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# THE ENERGY LEVEL STRUCTURE OF $^{89}Y$ FROM THE $(n,n'\gamma)$ REACTION(x)

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This paper reports preliminary results of $^{89}Y(n,n'\gamma)$ experiments to measure the energy, excitation functions, angular distributions and branching ratios of the de-excitation $\gamma$-rays of $^{89}Y$.

Previous work on $^{89}Y$ has been reviewed by Kocher(1). Further information regarding high spin states in this nucleus is found in ref. (2). Even though the energy levels of $^{89}Y$ can be considered well established up to an excitation energy of 4.6 MeV(3), the knowledge of the gamma-decay mode and of the branching ratios is still incomplete above 3.0 MeV, when not missing completely.

The present experiments on $^{89}Y$ consist of $\gamma$-ray excitation function measurements performed at incident neutron energies ranging from 2.2 MeV to 4.8 MeV. The physical equipment and electronics used in these experiments were similar to those previously used in $(n,n'\gamma)$ studies carried out in the Laboratori Nazionali di Legnaro (LNL)(4, 5, 6). We used the $^3H(p,n)^3He$ and the $D(d,n)^3He$ reaction as a source of neutrons having energy $E_n \leq 4.0$ MeV or $E_n > 4.0$ MeV respectively. In the two cases, the targets consisted of tritium or deuterium embebbed in metallic Ti.

The scatterer was a 143g, 99.9% pure yttrium sample in the shape of a solid cylinder 4.5 cm in length and 3.0 cm in diameter, suspended at $0^o$ with respect to the in-

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(x) - Work performed at the Laboratori Nazionali di Legnaro.

cident beam at a distance of 7.5 cm from the target. De-excitation $\gamma$-rays were observed by a 84 $cm^3$ HPGe detector of about 18% efficiency and 2.3 keV energy resolution at 1.33 MeV, placed at about 60 cm from the sample and at an angle of $90^o$ with respect to the beam direction. A 3 ns pulsed beam, provided by the 7 MV Van de Graaff accelerator of the LNL, permitted standard time-of-flight gating techniques(7) for n-$\gamma$ discrimination.

In order to protect the crystal from the direct flux of neutrons and $\gamma$-rays from the target and to minimize background $\gamma$-rays in the energy spectra, the Ge detector was surrounded by a lead ring 8 cm thick, welded into a shield of paraffin loaded with boric acid. At each energy the measurement consisted of a spectrum from the sample; a background spectrum from a carbon sample of dimensions chosen in such a way as to ensure that the total flux of scattered neutrons at the detector was approximately the same as in the case of $^{89}Y$; and a third spectrum from a sample of natural Fe in order to obtain absolute normalization.

To monitor the neutron flux incident on the samples, a neutron time-of-flight spectrometer (employing a NE213 scintillation counter) was located approximately 5 m from the neutron source at $30^o$ with respect to the incident beam. The spectra were recorded on a 4096-channel analyser with a dispersion of 1.3 keV/channel and then processed on a HP1000 computer with an automatic peak fitting code developed in this laboratory(8). In Fig. 1 we show the time-gated energy spectrum, obtained at a neutron energy of 4.8 MeV. The monitor-normalized background spectrum obtained with the C sample has been subtracted. The gain of the electronics and the relative efficiency of the HPGe detector were measured using the accurately known energies and relative intensities of the $\gamma$-rays emitted by the radioactive souces $^{152}Eu$ and $^{56}Co$ or originated by the de-excitation of $^{28}Si$ produced in the $^{27}Al(p,\gamma)^{28}Si$ reaction at the proton resonance energy Ep = 992 keV(9). The photopeak yields were corrected for $\gamma$-rays absorption in the scattering samples using the $\gamma$-ray absorption coefficients for Y and Fe given in ref. (10).

The excitation functions at $90^o$ of the absolute differential cross sections of the $^{89}Y$ $\gamma$-rays were finally obtained by comparing the photopeak intensity of a reference $\gamma$-ray of known production cross sections, the 847 keV $\gamma$-ray from the $^{56}Fe(n,n'\gamma)$ reaction(11) and then correcting for attenuation and multiple scattering of the incident neutron beam in the sample(12).

In the present work we have observed sixty-nine $\gamma$-ray transitions and identified forty-three $^{89}Y$ levels up to an excitation energy of 4.54 MeV. For these levels $\gamma$--ray branching ratios have been determined. The results are summarized in Table I.

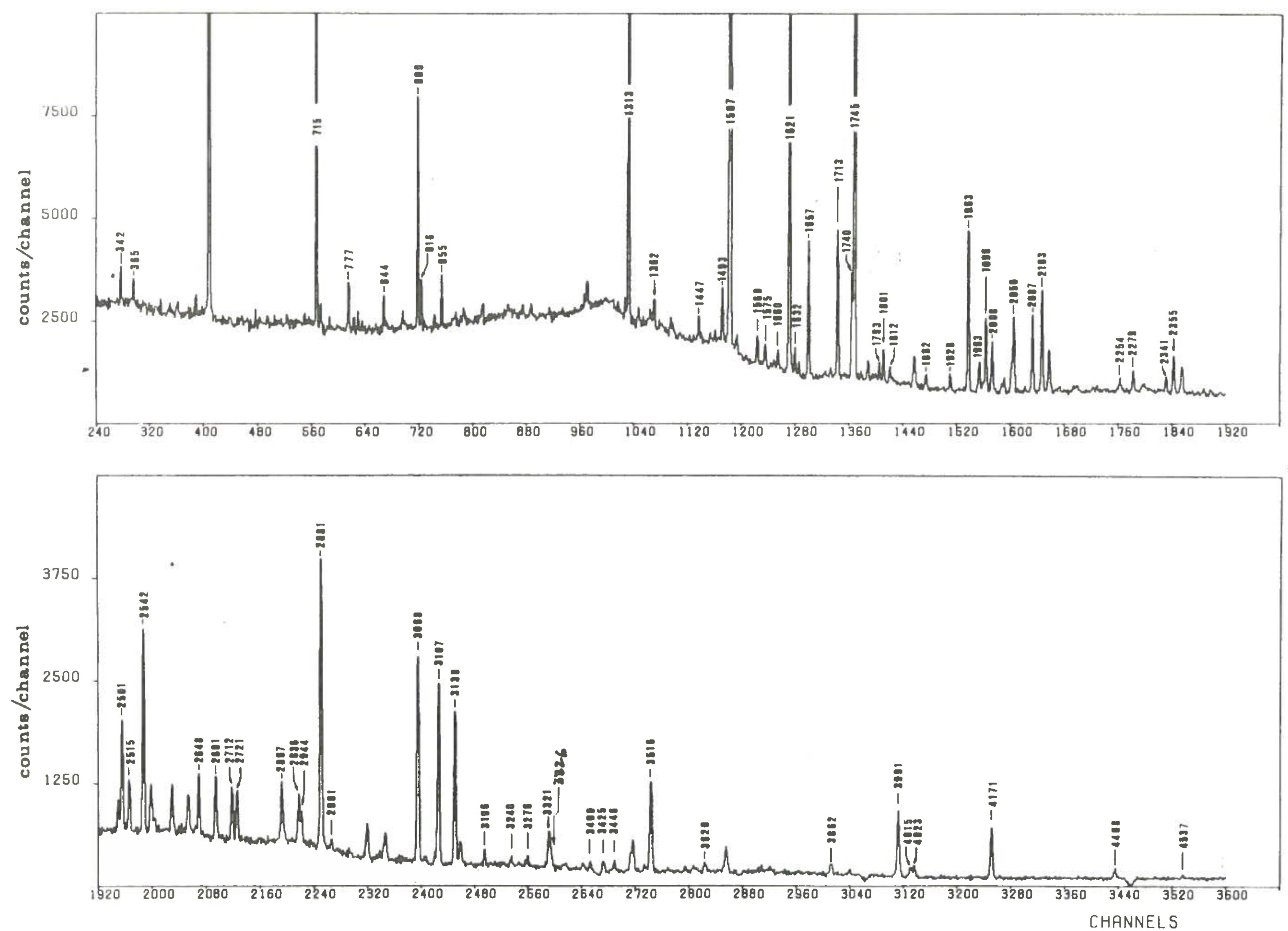


FIG. 1 - A $^{89}Y(n,n'\gamma)^{89}Y$ spectrum obtained at $\theta = 90^{o}$ and En = 4.8 MeV. A monitor-normalized background spectrum has been subtracted. Gamma-ray energies are in keV.

TABLE I - $^{89}Y$ level energies, $\gamma$-ray energies and branching ratios determined in the present experiment.

| Initial state (keV) | Final state (keV) | $E_\gamma$ (keV) | Branching ratios (%) |
|---|---|---|---|
| 909.0±0.3 | g.s. | 909.0±0.3 | 100 |
| 1507.2±0.3 | g.s. | 1507.2±0.3 | 100 |
| 1744.7±0.4 | g.s. | 1744.7±0.4 | 100 |
| 2222.3±0.4 | 909 | 1313.2±0.3 | 68.5±0.6 |
| | 1507 | 715.2±0.3 | 31.5±0.6 |
| 2529.8±0.4 | 909 | 1620.8±0.3 | 100 |
| 2566.3±0.5 | 909 | 1657.3±0.4 | 100 |
| 2622.0±0.5 | 909 | 1713.0±0.4 | 100 |
| 2871.8±0.5 | 909 | 1962.8±0.4 | 100 |
| 2881.2±0.6 | g.s. | 2881.2±0.6 | 100 |
| 2892.5±0.7 | 909 | 1983.5±0.6 | 100 |
| 3067.5±0.5 | g.s. | 3067.6±0.6 | 90.4±0.7 |
| | 1507 | 1559.8±0.5 | 9.6±0.7 |
| 3107.2±0.7 | g.s. | 3107.5±0.6 | 82.5±1.1 |
| | 1507 | 1599.8±0.4 | 8.4±0.8 |
| | 1745 | 1361.8±0.9 | 9.1±0.7 |
| 3138.9±0.6 | g.s. | 3139.2±0.6 | 77.9±0.9 |
| | 1507 | 1631.6±0.4 | 9.4±0.8 |
| | 2222 | 916.1±0.5 | 12.7±0.6 |
| 3247.4±0.6 | g.s. | 3247.5±0.9 | 6.9±1.8 |
| | 1507 | 1740.2±0.5 | 93.1±1.8 |
| 3343.3±0.7 | 2566 | 777.0±0.4 | 100 |
| 3410.4±0.6 | 909 | 2501.4±0.5 | 100 |
| 3451.3±0.7 | 909 | 2542.3±0.6 | 100 |

| | | | |
|---|---|---|---|
| 3503.4±0.6 | 1507 | 1996.2±0.5 | 94.1±0.9 |
| | 3139 | 364.7±0.5 | 5.9±0.9 |
| 3516.2±0.8 | g.s. | 3516.2±0.8 | 100 |
| 3557.3±0.7 | 909 | 2648.3±0.6 | 37.8±1.5 |
| | 1507 | 2050.1±0.8 | 49.8±1.6 |
| | 1745 | 1812.5±0.9 | 12.4±1.8 |
| 3621.1±0.7 | 909 | 2712.1±0.6 | 100 |
| 3630.4±0.7 | 909 | 2721.4±0.6 | 100 |
| 3715.1±0.5 | 909 | 2806.7±0.8 | 47.3±2.3 |
| | 2222 | 1492.7±0.4 | 38.0±1.9 |
| | 2872 | 843.6±0.5 | 14.7±1.1 |
| 3747.7±0.9 | 909 | 2838.7±0.8 | 100 |
| 3752.8±0.7 | 909 | 2844.2±0.8 | 23.7±1.7 |
| | 1745 | 2008.3±0.6 | 68.1±1.8 |
| | 3410 | 341.9±0.5 | 8.2±0.8 |
| 3848.1±0.6 | 1507 | 2340.8±0.6 | 15.1±1.2 |
| | 1745 | 2103.5±0.5 | 84.9±1.2 |
| 3862.1±0.6 | g.s. | 3861.8±0.9 | 23.7±1.8 |
| | 1507 | 2355.1±0.5 | 76.3±1.8 |
| 3976.8±0.7 | 2530 | 1447.0±0.5 | 100 |
| 3991.5±0.8 | g.s. | 3991.5±0.8 | 100 |
| 4015.1±1.0 | g.s. | 4015.4±1.5 | 57.3±3.6 |
| | 2222 | 1792.8±0.7 | 42.7±3.6 |
| 4022.8±0.7 | g.s. | 4022.9±1.5 | 11.5±1.1 |
| | 1507 | 2515.3±0.6 | 28.8±1.2 |
| | 1745 | 2278.6±0.7 | 22.3±1.2 |
| | 2222 | 1800.8±0.4 | 20.9±1.0 |
| | 3067 | 955.0±0.3 | 16.5±0.8 |
| 4104.9±0.9 | 909 | 3196.3±1.2 | 22.5±2.2 |
| | 2222 | 1882.5±0.8 | 32.6±2.5 |
| | 2530 | 1574.9±0.7 | 41.8±2.6 |
| 4170.8±1.1 | g.s. | 4170.8±1.1 | 100 |

| | | | |
|---|---|---|---|
| 4187.9±0.8 | 909 | 3278.7±0.9 | 16.1±1.8 |
| | 1507 | 2680.9±0.7 | 83.9±1.8 |
| 4230.4±1.3 | 909 | 3221.4±1.2 | 100 |
| 4309.1±0.8 | 909 | 3400.5±0.9 | 11.6±1.2 |
| | 2222 | 2086.7±0.7 | 88.4±1.2 |
| 4334.1±1.3 | 909 | 3425.1±1.2 | 100 |
| 4354.7±1.1 | 909 | 3445.7±1.0 | 100 |
| 4408.2±1.1 | g.s. | 4408.2±1.3 | 60.5±4.7 |
| | 1507 | 2901.0±1.0 | 39.5±4.7 |
| 4457.6±0.8 | 2530 | 1927.8±0.6 | 100 |
| 4476.1±1.3 | 2222 | 2253.8±1.2 | 100 |
| 4529.3±1.6 | 909 | 3620.3±1.6 | 100 |
| 4537.4±2.0 | g.s. | 4537.4±2.0 | 100 |

In Fig. 2 we present an energy level diagram of $^{89}$Y consistent with the present measurements.

As may be seen the energy level structure for $^{89}$Y as proposed by Kocher[1] is supported by the results of the present experiments up to an excitation energy of about 3.6 MeV.

In addition there is clear evidence for two $\gamma$-ray transitions of energy 1983.5 keV and 777 keV which are observed only for neutron energies above 4.0. They fit in extremely well with the decay to the first excited state of the known levels at Ex = 2893 keV and Ex = 3342.7 keV respectively. The observed irregular threshold behaviour supports the suggestion that these two levels are high spin (13/2) states of $^{89}$Y as reported by L. Hulstman et al.[3] and by M. Davidson et al.[2] respectively. Gamma rays with $E_\gamma$ = = 3247.5 keV and $E_\gamma$ = 2542.3 keV appear in the spectrum from En = 3.6 MeV upwards, thus supporting the existence of the level at Ex = 3247 keV observed by L. Hulstman et al.[3] and of the level at Ex = 3450 keV proposed by P. S. Buchanan et al.[13] respectively.

Above 3.6 MeV of excitation energy, on the basis of the excitation data, the multiplicity of several $^{89}$Y states may be inferred. According to Fig. 1 the previously reported[3] 2717 keV and 2840 keV $\gamma$-rays are shown to be well resolved doublets. We

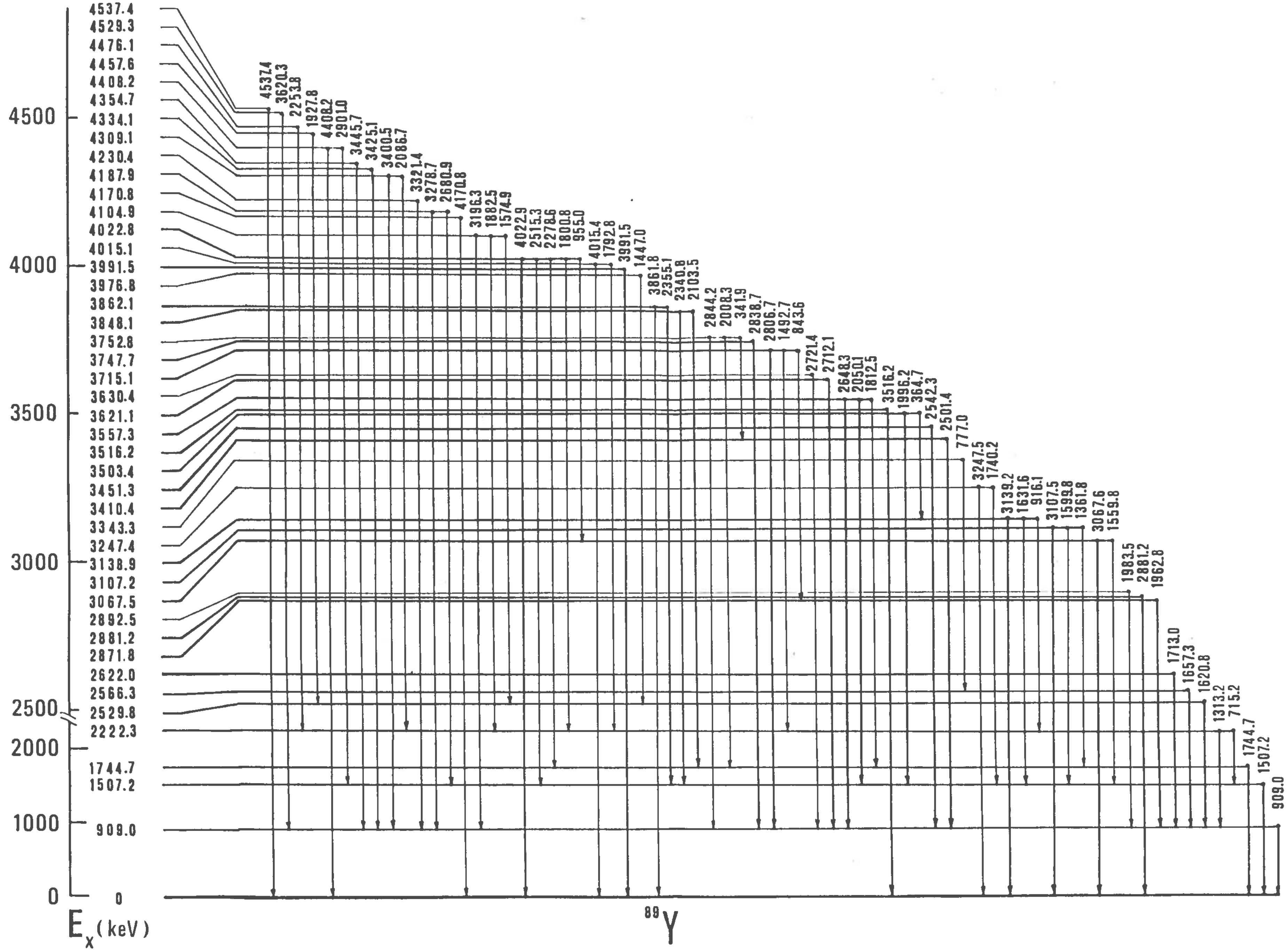


FIG. 2 - $^{89}$Y level and decay scheme. The thick lines represent the levels and decays of ref.(1), the thin ones the results of the present measurements.

have tentatively assigned their level origins at Ex = 3621.1 and 3630.4 keV, and Ex = = 3747.7 and Ex = 3752.8 keV respectively. The fourfold multiplicity at Ex = 4.0 MeV in $^{89}$Y, as reported in ref. (3), seems well supported by the existence of both the 1447.0 keV cascade $\gamma$-ray from a level at Ex = 3976.8 keV and the ground-state transition with $E_\gamma$ = 3991.5, $E_\gamma$ = 4015.4 and $E_\gamma$ = 4022.9 keV observed in the present experiments from En = 4.2 MeV upwards.

Finally, also the $\gamma$-ray peak at 3321 keV observed in the present experiments is probably due to an unresolved doublet (the automatic peak fitting procedure furnishes for the two peaks the values of $E_\gamma$ = 3321.4 keV and $E_\gamma$ = 3326.2 keV). On the basis of the excitation data we suggest a multiplicity also for the level observed by L. Hulstman et al.[3] at Ex = 4230 keV.

Experimental angular distributions for the $\gamma$-rays observed in the present study have been measured at mean incident-neutron energies of 3.4, 3.7, 4.2 and 4.5 MeV. The comparison of the statistical theory of the compound nucleus with experiment in regard to both the shape of the angular distribution and magnitude of the differential cross sections for the $\gamma$-rays observed provides a basis for the choice of level spin and parity assignements. Work is in progress along these lines.

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