefowicz	15.05 ±0.03		6	$^{23}Na(n,\gamma)$	liquid scin	61Jo26
Wyatt et al.	15.05 ±0.02	σ	3.1	$^{23}Na(n,\gamma)$	4πγic	61Wy01
Monahan et al.	15.05 ±0.05			$^{23}Na(n,\gamma)$	NaI	62Mo21
Lagoutine et al.	15.00 ±0.02	$3\sigma+\Sigma\delta_i$	2	$^{23}Na(n,\gamma)$	ic,4πpc,NaI	68La10
Merritt, Taylor	14.965±0.010	3σ	10		4πγic	71MeA
Emery et al.	15.030±0.003	σ+δ	> 10	$^{23}Na(n,\gamma)$ chem	NaI	72Em01
Gentz et al.	15.09 ±0.06			$^{23}Na(d,p)$		76Ge06
Merritt	14.965±0.002*	3				78Me
Martin, Blichert-Toft	15.00 ±0.04	50Co69,50So55,51Sr14,53Lo09,55To07,58Ca20,59Po64, 60Wo07,61Jo26,61Wy01,62Mo21,68La10 and three others others				70MaB1
Endt, Van der Leun	15.020±0.007	50Co69,50So55,51Sr14,53Lo09,55To07,58Ca20,59Po64, 60Wo07,61Jo26,61Wy01,62Mo21,68La10 and three others				73En
Evaluated value	14.965±0.002	78Me				

Table 4.3.1 Half-life of ^{46}Sc

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Schuman et al.	84.1 ±0.3	σ	8	Ti(n,p) chem	pc	56Sc87
Geiger	83.89±0.12	2σ	5.5	$^{45}Sc(n,\gamma)$	ic	57Ge07
Wright et al.	84.2 ±0.2	σ	3.8	$^{45}Sc(n,\gamma)$	ic	57Wr37
Poularikas, Fink	85 ±2			$^{46}Ti(n,p)$	pc	59Po64
Hontzeas, Yaffe	84.0 ±0.9			$^{51}V(p,3p3n)$ chem		63Ho17
Anspach et al.	83.80±0.03	σ	2.8		4πγic	65An07
Walker, Easterday	84.3 ±0.4	σ			ic	67Wa29
Cressy	84.34±0.13	σ	>3		NaI	74Cr05
Merritt	83.79±0.03*	3σ				78Me
Evaluated value	83.79±0.03	78Me				

Table 4.4.1 Half-life of ^{54}Mn

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Livingood, Seaborg	310 ±20					38Li
Stafford, Stein	324 ±11			$^{54}Fe(n,p)$ chem		53St66
Backofen, Herber	291 ± 1		0.35	Cr(d,xn) chem	AgI	55Ba10
Kafalas, Irvine	290 ± 6		0.4	Cr(d,xn) chem	NaI	56Ka33
Schuman et al.	278 ± 5	σ	2	$^{54}Fe(n,p)$ chem	GM	56Sc87
Wyatt et al.	313.5 ± 0.7	σ	2	Fe(n,p) chem	4πγic,NaI	61Wy01
Martin, Clare	303 ± 1		1	$^{54}Fe(n,p)$	ic	64Ma14
Anspach et al.	311.9 ± 0.2	σ	1.3	chem	4πγic	65An07
	311.9 ± 0.2	σ	1.5	chem	4πγic	
	312.6 ± 0.4	σ	1.6	chem	4πγic	
Salisbury, Chalmers	315 ±			$^{54}Fe(n,p)$	NaI	65Sa09
Taylor, Merritt	312.4 ± 0.6	σ		chem	4πγic	65Ta10
Boulanger	312.2 ± 0.6		1.3			66Bo33
Fabry, Deworm	308 ± 5		2.6			66Fa08
Vaninbroukx, Grosse	312.4 ± 0.3	σ	>2		NaI	66Va26
Anspach et al.	312.1 ± 0.3	σ	2.4	$^{54}Fe(n,p)$ chem	4πγic	68An01
Hammer	312 ± 5				NaI	68Ha47
Lagoutine et al.	312.2 ± 0.9	$3\sigma+\Sigma\delta_i$		$^{53}Cr(d,n)$ chem	ic,4πpc,NaI	68La10
Zimmer, Dahl	313.10± 0.19	2σ	2.56	$^{54}Fe(n,p)$	NaI	68Zi01
	312.93± 0.55	2σ	3.75	$^{54}Fe(n,p)$	NaI	
	312.89± 0.42	2σ	2.55	$^{84}Fe(n,p)$	NaI	
	312.96± 0.21	2σ	2.28	$^{54}Fe(n,p)$	NaI	
Merritt, Taylor	312.16± 0.11	3σ	3.1		4πγic	73Me
Cressy	312.6 ± 0.8	σ	>3		NaI	74Cr05
Merritt	312.21± 0.05*	3σ				78Me
Martin,Blichert-Toft	312.5 ± 0.5	61Wy01, 65An07, 65Ta10, 68An01, 68La10, 68Zi01				70MaB1
Evaluated value	312.21± 0.05	78Me				

Table 4.5.1 Half-life of ^{60}Co

Authors	Half-life (y)	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Kastner, whyte	5.21 ±0.04			0.57		ic	53Ka21
Tobailem	5.27 ±0.07			0.02		ic	55To07
Evans	5.28 ±0.03			2		ic	56Ev18
Lockett, Thomas	5.20 ±0.03			0.85		electroscope	56Lo31
Perry, Dale	5.25 ±0.04			1.2		ic	56Pe52
Geiger	5.24 ±0.03		2σ	1.3	$^{59}Co(n,\gamma)$	ic	57Ge07
Brosi, Ketelle	5.29 ±0.03			0.2			58B192
Keene et al.	5.33 ±0.04			0.23	$^{59}Co(n,\gamma)$	ic	58Ke26
Loftus, Lee	5.29 ±0.02				$^{59}Co(n,\gamma)$	electroscope	58Lo61
Seliger, Cavallo	5.26 ±0.03						58Se53
Gorbics et al.	5.263 ±0.003			0.61		ic	63Go03
Anspach et al.	5.242 ±0.008		σ	1		4πγic	65An07
Anspach et al.	5.259 ±0.003		σ	1.0	$^{59}Co(n,\gamma)$	ic	68An01
Lagoutine et al.	5.27 ±0.02		$3\sigma+\Sigma\delta_i$	0.19	$^{59}Co(n,\gamma)$	ic,4πpc,NaI	68La10
Merritt, Taylor	5.279 ±0.008	1928 ±3	3σ	0.7∿2.0	chem	4πγic	69Me
Walz, Weiss	5.2719±0.0011		σ+δ	0.6	chem	4πγic	70Wa19
Merritt, Taylor	5.272 ±0.003	1925.7 ±0.9	3σ	0.7∿3		4πγic,4πβγ	71MeB
Harbottle et al.	5.24 ±0.21						73Ha60
Rytz	5.270 ±0.003			1.1		4πβγ	73Ry
Vaninbroukx, Grosse	5.283 ±0.002		σ	0.6∿2	$^{59}Co(n,\gamma)$	NaI	76Va30
	± .008		$3.3\sigma+\Sigma\delta_i$				
Merritt	5.2699±0.0012	1924.78±0.45*	3σ			4πγic	78Me
	5.2688±0.0011	1924.39±0.40*	3σ			4πβγ	
Martin, Blichert-Toft	5.26 ±0.01	(1921.1 ±3.7)	53Ka21,55To07,56Ev18,56Lo31,56Pe52, 57Ge07,58B192,58Ke26,58Lo61,58Se53, 63Go03,68An01,68La10				70MaB1
Grinberg et al.	5.2721±0.0024	(1925.6 ±0.9)	68La10,69Me,70Wa19,73Ry				74Gr
Evaluated value	5.2694±0.0008	1924.6 ±0.3	78Me				

Table 4.6.1 Half-life of ^{85}Sr

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
DuBridge, Marshall	66			Rb(p,n) chem	ic	40Du05
Ter-Pogossian, Porter	65 ±3		2.2	Rb(d,2n) chem	mag spect	51Te11
Herrmann, Strassmann	65.0 ±0.7			U(n,f) chem	NaI	56He77
Wright et al.	64.0 ±0.2	σ	3.3	$^{84}Sr(n,\gamma)$ chem	NaI	57Wr37
Sattler	63.90±0.27		4	$^{84}Sr(n,\gamma)$	NaI	62Sa12
Anspach et al.	65.19±0.13	σ	1.4		4πγic	65An07
Grotheer et al.	66.6 ±0.6		0.8		NaI	69Gr12
Emery et al.	64.93±0.22	σ+δ	2.0	$^{84}Sr(n,\gamma)$	NaI	72Em01
Lagoutine et al.	64.68±0.23	$3\sigma+\Sigma\delta_i$	3	$^{84}Sr(n,\gamma)$	4πpc	72La14
Merritt, Gibson	64.84±0.03*	3σ	15		4πγic	75MeA
Martin, Blichert-Toft	64.5 ±0.5	56He77, 57Wr37, 62Sa12, 65An07, 67Gl05				70MaB1
Evaluated value	64.84±0.03	75MeA				

Table 4.7.1 Half-life of ^{88}Y

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Wyatt et al.	108.1 ±0.3	σ	3.1	Sr(p,n) chem	4πγic	61Wy01
Anspach et al.	106.52±0.03	σ	2.6	Sr(p,n) chem	4πγic	65An07
	106.67±0.03	σ	2.7	Sr(p,n) chem	4πγic	
Anspach et al.	106.61±0.02*	σ	4.3	Sr(p,n) chem	4πγic	68An01
Grotheer et al.	108.4 ±0.9		0.5		NaI	69Gr12
Lagoutine et al.	106.6 ±0.4*	$3\sigma+\Sigma\delta_i$		$^{88}Sr(p,n)$	NaI	75La16
Bormann et al.	107.1 ±1.4			$^{89}Y(n,2n)$	NaI	76Bo19
Martin,Blichert-Toft	107 ±1	61Wy01, 65An07, 68An01				70MaB1
Bunting, Kraushaar	106.60±0.04	65An07, 68An01				76NDS
Evaluated value	106.6 ±0.2	68An01, 75La16				

Table 4.8.1 Half-life of ^{95}Nb

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Cork et al.	35.0 ±0.5			$^{95}Zr(\beta^-)$ chem	GM	53Co23
Wyatt at al.	35.0 ±0.1	σ	5	U(n,f) chem	$4\pi\gamma$ic	61Wy01
Anspach et al.	34.846±0.016	σ			$4\pi\gamma$ic	65An07
Flynn et al.	35.8 ±0.5	σ	13	chem	2πpc	65Fl02
Anspach et al.	35.04 ±0.04	σ	4	$^{95}Zr(\beta^-)$ chem	ic	68An01
Lagoutine et al.	35.1 ±0.2	$3\sigma+\Sigma\delta_i$	2	U(n,f) chem	ic, 4πpc, NaI	68La10
Reynolds et al.	35.15 ±0.03	σ	3	$^{95}Zr(\beta^-)$ chem	$4\pi\gamma$ic	68Re04
Merritt, Taylor	34.98 ±0.02*	3σ			$4\pi\gamma$ic	70Me31
Hansen et al.	34.97 ±0.03*	$\sigma+\Sigma\delta_i$	4∿9		NaI, Ge	76Ha51
Martin, Blichert-Toft	35.1 ±0.1	53Co23, 61Wy01, 65Fl02, 68An01 68La10, 68Re04 and two others				70MaB1
Evaluated value	34.98 ±0.02	70Me31, 76Ha51				

Table 4.9.1 Half-life of ^{108m}Ag

Authors	Half-life (y)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Kistner, Sunyar	>5					66Ki03
Vonach et al.	310±132				(n,2n) cross sec	69Vo11
Harbottle	127± 7*	σ	(5y)	Ag(n,γ)	pc	70Ha32
Emery et al.	>50		(3.5y)	Ag(n,γ) chem	NaI	72Em01
Evaluated value	127± 21	70Ha32				

Table 4.10.1 Half-life of ^{134}Cs

Authors	Half-life (y)		Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Merritt et al.	2.19 ±0.02			2, 3	Cs(n,γ)	4πpc	57Me47
Geiger	2.07 ±0.02		2σ	0.8		ic	57Ge07
Bayly	$2.15^{+0.08}_{-0.04}$				Cs(n,γ)		58Ba
Edwards	2.26 ±0.05			3	Cs(n,γ)	mass spect	58Ed
Easterday, Smith	2.05 ±0.02					ic	60Ea
Wyatt et al.	2.07 ±0.02		σ	1.6	^{133}Cs(n,γ) chem	4πγic	61Wy01
Dietz et al.	2.046±0.004						63Di
Flynn et al.	1.99 ±0.02		σ	2.1		2πpc	65Fl02
Lagoutine et al.	2.058±0.012	(751.7±4.4)	3σ	1.5	^{133}Cs(n,γ)	4πpc	72La14
	2.05 ±0.02						
Dietz, Pachucki	2.062±0.005	(753.1±1.8)*	3σ	4.9	^{133}Cs(n,γ) chem	mass spect	73Di01
Merritt	(2.067±0.006)	755.1±2.1*	3σ				78Me
Evaluated value	2.065±0.004	754.1±1.4	73Di01, 78Me				

Table 4.11.1 Half-life of ^{133}Ba

Authors	Half-life (y)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Katcoff, Abrask	7.2 ±0.5					56Ka
Katcoff	7.2 ±0.3					61Ka
Wyatt et al.	10.7 ±0.2	σ	0.4	Ba(n,γ) chem	4πγic	61Wy01
Lagoutine et al.	7.8 ±0.1	$3\sigma+\Sigma\delta_i$	0.04	^{132}Ba(n,γ)	ic,4πpc,NaI	68La10
Reynolds et al.	10.66 ±0.12	σ	0.4	Ba(n,γ) chem	4πγic	68Re04
Walz, Weiss	10.352±0.040	σ+δ	0.3	chem	4πγic	70Wa19
Emery et al.	10.9 ±0.1	σ+δ	0.20	Ba(n,γ) chem	NaI	72Em01
Lloyd, Mays	11.3 ±0.7		0.4			73Ll01
Lagoutine et al.	10.35 ±0.15	$3\sigma+\Sigma\delta_i$		^{132}Ba(n,γ)	ic,4πpc,NaI	74La
Merritt, Gibson	10.67 ±0.15*	3σ		chem	4πγic	76Me
Schötzig et al.	10.74 ±0.05*	σ	1		4πγic	77Sc31
Henry	10.5 ±0.1	61Wy01, 68Re04, 70Wa19, 72Em01, 73Ll01				74NDS
Evaluated value	10.71 ±0.11	76Me, 77Sc31				

Table 4.12.1 Half-life of ^{139}Ce

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Pool, Krisberg	140 ±1		8	La(d,2n) chem	ic	48Po01
Wille, Fink	140 ±10					60Wi10
Anspach et al.	137.5 ±0.3	σ	1.2		4πγic	65An07
Emery et al.	137.2 ±0.4	σ+δ	2.6	La(p,n) chem	NaI	72Em01
Merritt et al.	137.65±0.07*	3σ	10		4πγic	75MeB
Vaninbroukx, Grosse	137.66±0.02*	σ	2	Obtained from	NaI	76Va30
	±0.13	$4.3\sigma+\Sigma\delta_i$		TRC-Amersham		
Evaluated value	137.66±0.05	75MeB,76Va30				

Table 4.13.1 Half-life of ^{180m}Hf.

Authors	Half-life (h)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Burson et al.	5.5±0.1		8	^{179}Hf(n,γ) chem	GM	51Bu50
Rao, Yaffe	5.5±0.1*			Ta(p,2p) chem	NaI	63Ra14
Evaluated value	5.5±0.1	63Ra14				

Table 4.14.1 Half-life of ^{198}Au

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Lockett, Thomas	2.697 ±0.003		3.7	^{197}Au(n,γ)	electroscope	53Lo09
Bell, Yaffe	2.699 ±0.003	σ+δ	10	^{197}Au(n,γ)	electroscope	54Be61
Tobailem	2.686 ±0.005		1	^{197}Au(n,γ)	ic	55To07
Johansson	2.697 ±0.005		2.6	^{197}Au(n,γ)	NaI	56Jo24
Sastre, Price	2.694 ±0.006		9	^{197}Au(n,γ)	GM	56Sa75
Keene et al.	2.704 ±0.004		11		ic	58Ke26
Grigorescu, Sandru	2.696 ±0.004		6	^{197}Au(n,γ)	GM	59Gr09
Robert	2.699 ±0.004		1.9	^{197}Au(n,γ)	calorimeter	60Ro22
Starodubtsev et al.	2.687 ±0.005					63St20
Goodier	2.695 ±0.007		7	^{197}Au(n,γ) chem	ic	68Go22
Lagoutine et al.	2.697 ±0.005	$3\sigma+\Sigma\delta_i$		^{197}Au(n,γ)	ic,4πpc,NaI	68La10
Reynolds et al.	2.693 ±0.005	σ	3.2	^{197}Au(n,γ)	GM	68Re04
Cabell, Wilkins	2.701 ±0.008			^{197}Au(n,γ)	NaI	69Ca23
	2.688 ±0.028			^{197}Au(n,γ)	NaI	
	2.670 ±0.028			^{197}Au(n,γ)	NaI	
Vuorinen, Kaloinen	2.695 ±0.002					69Vu04
Cabell, Wilkins	2.6946±0.0010		6.7	^{197}Au(n,γ)	NaI	70Ca09
Costa Paiva, Martinho	2.696 ±0.004	$\sigma+\delta_\tau+\delta_i$ a)	10.6	^{197}Au(n,γ)	NaI	70Co14
Merritt, Gibson	2.6937±0.0002*	σ	14	^{197}Au(n,γ)	4πγic	77Me
Martin, Blichert-Toft	2.697 ±0.005	53Lo09, 54Be61, 55To07, 56Jo24, 56Sa75, 58Ke26, 59Gr09, 60Ro22, 63St20, 68Go22, 68La10, 68Re04				70MaB1
Harmatz	2.696 ±0.002	53Lo09, 54Be61, 56Jo24, 60Ro22, 68La10, 68Re04, 69Vu04, 70Ca09, 70Co14				77NDS
Evaluated value	2.6937±0.0007	77Me				

a) δ_τ and δ_i mean uncertainties in the resolving time and due to impurities, respectively.

Table 4.15.1 Half-life of ^{203}Hg

Authors	Half-life (d)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Lyon	46.5					51Ly10
Wilson, Curran	45.9 ±0.2		2	Hg(n,γ)	pc	51Wi22
Cork et al.	47.9 ±0.2		> 1	^{202}Hg(n,γ)		52Co01
Eickholz, Krzyzewski	46.91 ±0.14		5	Hg(n,γ)	ic	56Ei14
Thiry	47.1 ±0.2		3	Hg(n,γ)	GM	57Th11
Wright et al.	45.4 ±0.5	σ	4	Hg(n,γ) chem	ic	57Wr37
Cali, Lowe	47.2 ±0.7		2∿6	Hg(n,γ)	pc	59Ca12
Taylor	46.8 ±0.2		2	^{202}Hg(n,γ)	NaI,pc	62Ta06
Anspach et al.	46.56 ±0.02		4.8	Hg(n,γ) chem	4πγic	65An07
	46.577±0.008		5.1	Hg(n,γ) chem	4πγic	
Vaninbroukx, Grosse	46.70 ±0.21	σ	> 2		NaI	66Va26
Gleason	46.64 ±0.27		2		NaI	67Gl05
Anspach et al.	46.600±0.010		3	Hg(n,γ) chem	ic	68An01
Lagoutine et al.	47.0 ±0.1	$3\sigma+\Sigma\delta_i$		^{202}Hg(n,γ)	ic,4πpc,NaI	68La10
Emery et al.	46.76 ±0.08	σ+δ	2	Hg(n,γ) chem	NaI	72Em01
	46.75 ±0.09	σ+δ	2	Hg(n,γ) chem	NaI	
Merritt, Taylor	46.60 ±0.02*	3σ	9.0		4πγic	72MeZQ
Martin, Blichert-Toft	46.59 ±0.05	51Wi22, 52Co01, 56Ei14, 57Th11, 57Wr37, 59Ca12 62Ta06, 65An07, 67Gl05, 68An01, 68La10				70MaB1
Evaluated value	46.60 ±0.02	72MeZQ				

Table 4.16.1 Half-life of ^{207}Bi

Authors	Half-life (y)	Error assignment	No. $T_{1/2}$ followed	Production & separation	Method	Ref.
Neumann, Perlman	≃50		(2.75y)	$^{209}Bi(\alpha,2n)^{211}At \rightarrow$	GM	51Ne02
Harbottle	30.2±0.5		(280d)	$^{209}Bi(p,3n)^{207}Po \rightarrow$	ic	59Ha20
Sosniak, Bell	28 ±3	σ+δ		$^{209}Bi(\alpha,2n)^{211}At \rightarrow$	NaI	59So12
Appelman	38 ±3	2σ			pc,ic	61Ap01
Rupnik	38 ±4		(0.5y)		NaI	72Ru10
Yanokura et al.	33.4±0.8*	σ		$^{209}Bi(\alpha,2n)^{211}At \rightarrow$ $^{209}Bi(p,3n)^{207}Po \rightarrow$	Ge	78Ya
Evaluated value	33.4±0.8	78Ya				

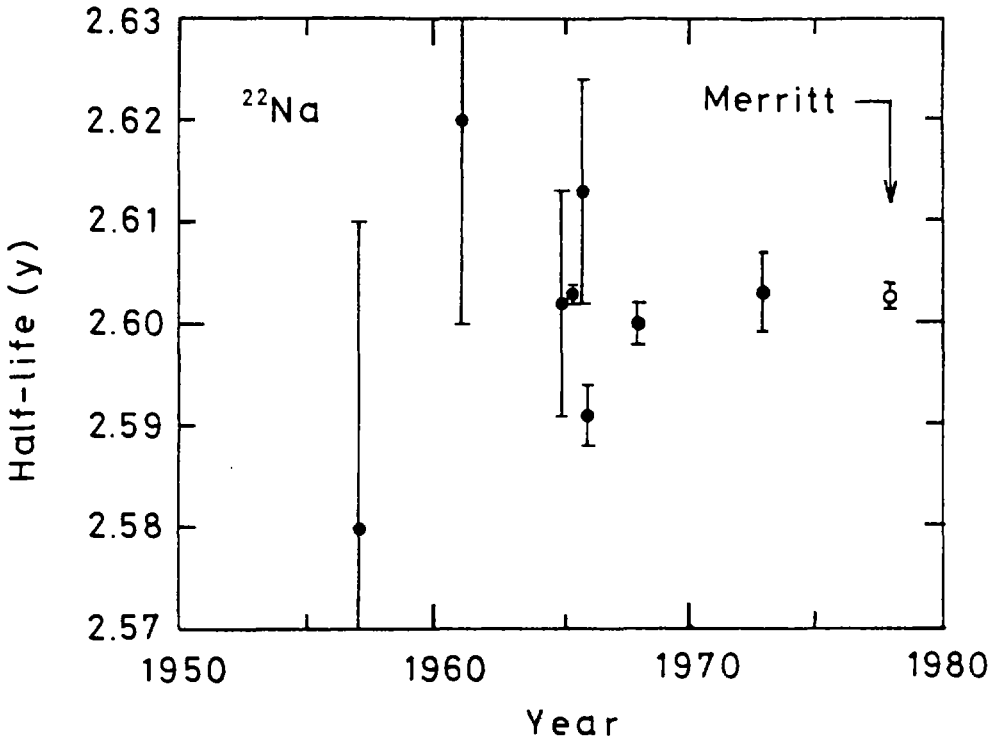

Fig. 4.1.1 Half-life of ^{22}Na.

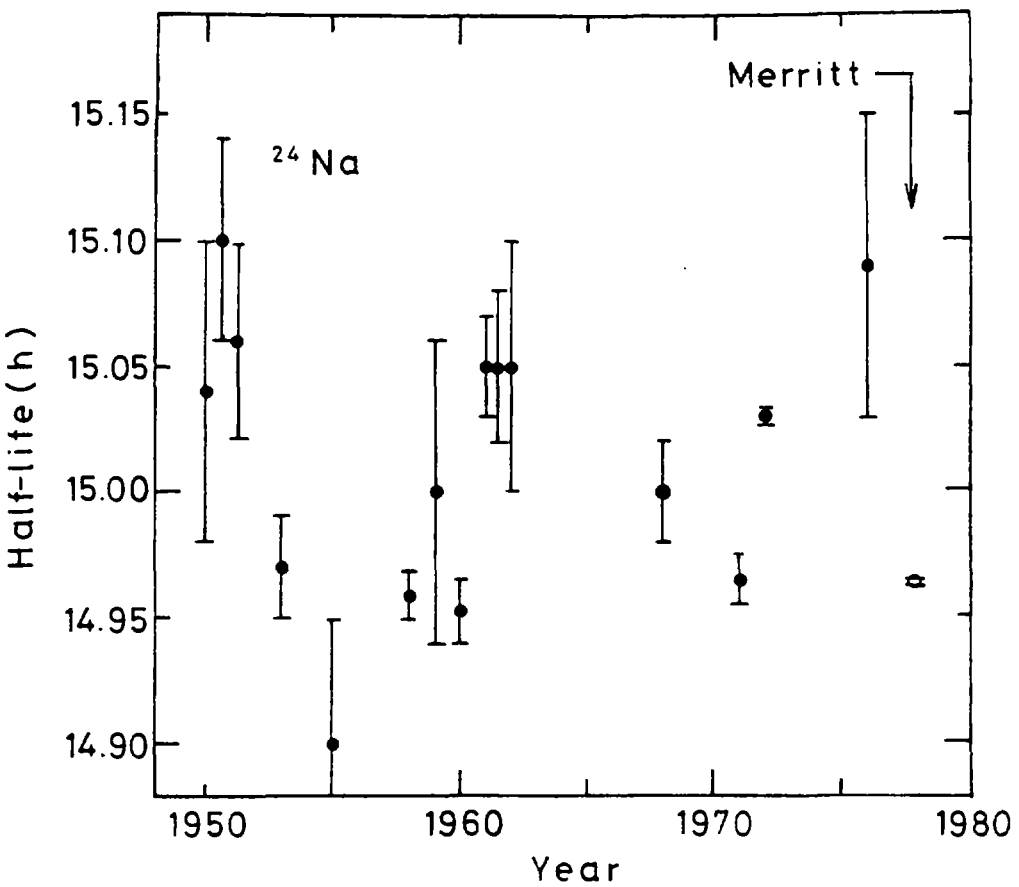

Fig. 4.2.1 Half-life of ^{24}Na.

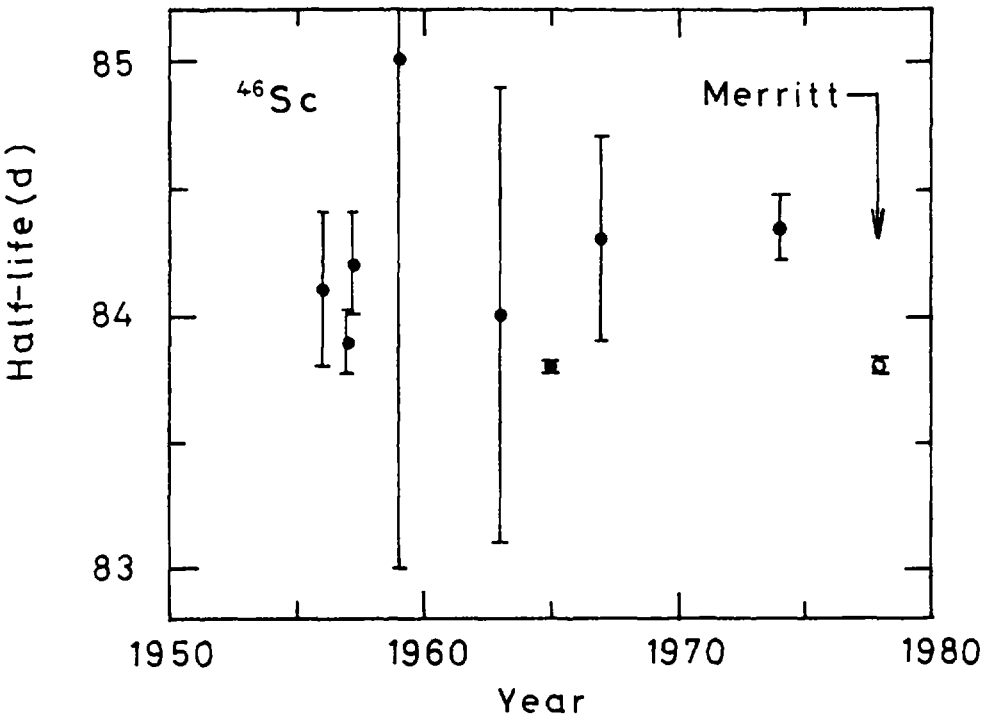

Fig. 4.3.1 Half-life of ^{46}Sc.

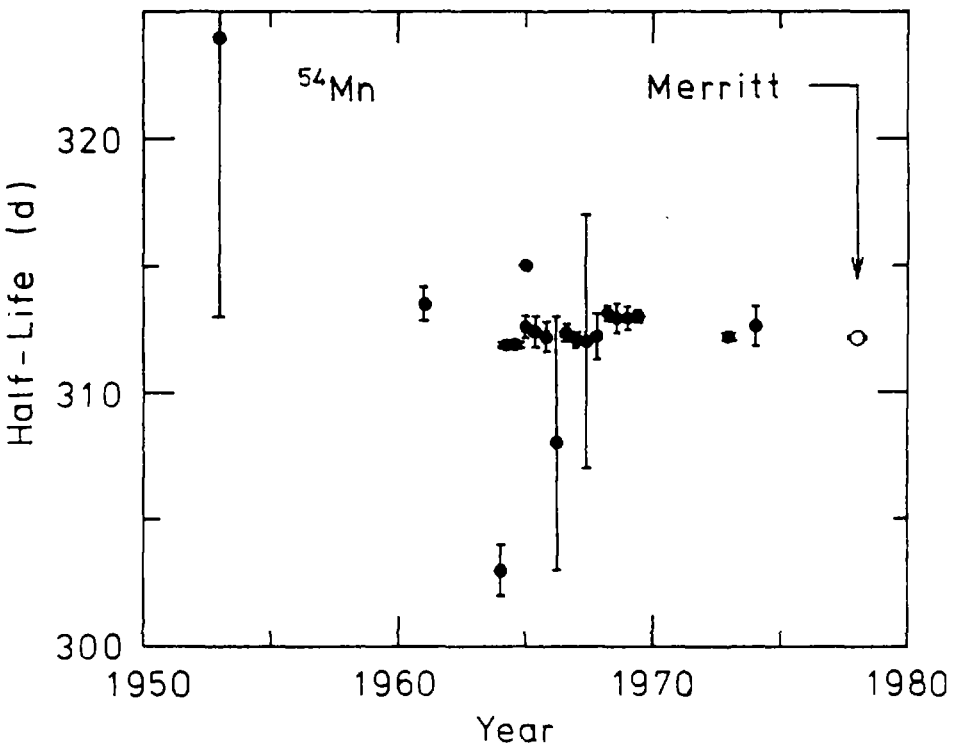

Fig. 4.4.1 Half-life of ^{54}Mn.

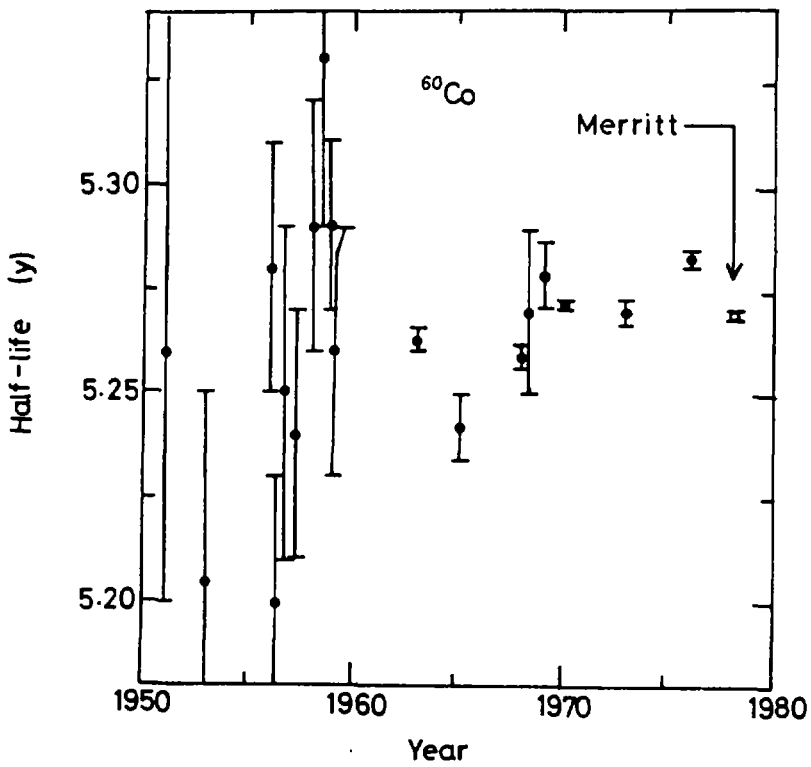

Fig. 4.5.1 Half-life of ^{60}Co.

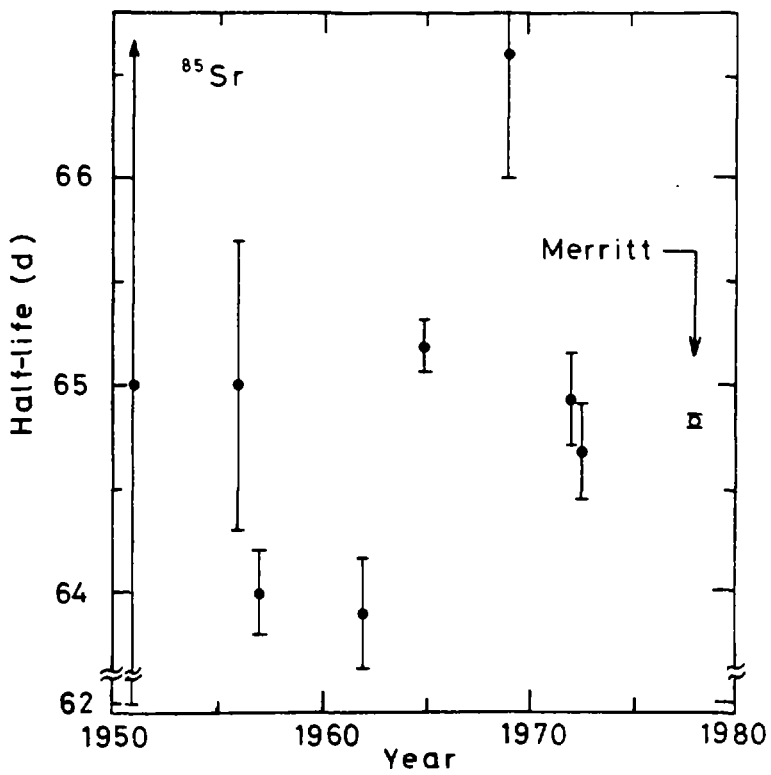

Fig. 4.6.1 Half-life of ^{85}Sr.

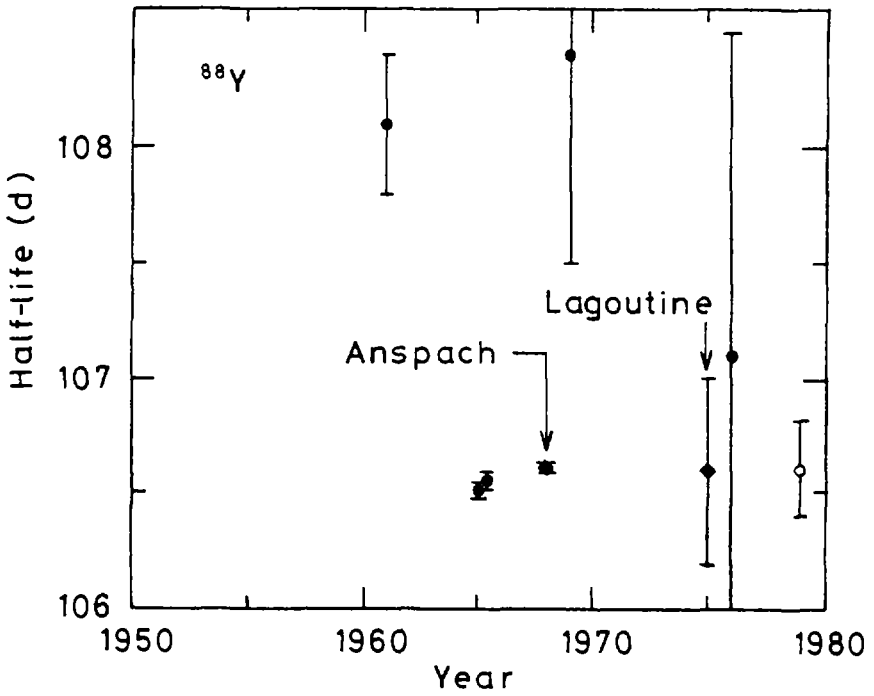

Fig. 4.7.1 Half-life of ^{88}Y.

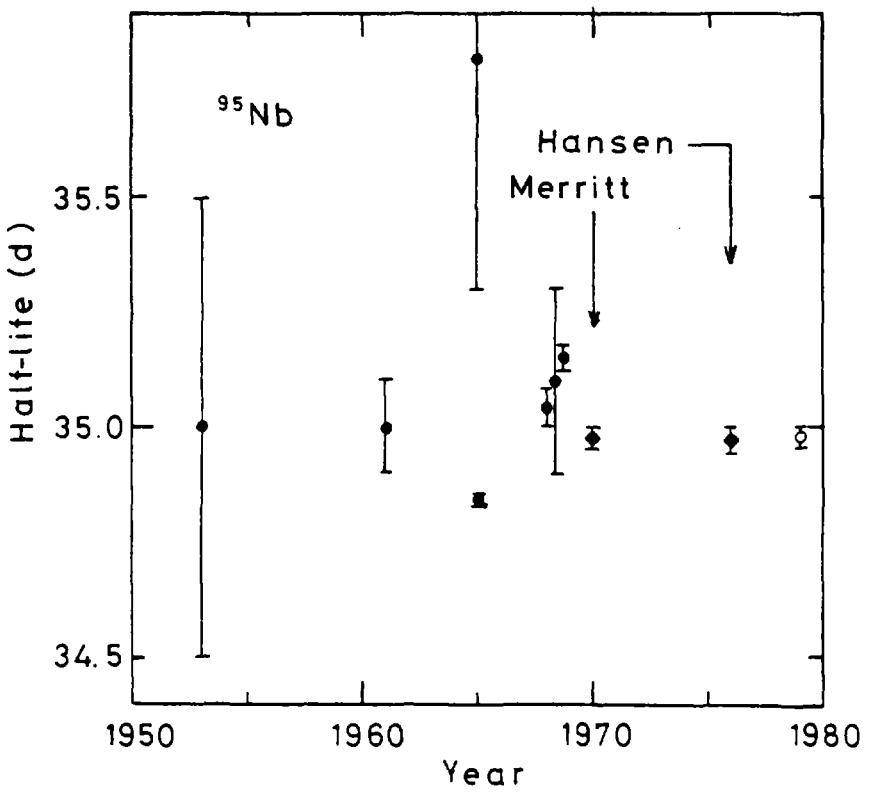

Fig. 4.8.1 Half-life of ^{95}Nb.

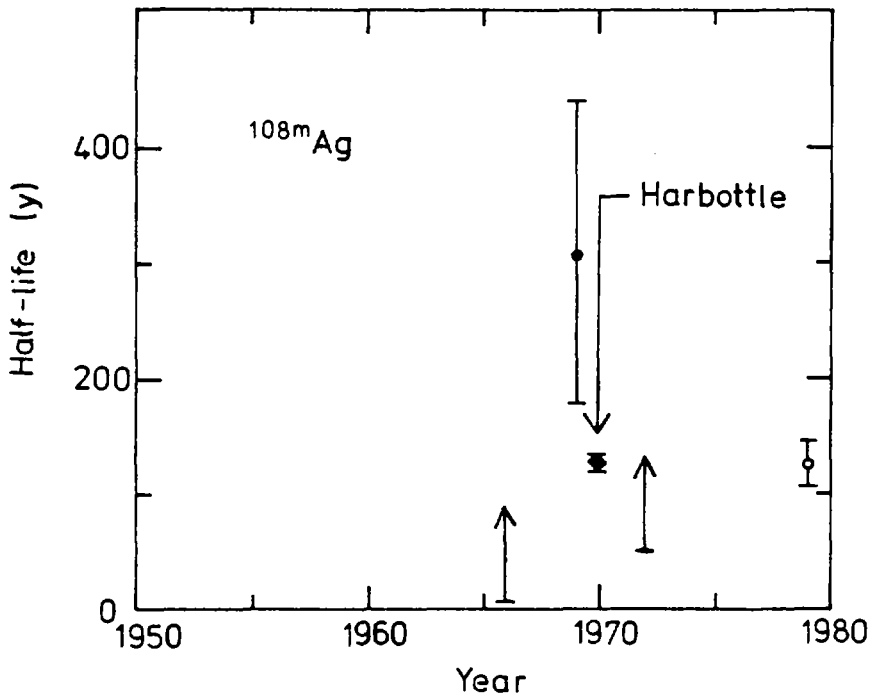

Fig. 4.9.1 Half-life of ^{108m}Ag.

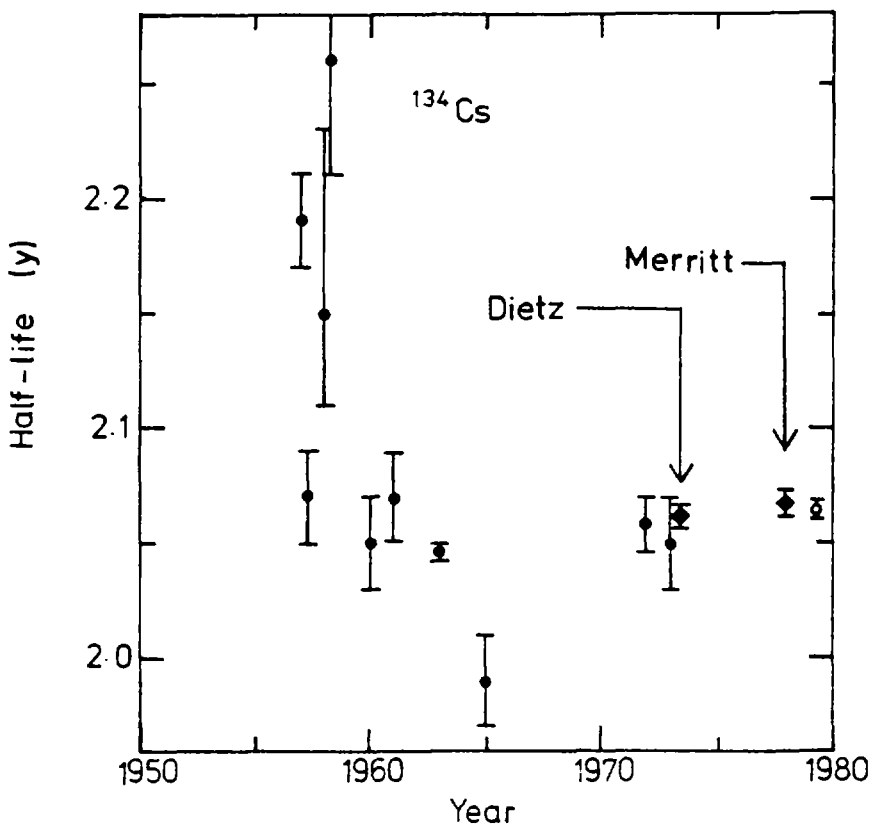

Fig. 4.10.1 Half-life of ^{134}Cs.

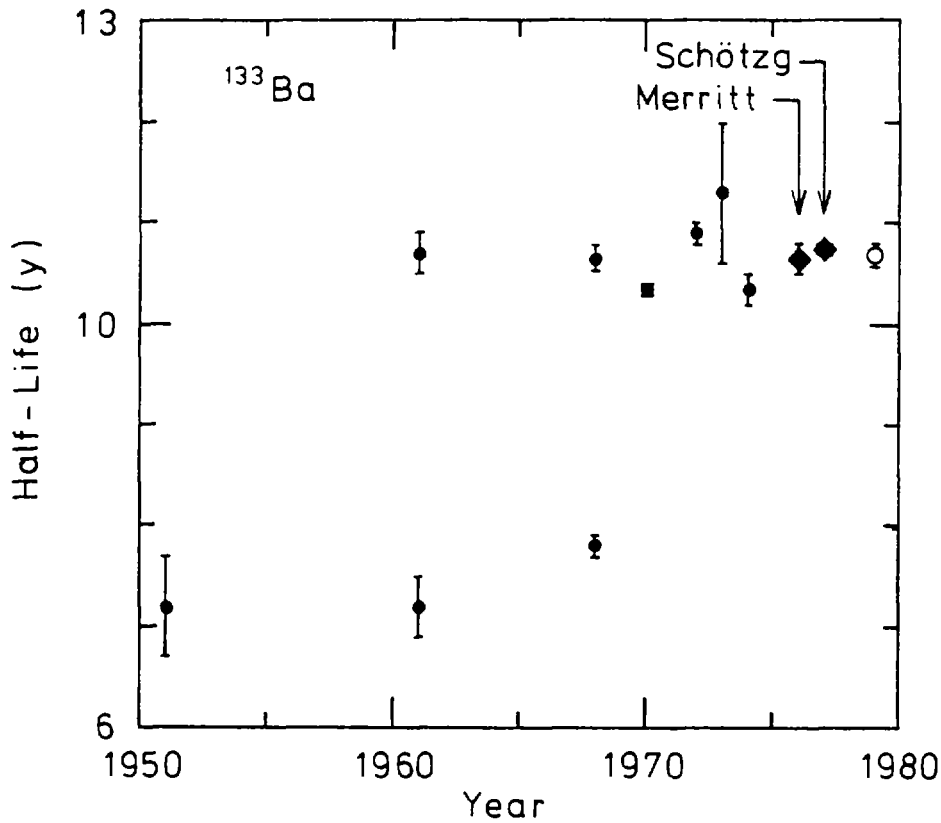

Fig. 4.11.1 Half-life of ^{133}Ba.

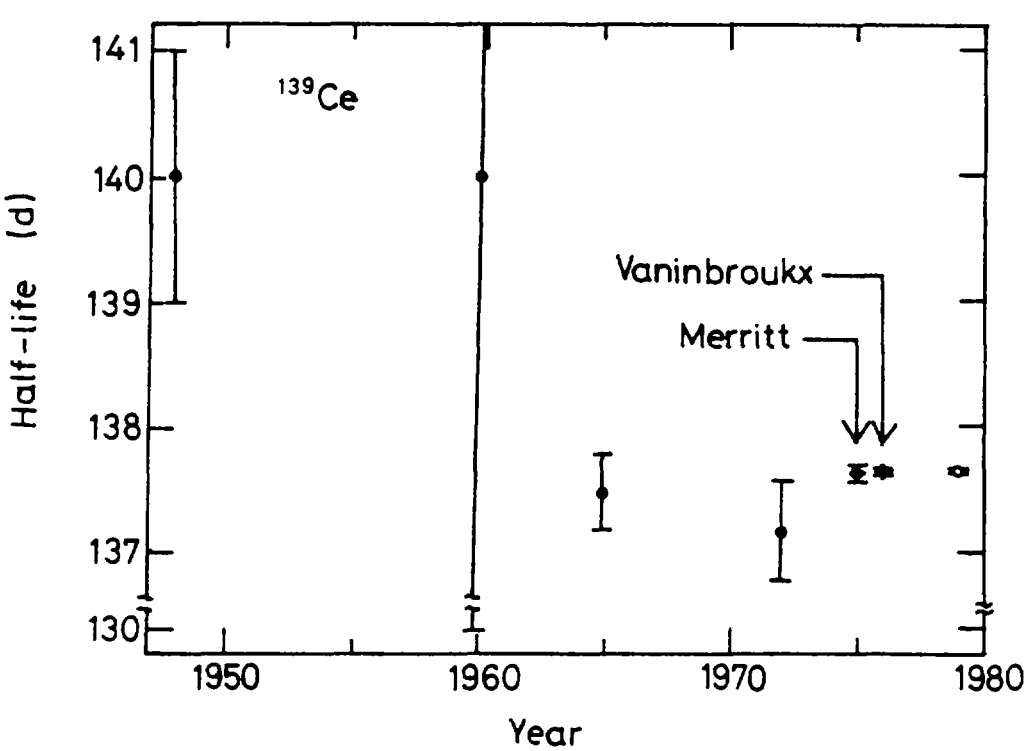

Fig. 4.12.1 Half-life of ^{139}Ce

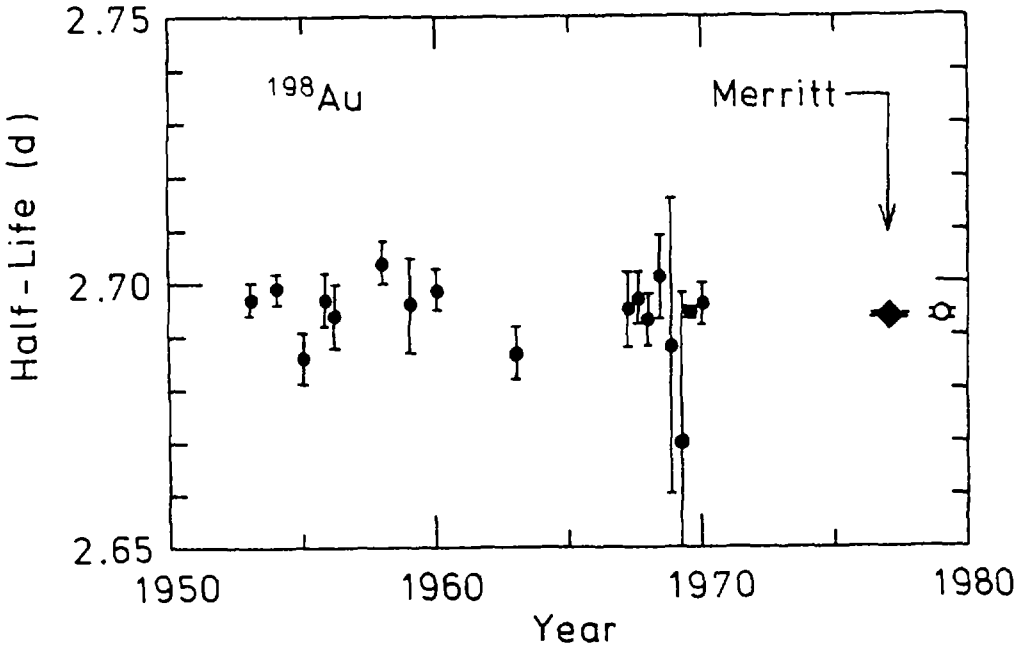

Fig. 4.14.1 Half-life of ^{198}Au.

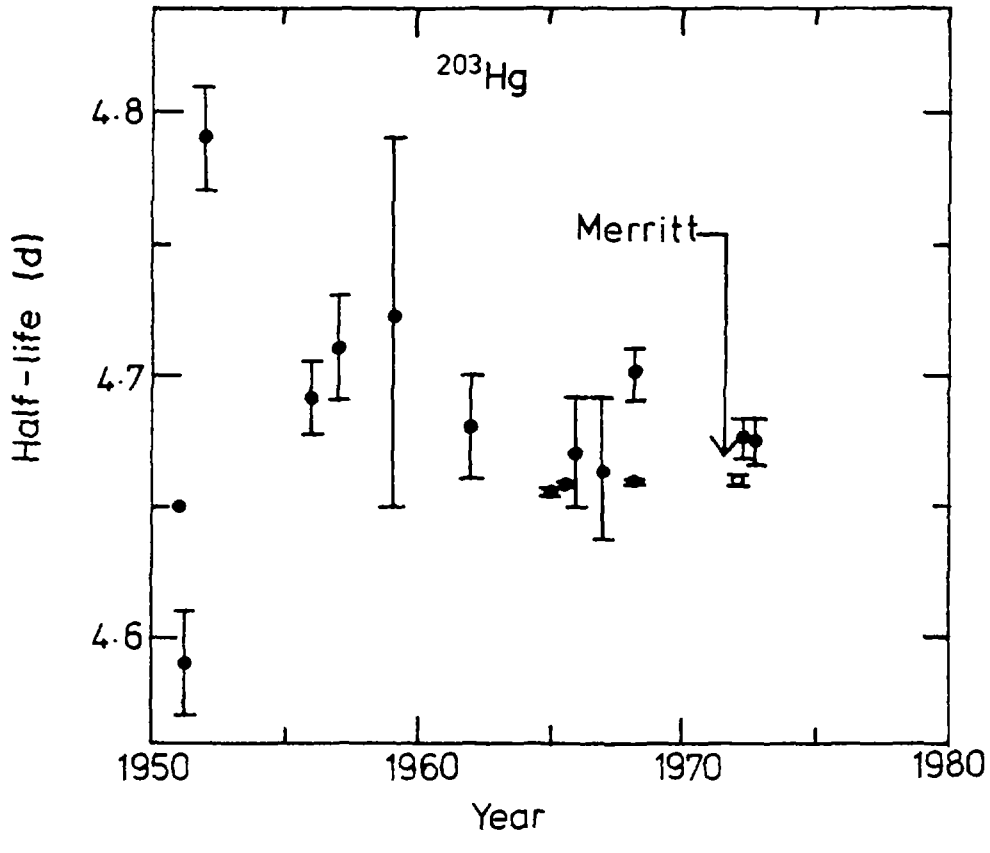

Fig. 4.15.1 Half-life of ^{203}Hg.

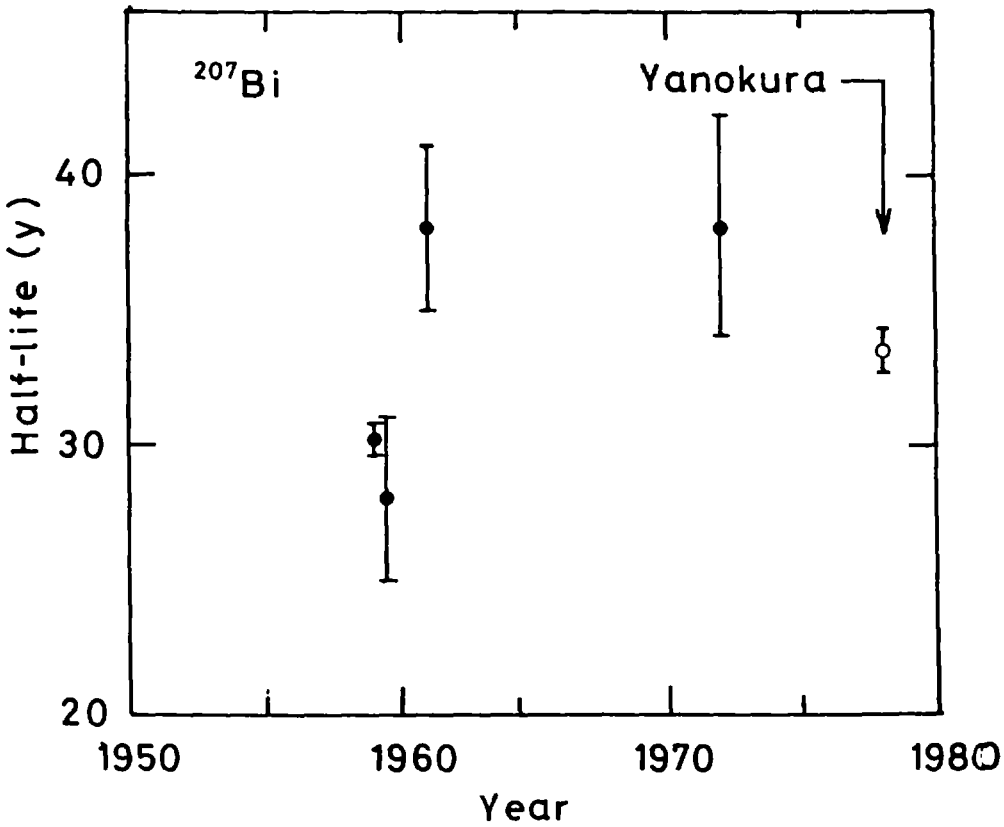

Fig. 4.16.1 Half-life of ^{207}Bi.

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