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REPORT

Transition rates in $^{76,77,79}Br$

by

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USIP Report 72-05 April 1972

Abstract

Lifetime measurements of levels in the ^{76}Br, ^{77}Br and ^{79}Br isotopes are reported. Using the delayed coincidence technique the following half-lives were determined: ^{76}Br: $T_{\frac{1}{2}}$ (45.5 keV) = 1.13 ± 0.03 ns, $T_{\frac{1}{2}}$ (103.2 keV) = 0.5 ± 0.2 ns, $T_{\frac{1}{2}}$ (136.2 keV) = 0.4 ± 0.1 ns. ^{77}Br: $T_{\frac{1}{2}}$ (276.2 keV) = 0.09 ± 0.02 ns. ^{79}Br: $T_{\frac{1}{2}}$ (261.4 keV) = 0.13 ± 0.02 ns. The energy given in paranthesis denotes the second transition in a measured cascade.

Introduction

Only a limited amount of information is available about the decays of Kr nuclides. For A = 76 a few gamma rays are reported [1, 2] but no level scheme has been constructed. For A = 77 and 79 preliminary level schemes and some conversion electron lines are given [2 - 7]. Also some half-lives have been measured or estimated [3, 7]. It was therefore decided to further investigate the decay of some Kr isotopes. The measurements were performed at CERN, Geneva in collaboration with the German Isolde group from Braunschweig. This group has measured the gamma ray energies and intensities as well as half-lives longer than 1 ns in the decays of ^{75}Kr and ^{76}Kr.

Experimental procedure

The gamma rays studied in this work are emitted in the decays of ^{76}Kr (14.8 h), ^{77}Kr (1.19 h) or ^{79}Kr (34.9 h) [8]. The isotopes were produced by bombarding a $ZrO_2 \cdot (H_2O)_x$ powder target with 600 MeV protons in the synchrocyclotron at CERN [9]. The Kr spallation products were then mass-separated in the ISOLDE on-line facility [10] and collected on Al strips.

The half-life measurements of excited levels in the Br isotopes are performed off-line using a double lens coincidence spectrometer [11, 12]. A scheme of the coincidence system is shown in fig. 1. It consists of a slow coincidence circuit and a fast circuit feeding the pulses through constant fraction discriminators to a time-to-pulse-height converter. The delayed coincidence events are stored in a multichannel analyser. Prompt reference curves for a direct comparison were obtained from cascades in ^{134}Cs and ^{212}Pb sources. The delayed coincidence curves were analysed using both the momentum and the convolution methods [13].

Results

For the decay of ^{76}Kr to ^{76}Br no level scheme is available. This makes measurements of nuclear lifetimes with the delayed coincidence method rather delicate. Although delayed transitions are observed a measured half-life can not be referred to a certain level. That means that the true half-lives of the nuclear levels can not be deduced until a reliable level scheme is obtained.

The energies used in this paper are measured by the German Isolde group [14] and differ slightly from earlier given values [1, 2].

For all three transitions (45.5, 103.2 and 136.2 keV) coincidences were measured between the low energy Compton continuum (50 - 100 keV) and the K conversion electrons of the transitions. A pre-acceleration of 12 kV for the 103.2 keV transition and 10 kV for those of 45.5 keV and 136.2 keV was used. A prompt curve was determined with a ^{134}Cs source with the same conditions.

The analysis of the delayed curves give $T_{\frac{1}{2}}$ (45.5 keV) = 1.13 ± 0.03 ns (fig. 2), $T_{\frac{1}{2}}$ (103.2 keV) = 0.5 ± 0.2 ns and $T_{\frac{1}{2}}$ (136.2 keV) = 0.4 ± 0.1 ns. For the 45.5 keV and the 103.2 keV transitions several measurements were performed and the half-life reported is obtained as a weighted mean value. In the two last cases the uncertainties are fairly large due to the unfavourably low counting rate.

In the case of ^{77}Br only the half-life of the 276.2 keV level is determined. The measurement is performed utilizing the 276.2 keV K-line in coincidence with Compton events between 250 and 450 keV of the feeding gamma rays. The comparison with a prompt curve obtained with a ^{134}Cs source with the same experimental conditions gave $T_{\frac{1}{2}}$ (276.2 keV) = 0.09 ± 0.02 ns (fig. 3) in good accordance with the value of 0.07 ns estimated by G. Holm et al. [3].

As is seen from the level scheme of ^{79}Br [5, 6, 7] (fig. 4) the 261.4 keV level de-excites via two M1 transitions, one to the ground-state and one of only 44.3 keV, to the neighbouring $5/2^-$ state. In this case the double-lens spectrometer was adjusted to record coincidences between the feeding KLL Auger electrons and the 261.4 keV K-line. The β - 238.6 keV L cascade in the decay of ^{212}Pb was used as a time reference. Even though a pre-acceleration of 14 kV was used the energy settings had to be slightly changed in the measurement of the prompt curve. This causes a small shift in the time position of the prompt spectrum. However, the change in the shape of the prompt curve should be negligable. An analysis with the momentum method gives $T_{\frac{1}{2}}$ (261.4 keV) = = 0.13 ± 0.02 ns (fig. 4). This is of the same order of magnitude as the lower limit of 0.18 ns reported by J. Weiss et al. [7].

Comments

Many methods have been devised for the measurement of transition probabilities [15]. One of them is the delayed coincidence technique, which is a direct measurement of the meanlife of the nuclear state. The meanlife is proportional to the inverse of the sum of the de-exciting partial transition probabilities. Hence, in order to determine the partial transition rates one usually has to supplement the lifetime measurements with determinations of relevant branching ratios, conversion coefficients, transition multipolarities and mixing ratios. We can here only give the measured half-lives together with the hindrance factors and B(M1)-values for A = 77 and 79.

The partial gamma ray half-life is obtained from

$$T_{\frac{1}{2}\gamma}(\text{exp}) = \frac{T_{\frac{1}{2}}(\text{level})\ \Sigma N}{N_\gamma}$$

where ΣN is the sum of all the relative intensities of the transitions depopulating the level and N_γ is the relative gamma ray intensity for which $T_{\frac{1}{2}\gamma}(\text{exp})$ is calculated.

The symbol F_W is the hindrance factor calculated relative to the theoretical single-particle Weisskopf estimate

$$F_W = \frac{T_{\frac{1}{2}\gamma}(\text{exp})}{T_{\frac{1}{2}\gamma}(\text{Weisskopf})}$$

To obtain the Weisskopf estimate a nuclear radius of 1.2 fm and a statistical factor S = 1 was used [16].

The reduced transition probabilities for the M1 transition component are given by the following formula:

$$B(M1)\downarrow = \frac{3.94 \cdot 10^{-5}\ E^{-3}}{T_{\frac{1}{2}}(1+\alpha)\ (1+\delta^2)}\ (e\hbar/2Mc)^2$$

where E is the transition energy in keV, $T_{\frac{1}{2}}$ is the measured half-life in seconds, α is the total conversion coefficient and $\delta^2 = E2/M1$ the mixing ratio.

The results are summarized in table 1.
The statistical accuracy is in some cases fairly low causing large uncertainties.

The ground state spin J = 3/2 of ^{77}Br has been measured in an atomic beam experiment by T.M. Green et al. [18]. In the shell model it is interpreted as a $p_{3/2}$ proton state. The same interpretation should be valid for the ^{79}Br ground state.

The 276.2 keV $5/2^+$ level in ^{77}Br is depopulated by a 146.5 keV M1 (+ E2) transition to the 129.7 keV $5/2^+$ level and by a 276.2 keV E1 transition to the ground state. The retardation of $7.6 \cdot 10^4$ of the 276.2 keV transition is in agreement with the shell model which does not allow single particle E1 transitions. The life-time of 0.09 ns gives the resulting retardation factor for the 146.5 keV transition equal to 14.2, which is in line with what is generally obtained for M1 transitions.

The 261.4 keV level in ^{79}Br has been assigned spin and parity $3/2^-$ on the basis that it is fed from the $1/2^-$ ground state in ^{79}Kr and decays via a 44.3 keV M1 transition to a $5/2^-$ level at 217.7 keV. Its decay to the ground state proceeds through an M1 radiation. The B(E2) value observed in Coulomb excitation is relatively small [19]. The 261.4 keV level could thus be an example of a rather pure particle state.

A	Transition energy keV	$T_{\frac{1}{2}}$ (level) ns	α_{tot}	Relative N_γ	Relative N_e	Multi-polarity	$T_{\frac{1}{2}}$ exp ns	F_W	F_W (ref)	B(M1)
76	45.5	1.13 ± 0.03								
	103.2	0.5 ± 0.2								
	136.2	0.4 ± 0.1								
77	146.5	0.09 ± 0.02	$4.74 \cdot 10^{-2}$ [3]	48 [3]	2.0	M1(+E2) [3]	0.10	14.2	~14 [3]*	0.13
	276.2		$4.5 \cdot 10^{-3}$ [3]	3.6 [3]	0	E1 [3]	1.19	$7.6 \cdot 10^4$	$\sim 1.7 \cdot 10^5$ [3]*	
79	44.3	0.13 ± 0.02	1.14 [6,17]	1.6 [7]	1.8	M1 [5]	8.48	33.4	>20 [7]	1.61
	261.4		$10.35 \cdot 10^{-3}$ [5,6]	100 [7]	1.0	M1 [5]	0.14	107.7	>84 [7]	0.02

* It is assumed in reference 3 that the E1 transitions have the same retardation factor of $1.7 \cdot 10^5$.
This gives F_W(146.5 keV) = 14 and $T_{\frac{1}{2}}$(276.2 keV) = 0.07 ns.

Figure Captions

Fig. 1 A schematic illustration of the coincidence circuit.

Fig. 2 Delayed time distribution for the 45.5 keV transition in ^{76}Br. The full line shows the corresponding prompt coincidence distribution.

Fig. 3 Same as fig. 2 but for the 276.2 keV level in ^{77}Br.

Fig. 4 Same as fig. 2 but for the 261.4 keV level in ^{79}Br.

Acknowledgements

I wish to thank fil.kand. Åke Höglund for valuable advice in running the spectrometer and for initiating me in this kind of measurements as well as his help during the runs.

I am also greatful to the Nuclear Chemistry Group at CERN for providing the sources.

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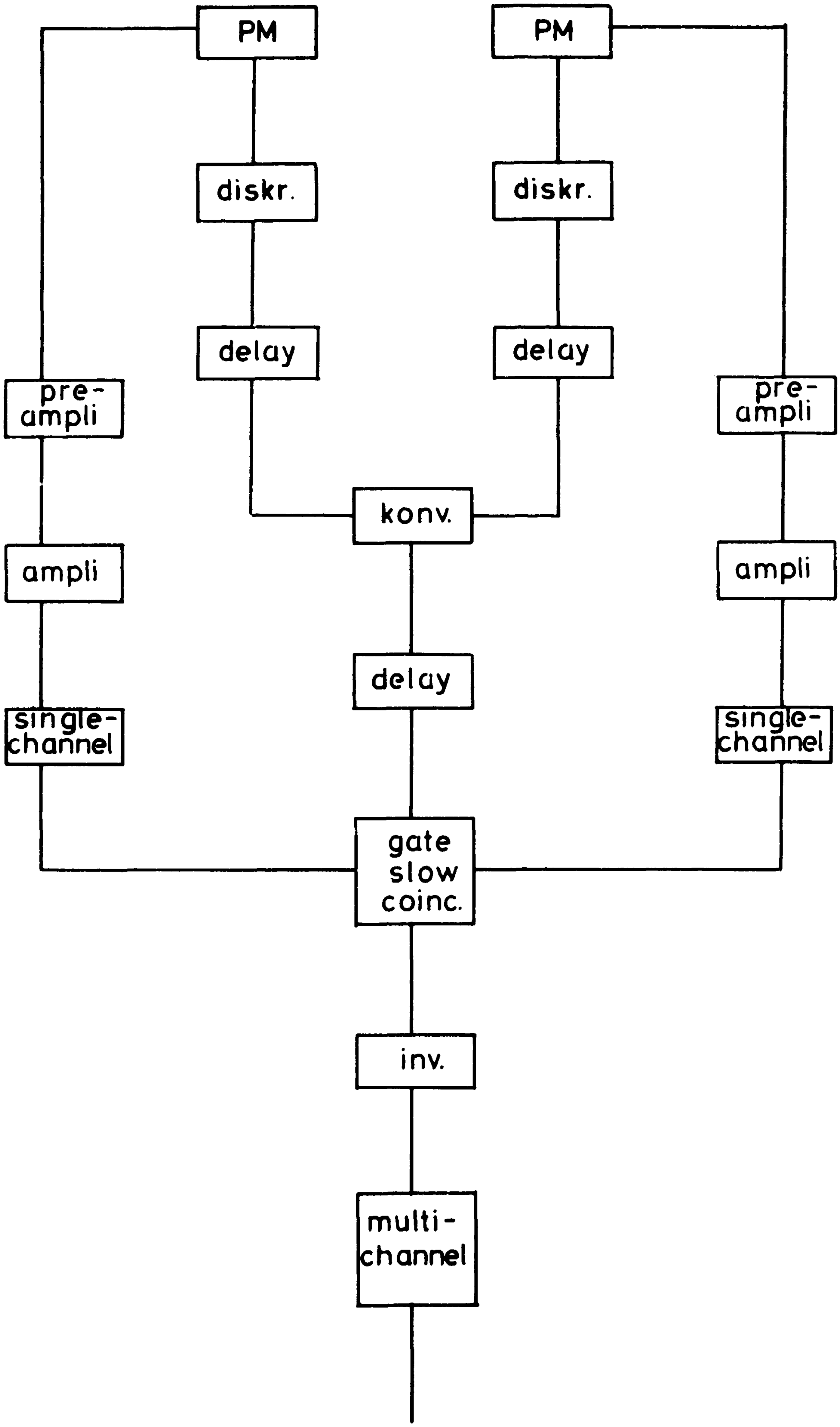
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PM
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single-
channel
gate
slow
coinc.
inv.
multi-
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Fig. 1

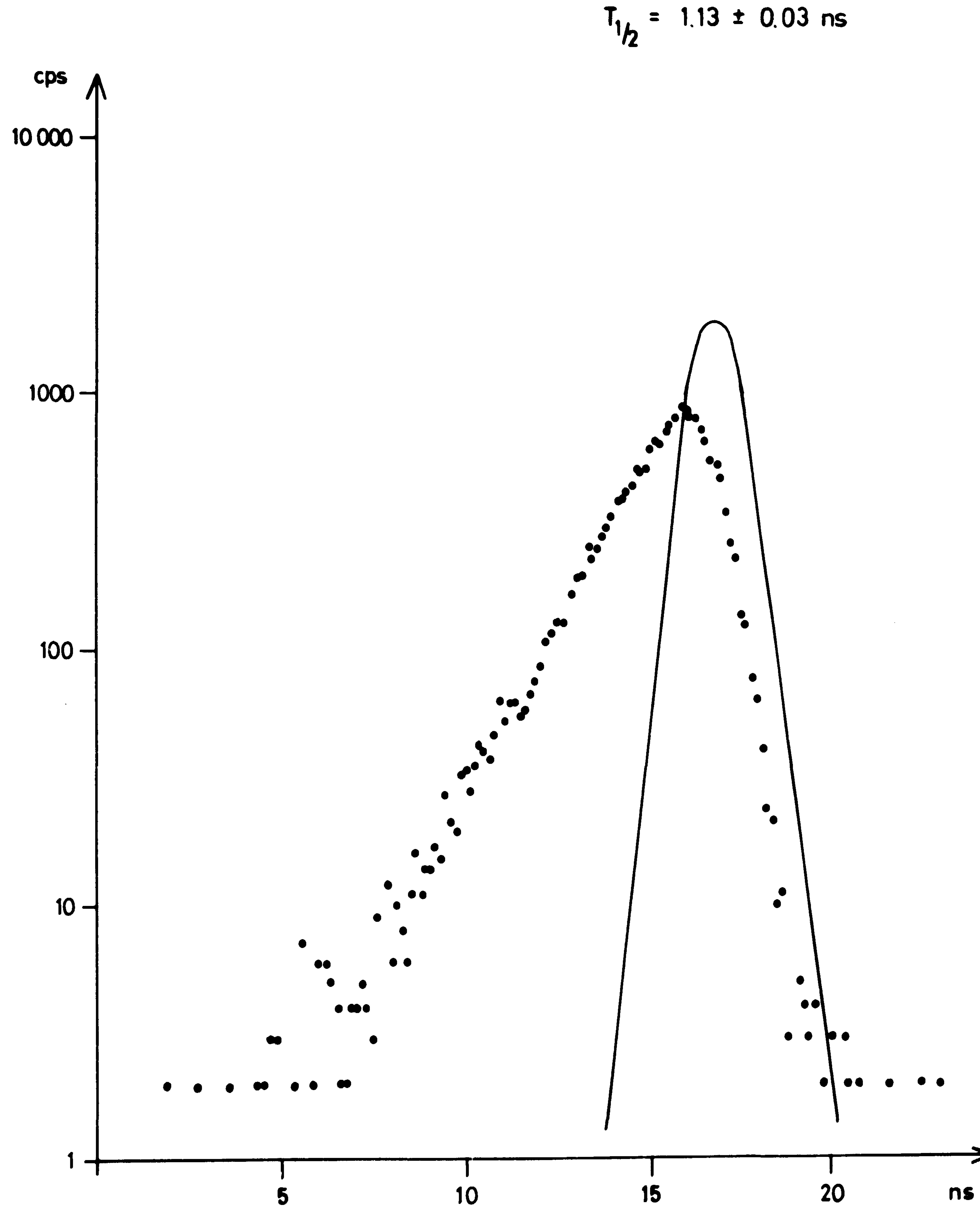
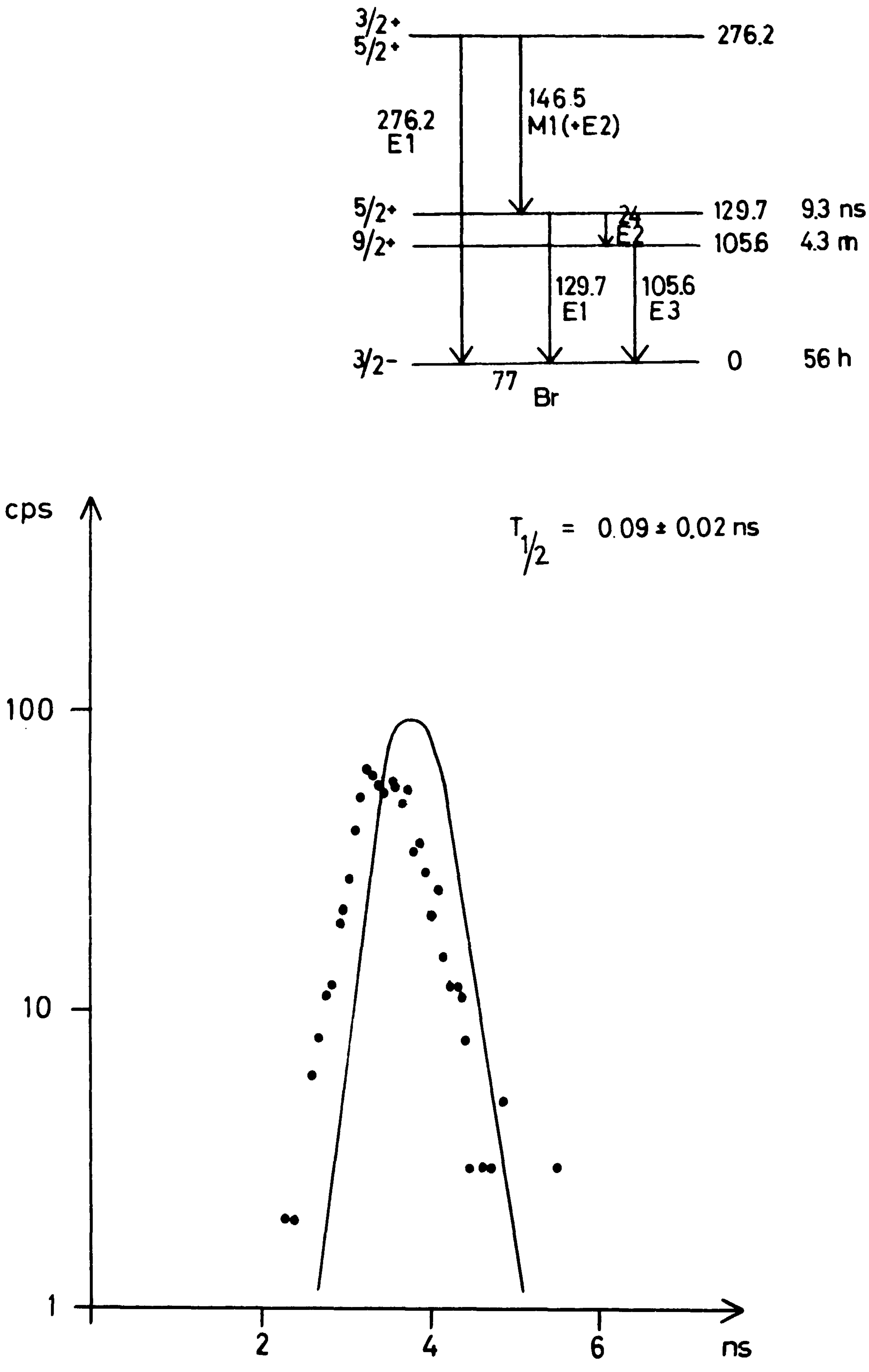
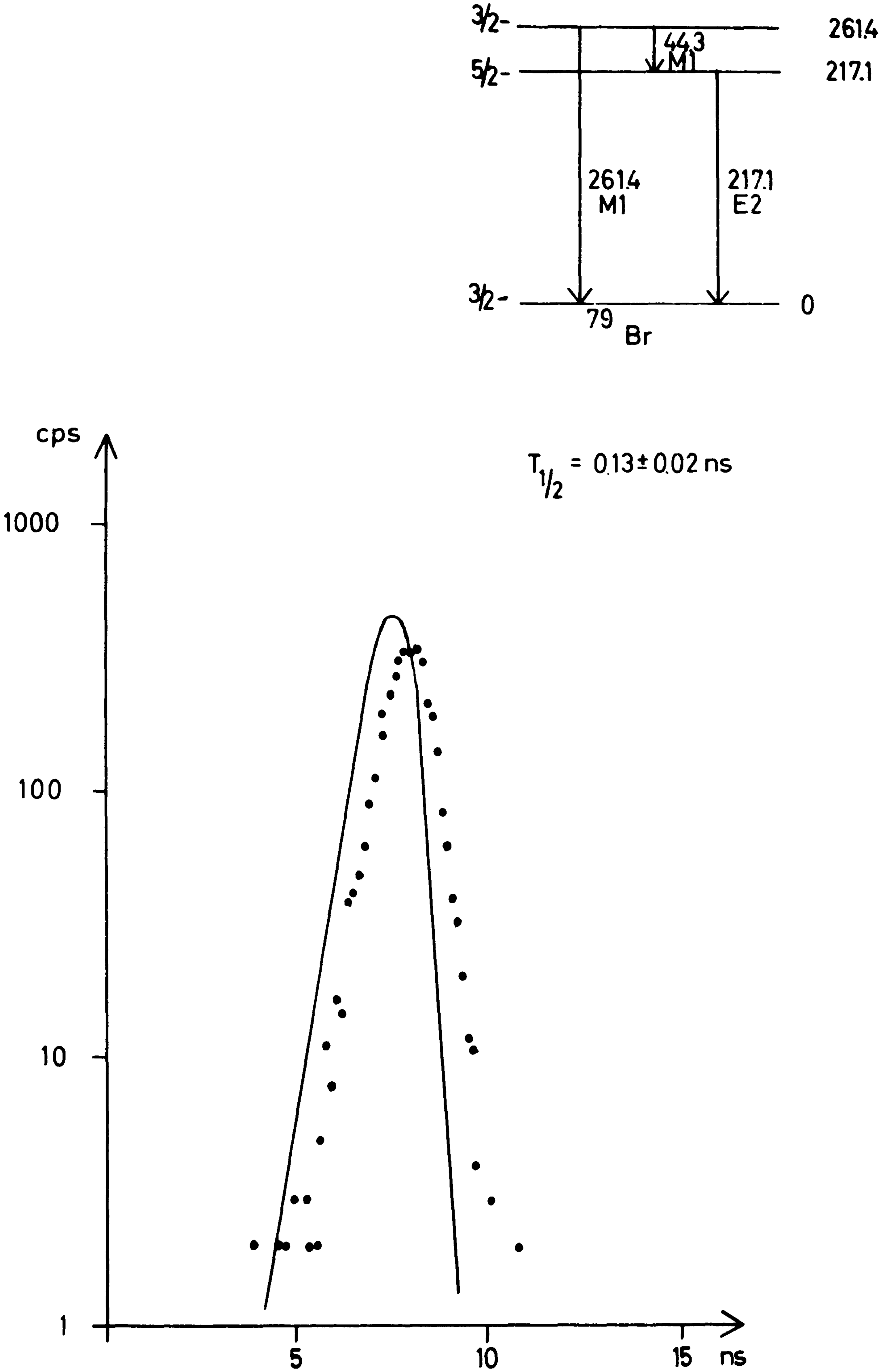


Fig. 2



3/2+
5/2+
276.2
276.2
E1
146.5
M1(+E2)
5/2+
129.7
9.3 ns
24
E2
9/2+
105.6
4.3 m
129.7
E1
105.6
E3
3/2-
0
56 h
77
Br
cps
$T_{1/2}$ = 0.09 ± 0.02 ns
100
10
1
2
4
6
ns

Fig. 3



3/2-
5/2-
3/2-
261.4
217.1
0
44.3
M1
261.4
M1
217.1
E2
79 Br
cps
$T_{1/2}$ = 0.13 ± 0.02 ns
1000
100
10
1
5
10
15
ns

Fig. 4