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Communications

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Determination of the half-life of the 56.5-keV level in ^{74}Ga by delayed coincident summing

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The half-life of the 56.5-keV level in ^{74}Ga was measured to be 31 ± 5 ns with what will be called the method of delayed coincident summing.

[RADIOACTIVITY Measured $t_{1/2}$ of the 56.5 keV state in ^{74}Ga.]

In an earlier investigation,[1] we reported the finding of an isomeric state in ^{74}Ga which decays by a cascade of 3.2- and 56.5-keV transitions (Fig. 1). In addition we have now measured the half-life of the 56.5-keV level in ^{74}Ga via a method which we call "delayed coincident summing" (dcs). The result complements the decay scheme of Ref. 1, and is of interest as it gives the transition probability of an $M1$ transition.

The standard way of deducing the half-life of an intermediate level from delayed coincidences between two fast detectors could not be applied to the present case. This is because the transition of 3.2 keV is invisible to usual detectors. In principle, standard timing could be performed using the decay of ^{74}Zn, but this activity[2] is difficult to produce. With our experimental facilities we could make ^{74}Ga^{m}, but not ^{74}Zn.

In its present application the dcs method can cope with the 3.2-keV transition. It takes advantage of the fact that the activity can be produced internal to the detector [via ^{74}Ge$(n,p)^{74}$Ga^{m}] by activating an intrinsic Ge detector itself (36% ^{74}Ge). We present here a brief overview of the method; more instrumental details will be described elsewhere,[3] where the method is applied to a 79-ns half-life in ^{71}Ge and to a 2.96-μs half-life in ^{73}Ge. These half-lives lie in the middle of the range of applicability of the dcs method, while the present case is at the lower half-life border of this range.

When two "promptly" cascading transitions T_1 and T_2 are detected by one detector, they give rise to a "sum peak" in the pulse height spectrum. If both radiations are detected with high efficiency (as for an internal ^{74}Ga^{m} source with low-energy transitions), then the sum peak may dominate the individual peaks of the cascade.[4] If the transitions T_1 with energy $E_1 = 3.2$ keV and T_2 with $E_2 = 56.5$ keV are not in prompt, but in delayed coincidence, then the sum peak acquires a distorted shape; the pulse from T_1 may begin to decline by the time the pulse from T_2 reaches its maximum, and the resultant summed pulses do not quite add to the sum energy $E_s = E_1 + E_2$. Depending on the half-life $t_{1/2}$ and the pulse shaping time constant t_{sh}, the distortion ranges from a slight low-energy tail on the sum peak ($t_{1/2} < t_{\text{sh}}$) to no sum peak at all and a full-energy peak at E_1 ($t_{1/2} > t_{\text{sh}}$). For longer half-lives, dead time of the analog-to-digital converter can cause losses of pulses from T_2. In the dcs method, the unknown half-life is found by analyzing the distorted shape of the sum peak.

To calculate this shape, one must know the response of the pulse-height-analysis system to two pulses separated in time. We simulated T_1 and T_2 with pulsers and determined the position of the sum pulse in the pulse-height spectrum when T_2 is delayed with respect to T_1 by a (variable) time t. In Fig. 2 we indicate the shifting position of the sum peak by an empirical curve $f(t)$. In an actual measurement, with a decay constant $\lambda = \ln 2/t_{1/2}$ for the intermediate level, the measured spectrum becomes a time integral over exponentially

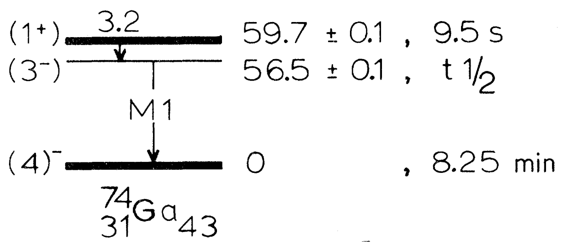

FIG. 1. Decay of ^{74}Ga^{m}.

decaying distributions of shifted pulses. Under the justified assumption that a monochromatic transition between 56.5 and 59.7 keV will give a Gaussian peak with a constant width σ, we find the following expression for the dcs spectrum:

$$N(E,\lambda) = \int_0^\infty dt\, \lambda\, e^{-\lambda t} (2\pi\sigma)^{-1/2} \exp\{-[E - f(t)]^2/2\sigma^2\}. \tag{1}$$

An intrinsic Ge detector with an area of 1 cm^2 and a depletion depth of 5 mm has been activated for 5-s periods by 14-MeV neutrons from the $^3\text{H}(d,n)^4\text{He}$ reactions with the LAN Cockcroft-Walton generator. Subsequent counting periods of 0.4, 1.6, 8, 8, 8, 16, and 256 s were chosen to follow 0.53-s $^{73}\text{Ge}^m$ and prevent buildup of 8.25-min $^{74}\text{Ga}^g$. Activation and counting were recycled automatically. Figure 3(a) shows the spectrum of the first and second 8-s periods with the $^{74}\text{Ga}^m$ sum peak at 59.7 keV and the unperturbed 53.4-keV peak from 0.53-s $^{73}\text{Ge}^m$ and 4.8-h ^{73}Ga decays, as observed with a pulse shaping time constant of 0.1 μs. Figure 3(b) shows the same data with the two peaks plotted above each other, normalized to equal areas. The drawn curve fits the datum points of the unperturbed line of $^{73}\text{Ge}^m$, but it can be seen in both the spectra of Fig. 3(a) and in Fig. 3(b) that the ^{74}Ga sum peak has a tail on its low-energy side. In other spectra accumulated with more usual pulse shaping times of 1 to 3 μs, no such tailing was observed although the resolution was better: 0.4 keV at 59 keV with $t_{\text{sh}} = 1$ μs, while being 0.75 keV in Fig. 3 with $t_{\text{sh}} = 0.1$ μs.

We have made a computer fit of Eq. (1) to the data of Fig. 3. Three parameters were free during fitting: a horizontal background, the amplitude or area of the peak, and the half-life. A cubic spline function was used for smooth interpolation between

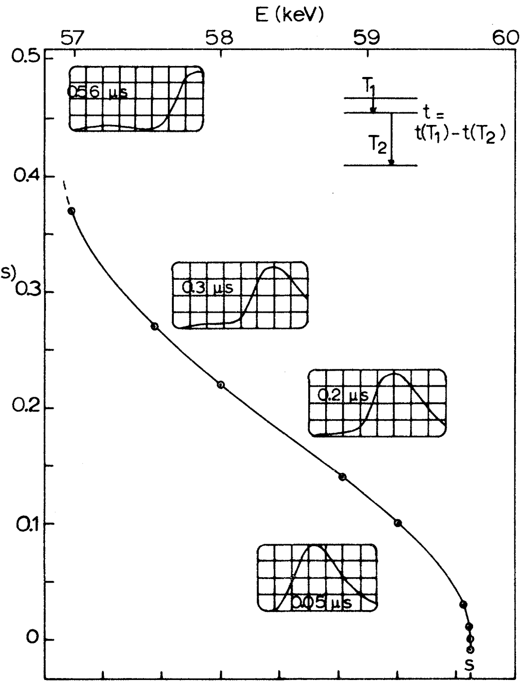

FIG. 2. Shift curve. Plotted is the observed peak position $f(t)$ in the pulse-height spectrum when the time t between artificial pulses T_1 and T_2 is varied from 0 to 0.4 μs. Oscilloscope photographs show pulses at the amplifier output at four values of t. For $t > 0.4$ μs only the smaller first pulse T_1 is counted, the analog-to-digital converter (ADC) being busy when T_2 arrives. For $t < 0.4$ μs the ADC no longer recognizes T_1 and digitizes T_2 added to a fraction of T_1. For $t = 0$, the sum peak occurs at channel s with $E_s = E_1 + E_2$. The present dcs application involves a short half-life with only a modest shift from the position s.

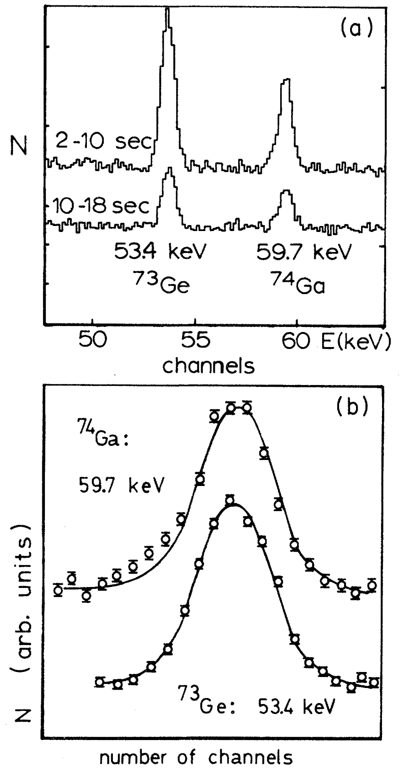

FIG. 3. (a) Spectra accumulated during the first and second 8-s counting periods with $t_{\text{sh}} = 0.1$ μs. The undistorted 53.4-keV peak decays with two half-life components: 0.53 s ($^{73}\text{Ge}^m$) and 4.9 h (^{74}Ga). The visibly distorted sum peak at 59.7 keV decays with the 9.5-s half-life of $^{74}\text{Ga}^m$. (b) The two peaks from the 2- to 10-s spectrum plotted on top of each other. The drawn curves are identical and fit to data points of the 53.4-keV line.

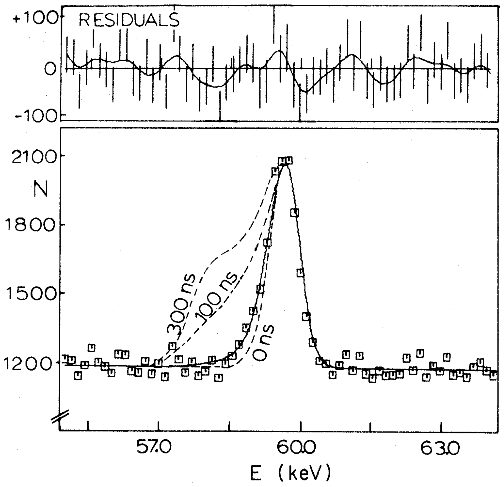

FIG. 4. Computer fit (drawn line) to the observed spectrum and (dashed) curves calculated for hypothetical half-lives of 300, 100, and 0 ns, all adjusted to equal height and to a common upper side of the distribution. The unperturbed peak (0 ns) fits well with the 53.4-keV line observed in all seven counting spectra mentioned in the text.

empirical $f(t)$ values. The best fit in Fig. 4 yielded the result:

$$t_{1/2}(56.5) = 31 \pm 5 \text{ ns}.$$

The peak position was adjusted to minimize systematic structure in the residuals. Statistical uncertainty accounts for about 2.5 ns of the quoted error. Conservative systematic errors were estimated for the system resolution (held constant during the fitting process), for transition energies, for the pulse simulation, and especially for the construction of the shift curve $f(t)$.

The peak tailing effect in Figs. 3 and 4, though definite, is not large. We have considered whether the cause could be due to the "ballistic deficit" effect[5] with short shaping time constants, or to radiation damage of the detector. Since the 53.4-keV line of ^{73}Ge^{m} as well as other lines in the spectrum (at 11, 23, and 140 keV; not shown) are symmetrical, and since these effects should apply equally to all lines, we conclude that the tailing is due to dcs. The experiments were ended when periodic control measurements indicated the first signs of radiation damage through line broadening and tailing of *all* peaks. During the course of this and our previous[1] investigation, as well as other experiments in an environment with fast neutrons, the detector received a total dose of about 3×10^{8} n/cm^{2}.

Observations of x rays following ^{74}Ga^{m} decay in Ref. 1 determined without ambiguity the multipole order of the 56.5-keV transition as $L = 1$. Arguments based on other features of the decay scheme led to the $M1$ assignment. The present half-life represents a retardation factor of 320 from the single-particle estimate, which is to be compared with a factor of 3 to 30 for "normal" $M1$ transitions in lighter nuclei. We know of no special selection rule forbidding this $M1$ transition. The three $(g_{9/2})$ neutrons outside $N = 40$ and the three protons outside $Z = 28$ can give rise to complex couplings[6] so that it is difficult to draw conclusions without more data on the internal structure of the states.[7]

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[1] J. van Klinken and L. M. Taff, Phys. Rev. C 9, 2252 (1974).

[2] B. B. Erdal *et al.*, Nucl. Phys. A194, 449 (1972).

[3] L. M. Taff and J. van Klinken (unpublished).

[4] In the present case of ^{74}Ga^{m}, the detection efficiency for the 3.2-keV transition is essentially 100%, while less than 10% of the 56.5-keV transitions escapes. Hence, we saw only a tentative trace of a peak at 3.2 keV, corresponding to escape of 56.5-keV quanta.

[5] E. Baldinger and W. Franzen, in *Advances in Electronics and Electron Physics*, edited by L. Marton (Academic, New York, 1956), p. 225.

[6] D. Kurath and R. D. Lawson, Phys. Rev. C 6, 901 (1972).

[7] W. Daehnick, University of Pittsburgh, private communication on ^{76}Ge(d, α) data.