## $^{91}$Zr(p,nγ) 1973Ma02,1977Sc28

| Type | Author | History Citation | Literature Cutoff Date |
|---|---|---|---|
| Full Evaluation | Coral M. Baglin | NDS 114, 1293 (2013) | 1-Sep-2013 |

Others: 1971Ma47, 1971Ma48.

1977Sc28: E=3.6-4.9 MeV. 89.2% $^{91}$Zr target. Ge(Li) detectors, FWHM=2.1 keV and 2.8 keV at 1.33 MeV. Measured Iγ, γ(θ), $T_{1/2}$ from DSA.

1973Ma02: E=3.25-5.51 MeV (30 keV steps). 90.9% enriched target (1971Ma47). Ge(Li) detectors, FWHM=4 keV at 3 MeV. Most of the data are also reported in 1971Ma47.

1971Ma48: E=3.0-6.3 MeV. 90.88% $^{91}$Zr target. Ge(Li) detectors, FWHM=3.0-3.5 keV at 1.0 MeV. Measured Eγ, Iγ, excit, γγ coin.

### $^{91}$Nb Levels

| E(level)[†] | $J^\pi$[‡] | $T_{1/2}$[#] | Comments |
|---|---|---|---|
| 0 | 9/2$^+$ | | $J^\pi$: from Adopted Levels. |
| 104.18 *25* | 1/2$^-$ | | $J^\pi$: from Adopted Levels. |
| 1186.76 *20* | 5/2 | >2.1 ps | $J^\pi$: IAR: 5/2$^-$. |
| 1312.54 *22* | 3/2$^-$ | 0.104 ps *+28−21* | $J^\pi$: IAR: 3/2$^-$. |
| 1580.97 *20* | 7/2$^+$ | 0.55 ps *+28−17* | $J^\pi$: IAR: 7/2$^+$,9/2$^+$. |
| 1612.4 *3* | 3/2$^-$ | 54 fs *+14−10* | $J^\pi$: IAR: 3/2$^-$. |
| 1637.1 *3* | 9/2$^+$ | | $J^\pi$: IAR: 7/2$^+$,9/2$^+$. |
| 1790.60 *19* | 11/2$^-$ | >1.5 ps | $J^\pi$: IAR: 9/2$^-$. |
| 1844.7 *3* | 5/2 | >1.5 ps | $J^\pi$: IAR: 5/2$^-$. |
| 1963.3 *3* | 5/2 | 0.20 ps *+7−4* | $J^\pi$: IAR: 3/2$^+$,5/2$^+$. |
| 1984.58 *21* | 13/2,15/2 | >0.4 ps | $J^\pi$: IAR: 1/2$^+$,11/2$^+$,≥13/2. γ to 9/2$^+$ g.s. disfavors J=15 and favors π=+. |
| 2120.84 *19* | 5/2,7/2$^-$ | >1.0 ps | $J^\pi$: IAR: 7/2$^-$. |
| 2292.0 *3* | 13/2,15/2 | 0.12 ps *+4−3* | $J^\pi$: IAR: 1/2$^+$,11/2$^+$,≥13/2. |
| 2324.50 *24* | 5/2,7/2$^-$ | 0.18 ps *+6−4* | $J^\pi$: IAR: 5/2$^-$. |
| 2330.2 *3* | 11/2 | 0.104 ps *+28−21* | $J^\pi$: IAR: 1/2$^+$,11/2$^+$,≥13/2. π=+ based on mult(2330γ). |
| 2345.1 *3* | 3/2 | 0.104 ps *+21−14* | $J^\pi$: IAR: 3/2$^-$. |
| 2389.8 *3* | 3/2$^+$,5/2 | 1.0 ps *+24−5* | $J^\pi$: IAR: 1/2$^-$,3/2$^+$,5/2$^+$. |
| 2413.51 *24* | 11/2$^-$,13/2$^-$ | 0.62 ps *+35−21* | $J^\pi$: IAR: 9/2$^-$,11/2$^-$. |
| 2531.6 *3* | 11/2 | 0.9 ps *+5−3* | $J^\pi$: IAR: 7/2$^+$,9/2,11/2$^-$. |
| 2579.6 *3* | 5/2 | 0.55 ps *+35−14* | $J^\pi$: IAR: 3/2$^+$,5/2$^+$. |
| 2612.7 *3* | 5/2,7/2$^-$,9/2$^-$ | 0.090 ps *+21−14* | $J^\pi$: IAR: 1/2$^-$,7/2$^-$. |
| 2632.2 *3* | 9/2 | 0.125 ps *+35−21* | $J^\pi$: IAR: not (1/2$^-$ to 7/2$^-$). |
| 2792.56 *24* | 5/2,7/2 | | $J^\pi$: IAR: not (1/2$^-$,7/2$^-$,3/2,5/2). |
| 2881.8 *4* | | | |
| 2911.8 *3* | | | |
| 2969.9 *3* | | | |
| 2991.1 *4* | | | |
| 3028.2 *3* | | | |
| 3065.0 *4* | | | |
| 3126.02 *24* | | | |
| 3149.2 *3* | | | |
| 3179.3 *3* | | | |
| 3187.4 *3* | | | |
| 3273.5 *3* | | | |
| 3328.6 *3* | | | |
| 3434.4? *10* | | | |
| 3461.6? *10* | | | |
| 3559.9? *10* | | | |
| 3634.5 *6* | | | |
| 3697.2? *10* | | | |
| 3835.4 *6* | | | |
| 3886.3 *6* | | | |

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## $^{91}$Zr(p,nγ) 1973Ma02,1977Sc28 (continued)

### $^{91}$Nb Levels (continued)

| E(level)[†] |
|---|
| 3915.6 *10* |
| 4023.5 *10* |
| 4180.3 *8* |
| 4237.1 *10* |

[†] From least-squares fit to Eγ, assigning $\Delta E_\gamma$=1 keV to Eγ values for which the authors did not state the uncertainty.
[‡] From Hauser-Feshbach analysis of excitation functions (1973Ma02). Limits on $J^\pi$ deduced by the same authors from IAR neutron yields are given under comments.
[#] From DSA (1977Sc28). The uncertainty includes both the statistical error and 15% uncertainty in the stopping power.

### γ($^{91}$Nb)

| $E_i$(level) | $J_i^\pi$ | Eγ[†] | Iγ[‡] | $E_f$ | $J_f^\pi$ | Mult.[#] | δ[#] | Comments |
|---|---|---|---|---|---|---|---|---|
| 104.18 | 1/2⁻ | (104.18 *25*) | 100 | 0 | 9/2⁺ | | | Not observed in this experiment; Eγ from level energy difference. |
| 1186.76 | 5/2 | 1082.5 *3* | 100 | 104.18 | 1/2⁻ | | | |
| 1312.54 | 3/2⁻ | 1208.2 *3* | 100 | 104.18 | 1/2⁻ | D(+Q) | | δ: −2.5≤δ≤+0.15. $A_2$=+0.04 *3* (1977Sc28). |
| 1580.97 | 7/2⁺ | 1581.2 *3* | 100 | 0 | 9/2⁺ | | | |
| 1612.4 | 3/2⁻ | 425.6[&] | 0.8[a] *1* | 1186.76 | 5/2 | | | |
| | | 1508.1 *3* | 99.2[a] *1* | 104.18 | 1/2⁻ | | | $A_2$=+0.01 *3* (1977Sc28). |
| 1637.1 | 9/2⁺ | 1637.1 *3* | 100 | 0 | 9/2⁺ | | | |
| 1790.60 | 11/2⁻ | 603.7 *3* | 3.3 *5* | 1186.76 | 5/2 | | | |
| | | 1790.6 *3* | 96.7 *5* | 0 | 9/2⁺ | D(+Q) | −0.15 *15* | δ: −0.15 *15* or +1.10 *4*; larger solution improbable since level scheme implies Δπ=yes. $A_2$=+0.12 *4*; $A_4$=−0.02 *4* (1977Sc28). |
| 1844.7 | 5/2 | 657.9 *3* | 34.9 *25* | 1186.76 | 5/2 | | | |
| | | 1740.5 *3* | 65.1 *25* | 104.18 | 1/2⁻ | | | |
| 1963.3 | 5/2 | 1963.3 *3* | 100 | 0 | 9/2⁺ | | | |
| 1984.58 | 13/2,15/2 | 194.1 *3* | 49.0 *30* | 1790.60 | 11/2⁻ | | | |
| | | 1984.4 *3* | 51.0 *30* | 0 | 9/2⁺ | (M2+E3) | −0.15 *5* | $A_2$=+0.18 *4*; $A_4$=−0.13 *4* (1977Sc28). Mult.: from γ(θ) and level scheme. |
| 2120.84 | 5/2,7/2⁻ | 330.0 *3* | 42.3 *15* | 1790.60 | 11/2⁻ | | | δ(D,Q)=−0.25≤δ≤+0.2 or <−3 or >+10. $A_2$=−0.19 *4*; $A_4$=−0.01 *5* (1977Sc28). |
| | | 808.4 *3* | 9.0 *15* | 1312.54 | 3/2⁻ | | | |
| | | 934.1 *3* | 38.5 *15* | 1186.76 | 5/2 | | | δ: −0.04≤δ≤+0.3 or <−6 or >+33. $A_2$=0.00 *3*; $A_4$=0.00 *3* (1977Sc28). |
| | | 2120.8 *3* | 10.1 *15* | 0 | 9/2⁺ | | | |
| 2292.0 | 13/2,15/2 | 2292.0 *3* | 100 | 0 | 9/2⁺ | Q(+O) | −0.03 *7* | $A_2$=+0.30 *6*; $A_4$=−0.10 *8* (1977Sc28). |
| 2324.50 | 5/2,7/2⁻ | 743.5 *3* | 3.9 *15* | 1580.97 | 7/2⁺ | | | $E_\gamma$: corrected value (1973Ma02) for 741.8γ of 1971Ma47. |
| | | 1012.0 *3* | 45.1 *15* | 1312.54 | 3/2⁻ | | | |
| | | 1137.7 *3* | 51.0 *15* | 1186.76 | 5/2 | | | |
| 2330.2 | 11/2 | 2330.2 *3* | 100 | 0 | 9/2⁺ | M1+E2 | −10 *+3−27* | $A_2$=−0.14 *4*; $A_4$=+0.07 *3* (1977Sc28). Mult.: from γ(θ) and RUL. |
| 2345.1 | 3/2 | 732.6 *3* | 9.2 *15* | 1612.4 | 3/2⁻ | | | |
| | | 1032.6 *3* | 35.8 *15* | 1312.54 | 3/2⁻ | | | |
| | | 1158.3 *3* | 17.5 *15* | 1186.76 | 5/2 | | | |
| | | 2241.1 *3* | 37.4 *15* | 104.18 | 1/2⁻ | | | |
| 2389.8 | 3/2⁺,5/2 | 1203.1 *3* | 33.0 *20* | 1186.76 | 5/2 | | | |

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**$^{91}$Zr(p,nγ) 1973Ma02,1977Sc28 (continued)**

γ($^{91}$Nb) (continued)

| $E_i$(level) | $J_i^\pi$ | $E_\gamma$[†] | $I_\gamma$[‡] | $E_f$ | $J_f^\pi$ | Mult.[#] | δ[#] | Comments |
|---|---|---|---|---|---|---|---|---|
| 2389.8 | 3/2+,5/2 | 2285.6 *3* | 67.0 *20* | 104.18 | 1/2− | | | |
| 2413.51 | 11/2−,13/2− | 428.9 *3* | 33.0 *20* | 1984.58 | 13/2,15/2 | M1+E2 | | Mult.,δ: −0.27≤δ≤−0.14 or −4.8≤δ≤−3; E1+M2 excluded by RUL, even for the smallest of these δ values. $A_2$=+0.09 *5*; $A_4$=−0.02 *4* (1977Sc28). |
| | | 2413.5 *3* | 67.0 *20* | 0 | 9/2+ | D(+Q) | 0.00 *4* | $A_2$=−0.19 *4*; $A_4$=−0.03 *4* (1977Sc28). |
| 2531.6 | 11/2 | 410.4[&] | 12.5 *20* | 2120.84 | 5/2,7/2− | | | |
| | | 2531.6 *3* | 87.5 *20* | 0 | 9/2+ | D+Q | +0.22 *3* | $A_2$=+0.07 *4*; $A_4$=0.00 *4* (1977Sc28). |
| 2579.6 | 5/2 | 998.6 *3* | 31.8 *18* | 1580.97 | 7/2+ | | | |
| | | 1267.0 *3* | 68.2 *18* | 1312.54 | 3/2− | | | |
| | | 2578.8[@] | | 0 | 9/2+ | | | I(2579γ):I(1267γ):I(999γ)=3.0:16.9:5.0 (1971Ma48). |
| 2612.7 | 5/2,7/2−,9/2− | 2612.7 *3* | 100 | 0 | 9/2+ | | | |
| 2632.2 | 9/2 | 1051.5[&d] | 4.2 *20* | 1580.97 | 7/2+ | | | |
| | | 2632.1 *3* | 95.8 *20* | 0 | 9/2+ | | | $A_2$=−0.08 *4*; $A_4$=0.00 *4* (1977Sc28). |
| 2792.56 | 5/2,7/2 | 1605.8 *3* | 45[b] | 1186.76 | 5/2 | | | |
| | | 2792.5 *3* | 55[b] | 0 | 9/2+ | | | |
| 2881.8 | | 1569.2 *3* | 100 | 1312.54 | 3/2− | | | |
| 2911.8 | | 2911.7 *3* | 100 | 0 | 9/2+ | | | |
| 2969.9 | | 2969.8 *3* | 100 | 0 | 9/2+ | | | |
| 2991.1 | | 1804.4 *3* | 100 | 1186.76 | 5/2 | | | |
| 3028.2 | | 3028.1 *3* | 100 | 0 | 9/2+ | | | |
| 3065.0 | | 1273.7[@] | 33[c] | 1790.60 | 11/2− | | | |
| | | 2960.8 *3* | 67[c] | 104.18 | 1/2− | | | |
| 3126.02 | | 1545.4 *3* | 34[b] | 1580.97 | 7/2+ | | | |
| | | 3125.6 *3* | 66[b] | 0 | 9/2+ | | | |
| 3149.2 | | 3149.1 *3* | 100 | 0 | 9/2+ | | | |
| 3179.3 | | 1866.6 *3* | 39[b] | 1312.54 | 3/2− | | | |
| | | 3075.3 *3* | 61[b] | 104.18 | 1/2− | | | |
| 3187.4 | | 3187.3 *3* | 100 | 0 | 9/2+ | | | |
| 3273.5 | | 3273.4 *3* | 100 | 0 | 9/2+ | | | |
| 3328.6 | | 3328.6 *3* | 100 | 0 | 9/2+ | | | |
| 3434.4? | | 3434.3[@d] | 100 | 0 | 9/2+ | | | |
| 3461.6? | | 3461.5[@d] | 100 | 0 | 9/2+ | | | |
| 3559.9? | | 3559.8[@d] | 100 | 0 | 9/2+ | | | |
| 3634.5 | | 1309.9[@] | 54[c] | 2324.50 | 5/2,7/2− | | | |
| | | 2320.5[@] | | 1312.54 | 3/2− | | | |
| | | 3636.0[@] | 45[c] | 0 | 9/2+ | | | |
| 3697.2? | | 3697.1[@d] | 100 | 0 | 9/2+ | | | |
| 3835.4 | | 1991.3[@] | | 1844.7 | 5/2 | | | |
| | | 2253.1[@] | 53[c] | 1580.97 | 7/2+ | | | |
| | | 3836.1[@] | 46[c] | 0 | 9/2+ | | | |
| 3886.3 | | 558.7[@] | | 3328.6 | | | | |
| | | 1764.4[@] | 17[c] | 2120.84 | 5/2,7/2− | | | |
| | | 3886.3[@] | 82[c] | 0 | 9/2+ | | | |
| 3915.6 | | 3915.5[@] | 100 | 0 | 9/2+ | | | |
| 4023.5 | | 4023.4[@] | 100 | 0 | 9/2+ | | | |
| 4180.3 | | 1189.8[@] | | 2991.1 | | | | |

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## $^{91}$Zr(p,nγ) 1973Ma02,1977Sc28 (continued)

### γ($^{91}$Nb) (continued)

| $E_i$(level) | $J^\pi_i$ | $E_\gamma$[†] | $I_\gamma$[‡] | $E_f$ | $J^\pi_f$ | Comments |
|---|---|---|---|---|---|---|
| 4180.3 | | 4179.6[@] | | 0 | 9/2$^+$ | |
| 4237.1 | | 4237.0[@] | 100 | 0 | 9/2$^+$ | Observed for E(p)=8.0 MeV only. |

[†] From 1973Ma02 when available; $\Delta E_\gamma$ is from 1971Ma47. 1977Sc28 determined Eγ only for lines which were not measured by 1973Ma02. The energy calibration of 1977Sc28 was based on the energies of adjacent peaks known from 1973Ma02; no uncertainties are given by 1977Sc28.

[‡] Branchings for each level at θ=55° as determined by 1977Sc28. Data of 1973Ma02 essentially support these results. Relative intensities at 90° for E(p)=6.3 MeV are reported by 1971Ma48.

[#] From γ(θ) (1977Sc28).

[@] From 1971Ma48. $\Delta E_\gamma$ unstated by authors; however, authors quote E(level) to ±1 keV.

[&] From 1977Sc28. No $\Delta E_\gamma$ given by authors.

[a] 1977Sc28 give 99% and 1% in their fig.3, 99.7% and 0.8% in table 3 for the 1509γ and 426γ, respectively. The evaluator assumes that 99.7% is a misprint (since branching would not sum to 100% in that case).

[b] From 1973Ma02. Uncertainty not given by the authors.

[c] From Iγ(90°) in 1971Ma48; reliability of value depends on the anisotropy of the γ (possibly 5% to 10% (1971Ma48)). Note that branchings implied by Iγ(90°) data are in only fair to poor agreement with branching data from 1973Ma02 and 1977Sc28, where comparisons are possible.

[d] Placement of transition in the level scheme is uncertain.

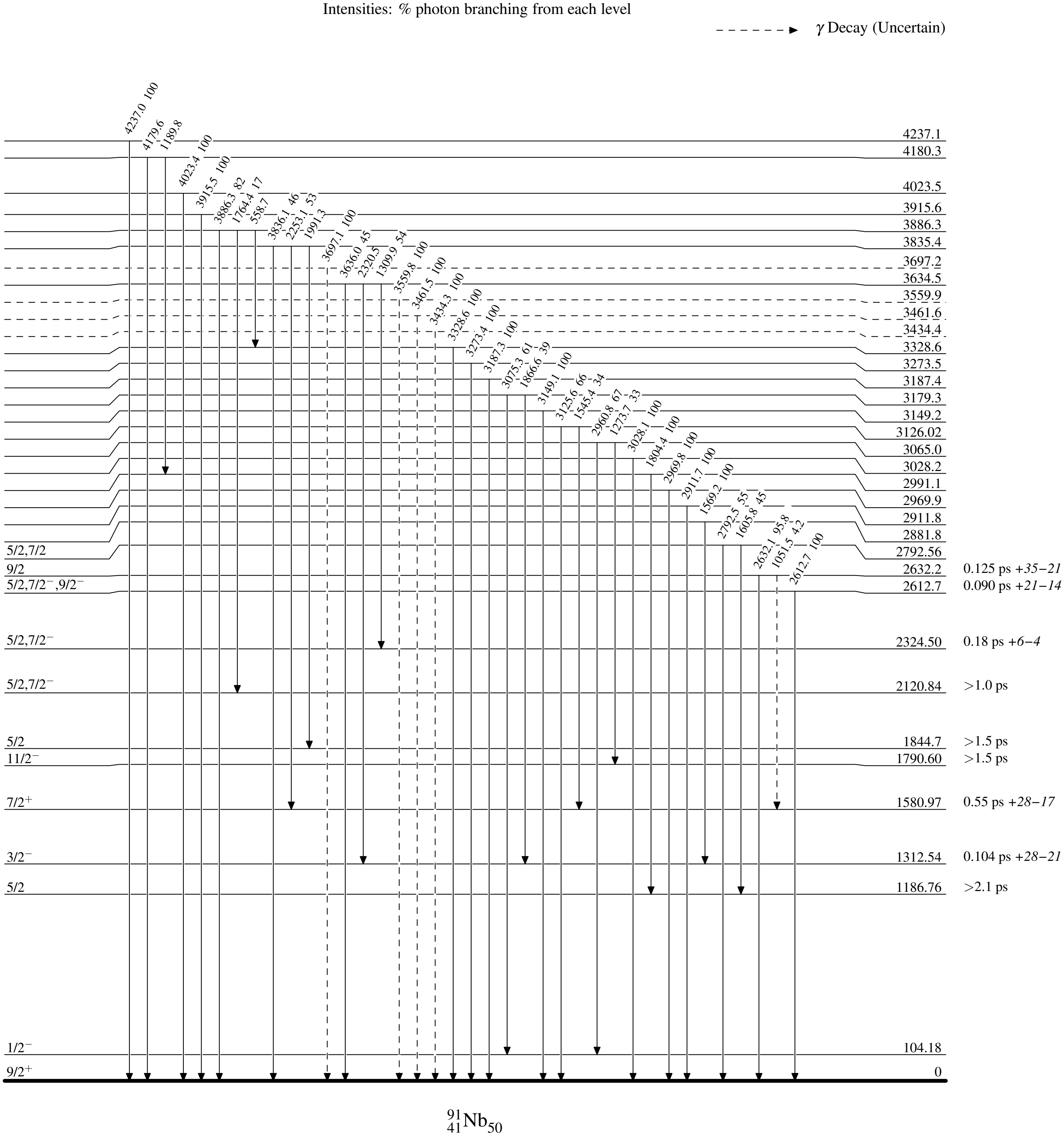
[x] γ ray not placed in level scheme.

## $^{91}Zr(p,n\gamma)$ 1973Ma02,1977Sc28

Legend

### Level Scheme

Intensities: % photon branching from each level



Legend

**$^{91}$Zr(p,nγ) 1973Ma02,1977Sc28**

Level Scheme (continued)

Intensities: % photon branching from each level

γ Decay (Uncertain)
Coincidence