THE PLACEMENT OF THE 188 keV TRANSITION IN ^{70}Ga

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Abstract

A careful study of the γ-rays following the ^{70}Zn(p, nγ)^{70}Ga reaction has shown no evidence for a first excited state at 188 keV in ^{70}Ga. However, a 188 keV γ-ray transition was found to de-excite the 879 keV level in ^{70}Ga, whose half-life was measured to be 24 ± 3 ns.

I. Introduction

Gossett and Butler (1959) first suggested the existence of states in ^{70}Ga at 0·18 and 0·50 MeV based on the observation of anomalies in their measured ratio of slow to fast neutrons produced via the reaction ^{70}Zn(p, n)^{70}Ga. The presence of a level at 509 KeV has since been substantiated by Tanaka *et al.* (1970).

The existence of a 0·18 MeV level in ^{70}Ga initially received support from lifetime measurements also made in 1959. Morozov and Yampolskii (1959), using NaI(Tl) detectors, found a $0·19 \pm 0·01$ MeV γ-ray with a half-life of 19 ± 1 ms following the bombardment of enriched ^{71}Ga targets with $\sim$19 MeV protons. An apparent threshold of $E_p = 9$ MeV led them to conclude that this γ-ray transition was produced in the ^{71}Ga(p, np)^{70}Ga reaction rather than in the ^{71}Ga(p, n)^{71}Ge reaction, which has a Q value of only about $-1·2$ MeV. Glagolev *et al.* (1959), who also used NaI(Tl) detectors, observed a $0·17 \pm 0·01$ MeV γ-ray with a half-life of 16 ± 1 ms following the bombardment of metallic germanium with 14 MeV neutrons, which they attributed to the ^{70}Ge(n, p)^{70}Ga reaction. The same conclusion was reached by Meyers and Schats (1966), who repeated this experiment with a natural Ge_2O_3 target and obtained a half-life of $21·2 \pm 1·2$ ms for a $0·18 \pm 0·01$ MeV γ-ray.

The strongest evidence in support of a level at 188 keV in ^{70}Ga came from the work of Rester *et al.* (1966), who observed conversion electrons and γ-rays produced following the ^{70}Zn(p, n)^{70}Ga reaction and found a relatively strong conversion line of 188 keV and a relatively weak γ-ray of 188 keV energy. They concluded that the 188 keV transition was of high multipolarity ($L \geqslant 3$) and that there existed an isomeric state at 188 keV in ^{70}Ga.

On the other hand, the Nuclear Data Sheets (1966) attributed the lifetime measurements to the 198 keV $9/2^+$ state in ^{71}Ge, which has a half-life of 20·2 ms.

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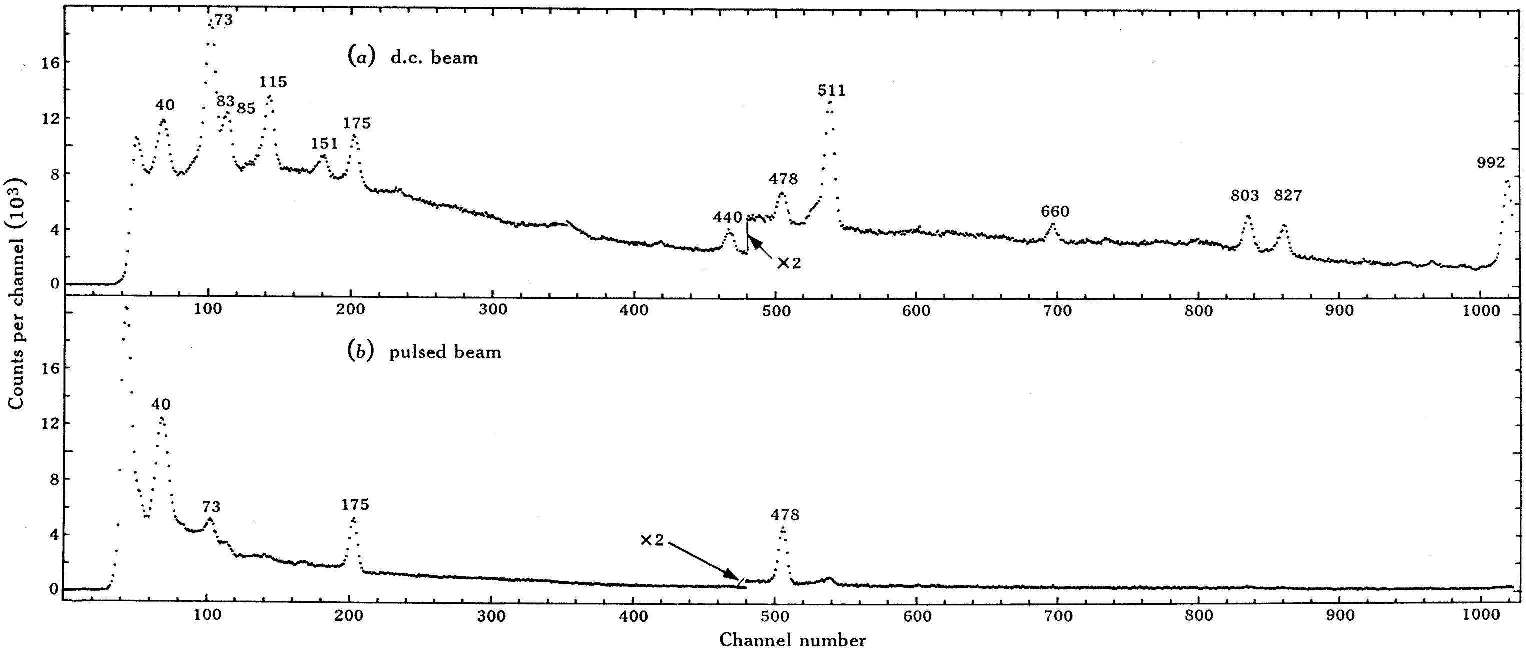
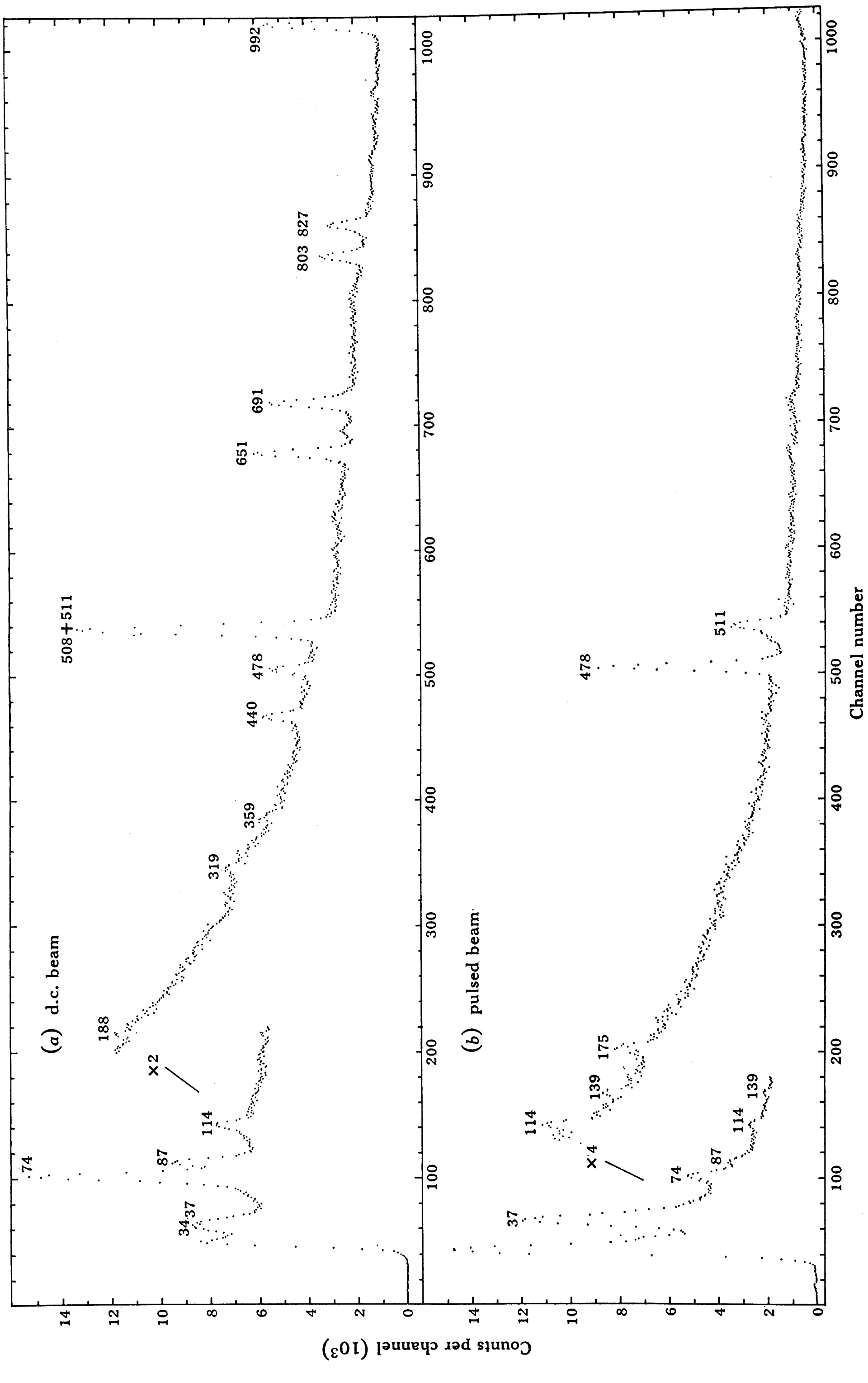


Fig. 1 (*above*).—Gamma-ray singles spectra taken with a 2·5 MeV proton beam incident on a GaO target for the reaction $^{71}Ga(p, n\gamma)^{71}Ge$. The energies (keV) of γ-ray peaks are indicated. Spectrum (*a*) was obtained with a 0·5 μA d.c. beam while spectrum (*b*) of delayed γ-rays was obtained with a pulsed proton beam of 5 μA (the pulses were 20 ms long and were repeated every 200 ms).

Fig. 2 (*below*).—Gamma-ray singles spectra taken with a 2·5 MeV proton beam incident on an enriched ^{70}Zn target for the reaction $^{70}Zn(p, n\gamma)^{70}Ga$. The energies (keV) of γ-ray peaks are indicated. The experimental conditions were the same as those described above in the caption to Figure 1. The 188 keV γ-ray is not present in the delayed spectrum.



(a) d.c. beam
(b) pulsed beam
Counts per channel (10^3)
Channel number
×2
×4
508+511
188
478
511

This level decays via a 23 keV transition to the 175 keV level, which in turn decays to the ground state. Indeed Morozov and Remaev (1963) rejected the former conclusion of Morozov and Yampolskii (1959) and suggested that the probable source of the $0 \cdot 19$ MeV γ-ray was the $^{71}Ga(p,n)^{71}Ge$ reaction.

Subsequent experiments on the $^{69}Ga(n,\gamma)^{70}Ga$ reaction by Linusson *et al.* (1969) and the $^{70}Zn(p,n\gamma)^{70}Ga$ reaction by Sawa (1970) have supported the presence of a 188 keV γ-ray and also a 319 keV γ-ray, which could be a transition between the 508 and a 188 keV level in ^{70}Ga but could also be a transition between the 319 keV first excited state and the ground state in ^{69}Ga. One of us (M.R.N.; unpublished data) in a study of the $^{70}Zn(p,n\gamma)^{70}Ga$ reaction has observed a weak γ-ray of $319 \pm 0 \cdot 8$ keV to have a threshold below that for the 508 keV ^{70}Ga level. From a Ge(Li)–Ge(Li) coincidence experiment, in which the $^{70}Zn(p,n)^{70}Ga$ reaction was used to populate levels up to $E_{ex} \approx 1$ MeV, Dohan and Summers-Gill (1970) found the 188 keV γ-ray to be in coincidence with 155 and 691 keV γ-rays. They placed the 188 keV γ-ray between the 879 and 691 keV levels in the decay scheme and the 155 keV γ-ray between the 1034 and 879 keV levels (the 155 keV γ-ray was not observed in the present work, which was carried out below the threshold for populating the 1034 keV level). Dohan and Summers-Gill also concluded that the 188 keV transition was dipole (+ quadrupole) in nature, which is inconsistent with a high internal conversion coefficient and leads to the possibility of two different 188 keV transitions.

Several groups (Finckh *et al.* 1970; Tanaka *et al.* 1970) have looked at the neutron spectrum from the $^{70}Zn(p,n)^{70}Ga$ reaction and found no direct feeding of a level near 188 keV. However, Finckh *et al.*, using a Ge(Li) detector, did observe a 188 keV γ-ray in a delayed spectrum obtained in a 30–950 ns time window following the $^{70}Zn(p,n)^{70}Ga$ reaction with $E_p = 3 \cdot 40$, $3 \cdot 96$, and $4 \cdot 50$ MeV and they suggested that this supported the existence of a 188 keV state with $J \geqslant 5$.

The aim of the present experiment was to clarify the situation regarding a 20 ms isomeric state in ^{70}Ga at 188 keV by observing the delayed γ-ray spectrum in a Ge(Li) detector and measuring its half-life relative to that of the known $20 \cdot 2$ ms isomeric state in ^{71}Ge.

II. Search for a 20 ms Isomeric State in ^{70}Ga

(*a*) *Experimental Procedure*

The experiment was carried out with the Lucas Heights 3 MeV Van de Graaff accelerator. Ge(Li) singles spectra were obtained using both the d.c. beam and the millisecond pulsed beam. The Ge(Li) pulses were also multiscaled in a PDP-7 computer to remeasure the lifetime of the 188 keV γ-ray. The measurements were carried out in two stages: (1) The $^{71}Ga(p,n\gamma)^{71}Ge$ reaction was used to populate the 198 keV $9/2^+$ isomeric state, which decays with a half-life of $20 \cdot 2$ ms to the 175 keV level, which in turn decays to the ground state. The observation of the 175 keV γ-ray served to check the equipment. The target was ~ 1 mg cm^{-2} of natural GaO evaporated onto a $0 \cdot 5$ mm Ta backing. The $^{69}Ga(p,n\gamma)$ reaction did not interfere owing to its high Q value. (2) The GaO target was replaced by a ^{70}Zn metallic foil (enriched to 68%) which had been rolled down to a thickness of $\sim 1 \cdot 5$ mg cm^{-2}. The experiment was repeated with the associated electronics remaining unchanged.

(*b*) *Results*

The γ-ray singles spectra obtained with the GaO and enriched ^{70}Zn targets are shown in Figures 1 and 2 respectively. (The peaks occurring at 440, 478, 803, 827, and 992 keV are background lines and do not emanate from the targets.) The upper spectra (*a*) were obtained with a 2·5 MeV d.c. proton beam of 0·5 μA and the lower spectra (*b*) with a 2·5 MeV pulsed proton beam of average current $\sim$5 μA, pulse duration 20 ms, and pulse repetition rate 5 Hz (or 1/200 ms^{-1}). The pulsed beam Ge(Li) spectra were collected during the 180 ms period following the pulse and thus do not contain peaks corresponding to prompt γ-rays. A comparison of Figures 1

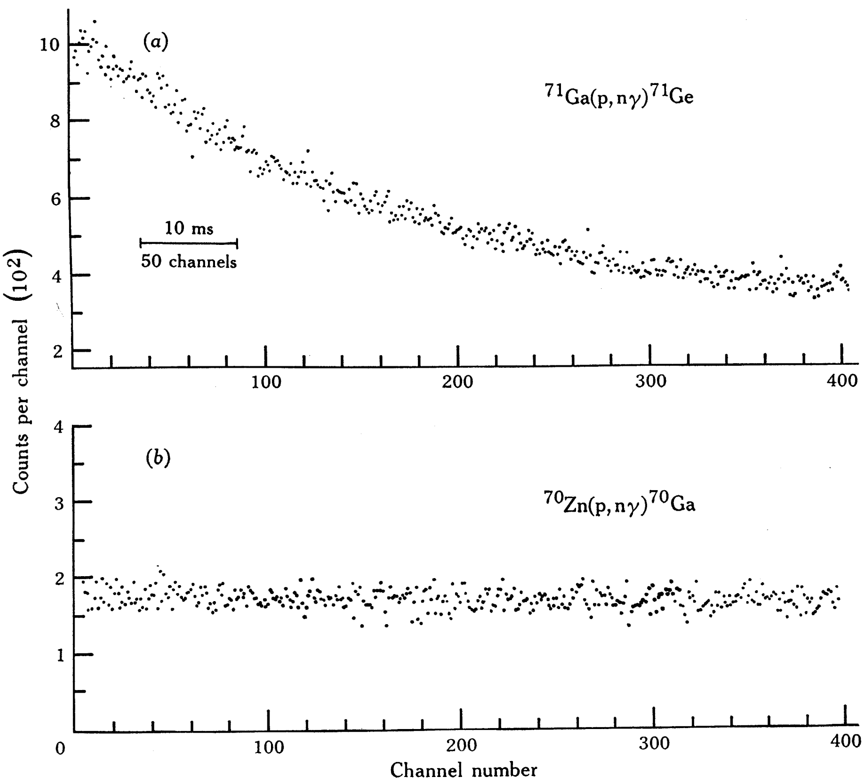


Fig. 3.—Multiscaler time spectra for the indicated reactions. Spectrum (*a*) shows the decay of the 175 keV 20·2 ms ^{71}Ge activity and spectrum (*b*) reveals the absence of any $\sim$20 ms activity for $140 \leqslant E_\gamma \leqslant 245$ keV from the ^{70}Zn(p, n)^{70}Ga reaction at $E_p = 2{\cdot}5$ MeV.

and 2 shows that the 175 keV γ-ray appears in the pulsed beam spectrum for the ^{71}Ga target but that the 188 keV γ-ray does not appear in the pulsed beam spectrum for the ^{70}Zn target. The corresponding multiscaler time spectra are given in Figure 3, in which the upper spectrum (*a*) shows the decay of the ^{71}Ge 20·2 ms activity while the lower spectrum (*b*) reveals the absence of any $\sim$20 ms activity produced via the ^{70}Zn(p, n)^{70}Ga reaction with $E_p = 2{\cdot}5$ MeV.

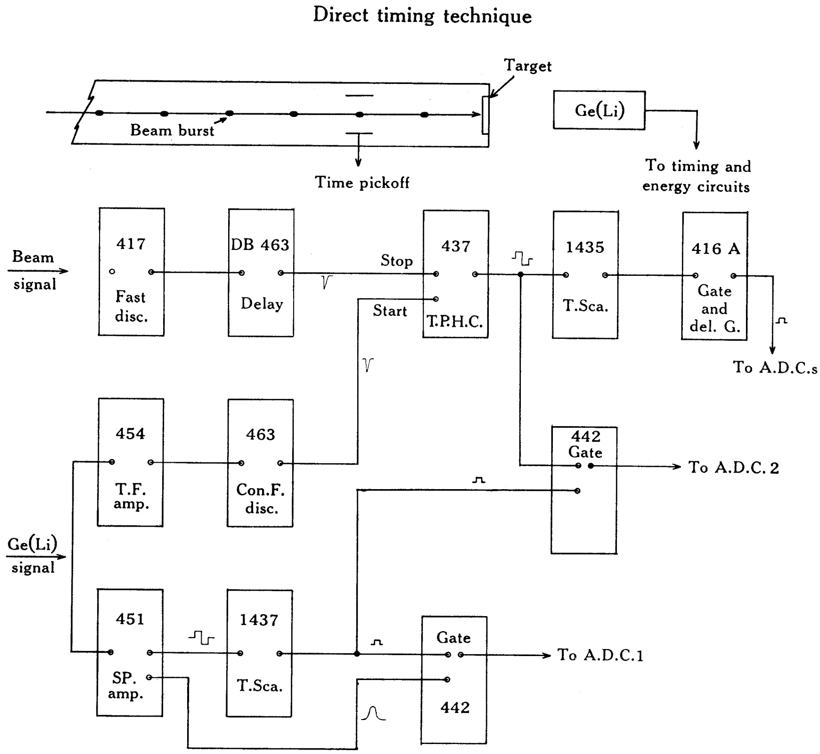


Fig. 4.—Block diagram of the fast electronics used in the nanosecond pulsed beam delayed coincidence measurements. A.D.C. 1 collects the γ-ray spectrum while A.D.C. 2 collects the corresponding time spectrum.

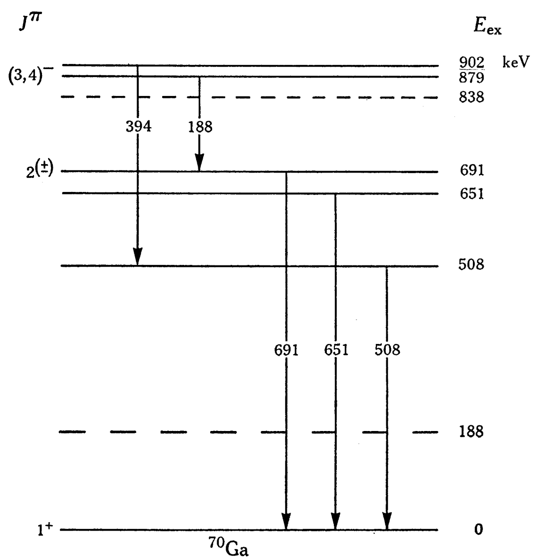


Fig. 5.—Gamma-ray decay scheme of ^{70}Ga that is relevant to the present work. The dashed horizontal lines indicate the positions of two levels suggested by previous studies (Dohan and Summers-Gill 1970; Finckh *et al.* 1970). Neither of these levels was confirmed by the present work.

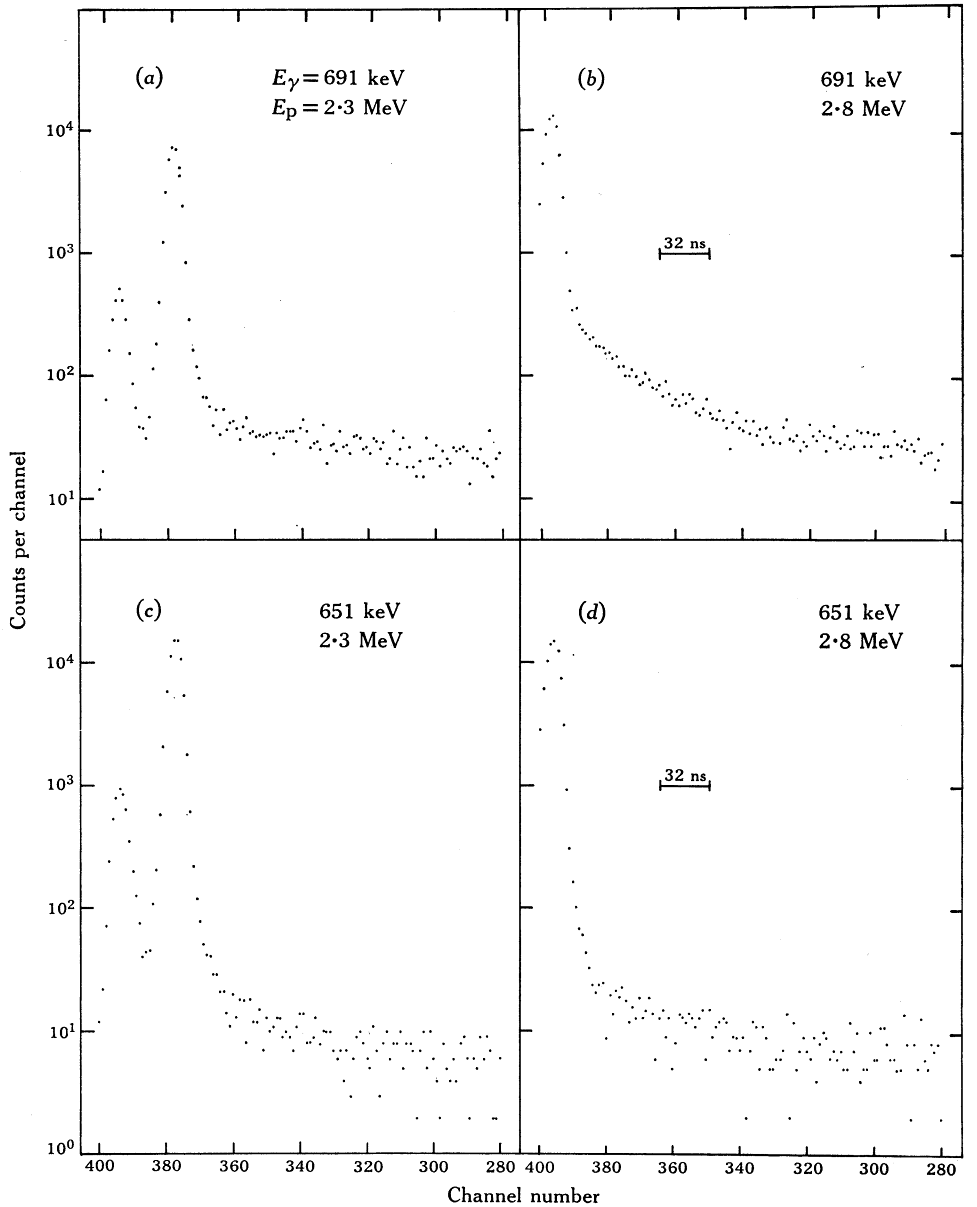


Fig. 6.—Time curves for the 691 and 651 keV γ-rays taken at $E_p = 2{\cdot}3$ and $2{\cdot}8$ MeV as indicated. The delayed activity shown by the 691 keV line is clearly present at $E_p = 2{\cdot}8$ but not at $2{\cdot}3$ MeV. This indicates that the delayed activity originates from the 879 and not from the 691 keV level. The prompt peak near channel 394 in the $E_p = 2{\cdot}3$ MeV spectra (*a*) and (*c*) results from γ-rays produced by the beam hitting a collimator upstream from the target.

III. Lifetime of 188 keV Transition

The time curve (Fig. 3 (*b*)) allowed an upper limit of 5 ms to be placed on the half-life of the 188 keV γ-transition. In view of the observation by Finckh *et al.* (1970) of a delayed γ-ray of 188 keV energy we considered it necessary to use the nanosecond beam pulsing facility to attempt to measure the half-life of the 188 keV γ-ray.

(*a*) *Experimental Procedure*

The nanosecond pulsing system of the Lucas Heights 3 MeV Van de Graaff accelerator was used to produce proton pulses of duration ~ 10 ns, repetition rate 1 kHz, and average current $\sim 0 \cdot 5$ μA. A block diagram illustrating the fast timing technique employed is given in Figure 4. The stop signal for the time to pulse height converter (T.P.H.C.) was derived from a capacitive pickoff placed at the exit of the accelerator while the start signal was derived from the Ge(Li) signals by means of an Ortec 454 timing filter amplifier and a 463 constant fraction timing unit. Both the T.P.H.C. and Ge(Li) spectra were processed by A.D.C.'s interfaced to a PDP-7 computer. Several digital windows were placed on the energy spectrum and the corresponding T.P.H.C. spectra were stored in the computer. The T.P.H.C. was calibrated by using a Coronetics nanosecond delay box to produce known delays in the stop signal.

The γ-ray decay scheme for ^{70}Ga that is relevant to the present study is shown in Figure 5. The energy spectrum covered the range from 40 keV to $1 \cdot 0$ MeV and the T.P.H.C. covered a range of 1000 ns. The procedure consisted in observing the delay curves gated by the 651 and 691 keV γ-ray transitions with beam energies of $2 \cdot 3$ MeV, which is below the threshold for populating the 879 keV level, and $2 \cdot 8$ MeV, for which the 879 keV level is populated. The 188 keV γ-ray transition was also used to gate the time spectrum at the higher beam energy.

(*b*) *Results*

The time curves gated by the 691 and 651 keV γ-ray photopeaks with beam energies of $2 \cdot 3$ and $2 \cdot 8$ MeV are shown in Figures 6(*a*)–6(*d*). The delay curve (*b*) for the 691 keV transition at $E_p = 2 \cdot 8$ MeV gives a value of 24 ± 3 ns for the half-life of the 188 keV transition on the assumption that the half-life of the 691 keV level is short on this time scale as indicated by the delay curve (*a*) obtained at $E_p = 2 \cdot 3$ MeV. Although the 188 keV γ-ray window also shows this lifetime, it contains an additional 87 ns half-life contribution from the 198 keV transition in ^{19}F (produced in the beam-stop behind the self-supporting ^{70}Zn target).

IV. Discussion

Dohan and Summers-Gill (1970) have shown that $J^{\pi} = 3^{-}$ or 4^{-} for the 879 keV level in ^{70}Ga while one of us (M.R.N.; unpublished data) has found that $J = 2$, with parity as yet undetermined, for the 691 keV level. Thus, if positive parity is assumed for the 691 keV level, a J^{π}(879 keV) $= 3^{-}$ assignment implies that the 188 keV γ-ray results from an inhibited electric dipole transition with $B(\mathrm{E1}) = 2 \cdot 5 \times 10^{-6}$ Weisskopf units (W.u.). On the simple shell model this entails the decay of a $g_{9/2}$ orbital into a $p_{1/2}$ or $f_{5/2}$ orbital, either of which is of course a forbidden transition. Alternatively a J^{π}(879 keV) $= 4^{-}$ assignment leads to the unrealistic M2 strength of 300 W.u.

If negative parity is assumed for the 691 keV level, a J^π(879 keV) = 4^- assignment implies that the 188 keV γ-ray results from an electric quadrupole transition with B(E2) = 6·0 W.u. while a J^π(879 keV) = 3^- assignment leads to an M1 strength of $\leqslant 1\cdot5\times10^{-4}$ W.u.

The present work has supported the conclusion that the 188 keV γ-ray arises from the decay of the 879 to the 691 keV level of ^{70}Ga. The measured lifetime of 24 ± 3 ns for the 879 keV level together with the J^π combinations described above rule out the conclusion of Rester *et al.* (1966) that this 188 keV γ-ray transition has $L \geqslant 3$. We have found no support for the presence of a level at 188 keV in ^{70}Ga. Thus the fact that the first excited state is at 508 keV in the odd–odd nucleus ^{70}Ga is quite remarkable as the same energy region contains 6 levels in ^{68}Ga and 14 levels in both ^{66}Ga and ^{72}Ga.

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