

**$^{63}\text{Cu}(\text{p},\text{p}'\gamma)$  1978Ha27,1977Pa15**

| Type            | Author   | History<br>Citation | Literature Cutoff Date |
|-----------------|----------|---------------------|------------------------|
| Full Evaluation | Jun Chen | NDS 196,17 (2024)   | 30-Sep-2023            |

**1978Ha27:** E=4.2, 5.0, 6.0 MeV proton beams were produced from the the University of Pennsylvania EN Tandem Van de Graaff Accelerator. Target was 3.7 mg/cm<sup>2</sup> 99.7% enriched  $^{63}\text{Cu}$ .  $\gamma$  rays were detected with Ge(Li) and NaI(Tl) detectors. Measured  $E_\gamma$ ,  $I_\gamma$ . Deduced levels,  $\gamma$ -ray branching ratios. Comparisons with available data.

**1977Pa15:** E=5 MeV proton beam was produced from the high intensity T11/25 tandem Van de Graaff accelerator of the Nuclear Research Centre, Demokritos. Target was 3.8 mg/cm<sup>2</sup> 99.7% enriched  $^{63}\text{Cu}$ .  $\gamma$  rays were detected with Ge(Li) detectors. Measured  $E_\gamma$ ,  $I_\gamma$ ,  $\gamma(\theta)$ , Doppler-shift attenuation. Deduced levels, J,  $\pi$ ,  $T_{1/2}$ .  $\gamma$ -ray multipolarities, mixing ratios, transition strengths. Comparisons with available data.

Others: [1974Wi15](#), [1968Sm07](#).

 $^{63}\text{Cu}$  Levels

| E(level) <sup>†</sup> | J <sup>π</sup> <sup>‡</sup>         | T <sub>1/2</sub> <sup>#</sup> | E(level) <sup>†</sup> | J <sup>π</sup> <sup>‡</sup>            | T <sub>1/2</sub> <sup>#</sup> |
|-----------------------|-------------------------------------|-------------------------------|-----------------------|----------------------------------------|-------------------------------|
| 0.0                   | 3/2 <sup>-</sup>                    |                               | 2336.6 5              | 5/2 <sup>-</sup>                       | 0.35 ps +12-7                 |
| 669.7 4               | 1/2 <sup>-</sup>                    |                               | 2404.9 4              | 7/2 <sup>-</sup>                       | 125 fs +37-21                 |
| 962.2 3               | 5/2 <sup>-</sup>                    |                               | 2497.2 8              | 3/2 <sup>-</sup> , (5/2 <sup>-</sup> ) | 101 fs +23-18                 |
| 1326.8 4              | 7/2 <sup>-</sup>                    | 0.51 ps +14-10                | 2512.1 10             | 1/2, 3/2, 5/2 <sup>-</sup>             | 0.15 ps +5-3                  |
| 1412.1 5              | 5/2 <sup>-</sup>                    | >0.5 ps                       | 2535.8 5              | 5/2 <sup>-</sup>                       | 0.33 ps +18-8                 |
| 1547.1 4              | 3/2 <sup>-</sup>                    | 97 fs +22-18                  | 2696.6 7              | 1/2, 3/2, 5/2 <sup>-</sup>             | 0.18 ps +10-5                 |
| 1861.3 6              | 7/2 <sup>-</sup>                    | 0.53 ps +14-9                 | 2716.7 5              | 3/2 <sup>-</sup> , 5/2 <sup>-</sup>    | >0.22 ps                      |
| 2011.3 6              | 3/2 <sup>-</sup>                    | 32 fs +7-5                    | 2780.5 7              | 3/2 <sup>-</sup> , 5/2 <sup>-</sup>    | 46 fs +17-11                  |
| 2062.1 7              | 1/2 <sup>-</sup> , 3/2 <sup>-</sup> | 0.30 ps +10-5                 | 2806.2 8              | 3/2 <sup>-</sup> , 5/2                 | >0.19 ps                      |
| 2081.5 6              | 5/2 <sup>-</sup>                    | 115 fs +26-13                 | 2857.8 6              |                                        |                               |
| 2092.7 5              | 7/2 <sup>-</sup>                    | 0.37 ps +11-6                 | 2889.5 6              |                                        |                               |
| 2207.7 4              | 9/2 <sup>-</sup>                    | 0.31 ps +10-5                 |                       |                                        |                               |

<sup>†</sup> From [1978Ha27](#) which utilized level energies from  $^{63}\text{Zn}$   $\varepsilon$  decay ([1974K102](#)), except for the 2208- and 2405-keV levels which are from  $E_\gamma$  data measured by [1978Ha27](#).

<sup>‡</sup> As given in [1977Pa15](#), based on measured  $\gamma(\theta)$ , known assignments of low-lying levels,  $\gamma$ -decay patterns.

<sup>#</sup> From DSAM in [1977Pa15](#).

 $\gamma(^{63}\text{Cu})$ 

| E <sub>i</sub> (level) | J <sub>i</sub> <sup>π</sup>         | E <sub>γ</sub> <sup>†</sup> | I <sub>γ</sub> <sup>†</sup> | E <sub>f</sub> | J <sub>f</sub> <sup>π</sup> | Mult. <sup>‡</sup> | δ <sup>‡</sup>                | Comments                     |
|------------------------|-------------------------------------|-----------------------------|-----------------------------|----------------|-----------------------------|--------------------|-------------------------------|------------------------------|
| 669.7                  | 1/2 <sup>-</sup>                    | 669.6                       | 100                         | 0.0            | 3/2 <sup>-</sup>            |                    |                               |                              |
| 962.2                  | 5/2 <sup>-</sup>                    | 962.1                       | 100                         | 0.0            | 3/2 <sup>-</sup>            |                    |                               |                              |
| 1326.8                 | 7/2 <sup>-</sup>                    | 365.0                       | 15.8 4                      | 962.2          | 5/2 <sup>-</sup>            | M1+E2              | -0.10 <sup>&amp;</sup> +3-5   |                              |
|                        |                                     | 1327.0                      | 84.2 4                      | 0.0            | 3/2 <sup>-</sup>            | E2(+M3)            | -0.017 <sup>&amp;</sup> 52    |                              |
| 1412.1                 | 5/2 <sup>-</sup>                    | 449.9                       | 22.0 10                     | 962.2          | 5/2 <sup>-</sup>            | D(+Q)              | +0.09 <sup>&amp;</sup> +49-23 |                              |
|                        |                                     | 742.4                       | 5.8 3                       | 669.7          | 1/2 <sup>-</sup>            | E2                 |                               | δ: -6.3≤δ≤0.2.               |
|                        |                                     | 1412.0                      | 72.2 12                     | 0.0            | 3/2 <sup>-</sup>            | D+Q                |                               | δ: +0.62 +5-7 or +3.5 +12-8. |
| 1547.1                 | 3/2 <sup>-</sup>                    | 585.0                       | 17.7 4                      | 962.2          | 5/2 <sup>-</sup>            | D(+Q)              | +0.17 <sup>&amp;</sup> +16-17 |                              |
|                        |                                     | 877.4                       | 2.1 2                       | 669.7          | 1/2 <sup>-</sup>            | D(+Q)              | -0.6 +7-16                    |                              |
|                        |                                     | 1547.0                      | 80.2 5                      | 0.0            | 3/2 <sup>-</sup>            | D(+Q)              | +0.05 <sup>&amp;</sup> +6-8   |                              |
| 1861.3                 | 7/2 <sup>-</sup>                    | 899.1                       | 42.7 21                     | 962.2          | 5/2 <sup>-</sup>            | M1+E2              |                               | δ: +0.05 +3-2 or -5.1 +9-16. |
|                        |                                     | 1861.2                      | 57.3 21                     | 0.0            | 3/2 <sup>-</sup>            | E2(+M3)            | +0.07 +7-5                    |                              |
| 2011.3                 | 3/2 <sup>-</sup>                    | 1049.2                      | 30.7 18                     | 962.2          | 5/2 <sup>-</sup>            | D(+Q)              | ≤+0.36                        |                              |
|                        |                                     | 1341.6                      | 13.5 18                     | 669.7          | 1/2 <sup>-</sup>            | D(+Q)              | -0.6 +7-16                    |                              |
|                        |                                     | 2011.2                      | 55.8 21                     | 0.0            | 3/2 <sup>-</sup>            | D(+Q)              |                               | δ: 0.00 +34-30 or >1.4.      |
| 2062.1                 | 1/2 <sup>-</sup> , 3/2 <sup>-</sup> | 515.1                       | 30 5                        | 1547.1         | 3/2 <sup>-</sup>            |                    |                               |                              |

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$^{63}\text{Cu}(\text{p},\text{p}'\gamma)$  **1978Ha27,1977Pa15** (continued) $\gamma(^{63}\text{Cu})$  (continued)

| $E_i(\text{level})$ | $J_i^\pi$         | $E_\gamma^\dagger$ | $I_\gamma^\dagger$ | $E_f$  | $J_f^\pi$ | Mult. $^\ddagger$ | $\delta^\ddagger$ | Comments                                                     |
|---------------------|-------------------|--------------------|--------------------|--------|-----------|-------------------|-------------------|--------------------------------------------------------------|
| 2062.1              | $1/2^-, 3/2^-$    | 1392.2             | 49.6 35            | 669.7  | $1/2^-$   | D(+Q)             |                   | $\delta$ : $\delta=+0.49 +\infty-19$ for $J=3/2$ (1977Pa15). |
|                     |                   | 2062.2             | 20.4 18            | 0.0    | $3/2^-$   |                   |                   |                                                              |
| 2081.5              | $5/2^-$           | 534.4              | 8.3 9              | 1547.1 | $3/2^-$   | M1+E2             | $+0.23^\& +13-11$ |                                                              |
|                     |                   | 754.4              | 33.6 27            | 1326.8 | $7/2^-$   | D(+Q)             | $0.4^\& +5-4$     |                                                              |
|                     |                   | 1119.4             | 19.2 15            | 962.2  | $5/2^-$   | M1+E2             |                   | $\delta$ : $-0.41 +31-46$ or $>2.2$ .                        |
|                     |                   | 2081.5             | 38.9 22            | 0.0    | $3/2^-$   | D(+Q)             |                   | $\delta$ : $+0.03 +11-10$ or $-3.7 +10-34$ .                 |
| 2092.7              | $7/2^-$           | 765.6              | 42.8 18            | 1326.8 | $7/2^-$   | D(+Q)             |                   | $\delta$ : $-0.10 19$ or $+1.28 +68-50$ .                    |
|                     |                   | 1130.7             | 47.5 18            | 962.2  | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 2092.7             | 9.7 8              | 0.0    | $3/2^-$   | E2(+M3)           | $+0.10 22$        |                                                              |
| 2207.7              | $9/2^-$           | 881.0 1            | 57.2 20            | 1326.8 | $7/2^-$   | M1+E2             |                   | $\delta$ : $-0.24 +6-8$ or $-2.0 4$ .                        |
|                     |                   | 1245.2 2           | 42.8 20            | 962.2  | $5/2^-$   | E2(+M3)           | $-0.01 +4-5$      |                                                              |
| 2336.6              | $5/2^-$           | 243.8              | 4.1 <sup>#</sup>   | 2092.7 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 475.3              | 4.4 <sup>#</sup>   | 1861.3 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 924.5              | 6.4 11             | 1412.1 | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 1374.4             | 24.9 16            | 962.2  | $5/2^-$   | D(+Q)             |                   | $\delta$ : $+0.08 +45-26$ or $+1.43 +117-85$ .               |
|                     |                   | 2336.5             | 60.2 23            | 0.0    | $3/2^-$   | D+Q               |                   | $\delta$ : $0.00 9$ or $-3.6 +10-15$ .                       |
| 2404.9              | $7/2^-$           | 992.8              | 20.4 <sup>@</sup>  | 1412.1 | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 1077.8 2           | 30.7 22            | 1326.8 | $7/2^-$   | D+Q               |                   | $\delta$ : $+0.07 +29-19$ or $+0.92 41$ .                    |
|                     |                   | 1442.7 1           | 45.1 25            | 962.2  | $5/2^-$   | M1+E2             |                   | $\delta$ : $-0.24 6$ or $-2.0 +5-6$ .                        |
|                     |                   | 2404.8             | 3.8 12             | 0.0    | $3/2^-$   | E2                |                   |                                                              |
| 2497.2              | $3/2^-, (5/2^-)$  | 1827.5             | 16.7 20            | 669.7  | $1/2^-$   | D(+Q)             |                   | $\delta$ : $-7.1 \leq \delta \leq +0.4$ .                    |
|                     |                   | 2497.1             | 83.3 20            | 0.0    | $3/2^-$   | D(+Q)             |                   | $\delta$ : $-0.14 +43-51$ or E2.                             |
| 2512.1              | $1/2, 3/2, 5/2^-$ | 2512.0             | 100                | 0.0    | $3/2^-$   |                   |                   |                                                              |
| 2535.8              | $5/2^-$           | 443.1              | 6.3 <sup>#</sup>   | 2092.7 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 674.5              | 5.7 <sup>#</sup>   | 1861.3 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 988.8              | 1.5 <sup>#</sup>   | 1547.1 | $3/2^-$   |                   |                   |                                                              |
|                     |                   | 1123.8             | 37.2 19            | 1412.1 | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 1208.8             | 4.7 <sup>#</sup>   | 1326.8 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 1573.7             | 8.8 12             | 962.2  | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 1866.2             | 7.5 <sup>#</sup>   | 669.7  | $1/2^-$   |                   |                   |                                                              |
|                     |                   | 2535.8             | 28.3 16            | 0.0    | $3/2^-$   | D+Q               |                   | $\delta$ : $-0.05 +24-42$ or $-3 +2-26$ .                    |
| 2696.6              | $1/2, 3/2, 5/2^-$ | 1149.5             | 25 6               | 1547.1 | $3/2^-$   |                   |                   |                                                              |
|                     |                   | 2026.9             | 42 4               | 669.7  | $1/2^-$   |                   |                   |                                                              |
|                     |                   | 2696.5             | 32.4 31            | 0.0    | $3/2^-$   |                   |                   |                                                              |
| 2716.7              | $3/2^-, 5/2^-$    | 624.0              | 16.3 <sup>#</sup>  | 2092.7 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 1169.7             | 6.4 27             | 1547.1 | $3/2^-$   |                   |                   |                                                              |
|                     |                   | 1389.7             | 52.8 35            | 1326.8 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 1754.6             | 4.7 13             | 962.2  | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 2047.1             | 3.9 11             | 669.7  | $1/2^-$   |                   |                   |                                                              |
|                     |                   | 2716.7             | 15.8 18            | 0.0    | $3/2^-$   |                   |                   |                                                              |
| 2780.5              | $3/2^-, 5/2^-$    | 1233.4             | 12.8 23            | 1547.1 | $3/2^-$   |                   |                   |                                                              |
|                     |                   | 2110.8             | 29.0 20            | 669.7  | $1/2^-$   |                   |                   |                                                              |
|                     |                   | 2780.4             | 58.2 24            | 0.0    | $3/2^-$   |                   |                   |                                                              |
| 2806.2              | $3/2^-, 5/2$      | 1479.3             | 33 3               | 1326.8 | $7/2^-$   |                   |                   |                                                              |
|                     |                   | 2806.3             | 67 3               | 0.0    | $3/2^-$   |                   |                   |                                                              |
| 2857.8              |                   | 1445.7             | 30 <sup>#</sup>    | 1412.1 | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 1895.6             | 11 5               | 962.2  | $5/2^-$   |                   |                   |                                                              |
|                     |                   | 2188.1             | 23 4               | 669.7  | $1/2^-$   |                   |                   |                                                              |
|                     |                   | 2857.7             | 36 5               | 0.0    | $3/2^-$   |                   |                   |                                                              |
| 2889.5              |                   | 1927.4             | 58 5               | 962.2  | $5/2^-$   |                   |                   |                                                              |

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$^{63}\text{Cu}(\text{p},\text{p}'\gamma)$     [1978Ha27,1977Pa15](#) (continued) $\gamma(^{63}\text{Cu})$  (continued)

| <u><math>E_i(\text{level})</math></u> | <u><math>J_i^\pi</math></u> | <u><math>E_\gamma</math> <sup>†</sup></u> | <u><math>I_\gamma</math> <sup>†</sup></u> | <u><math>E_f</math></u> | <u><math>J_f^\pi</math></u> |
|---------------------------------------|-----------------------------|-------------------------------------------|-------------------------------------------|-------------------------|-----------------------------|
| 2889.5                                |                             | 2219.8                                    | 26 <sup>#</sup>                           | 669.7                   | 1/2 <sup>-</sup>            |
|                                       |                             | 2889.4                                    | 16 3                                      | 0.0                     | 3/2 <sup>-</sup>            |

<sup>†</sup> From [1978Ha27](#), unless otherwise noted. Intensities are % photon branching from each level.

<sup>‡</sup> From  $\gamma(\theta)$  in [1977Pa15](#), with magnetic and electric characters determined based on RUL and measured  $T_{1/2}$  where available, unless otherwise noted.

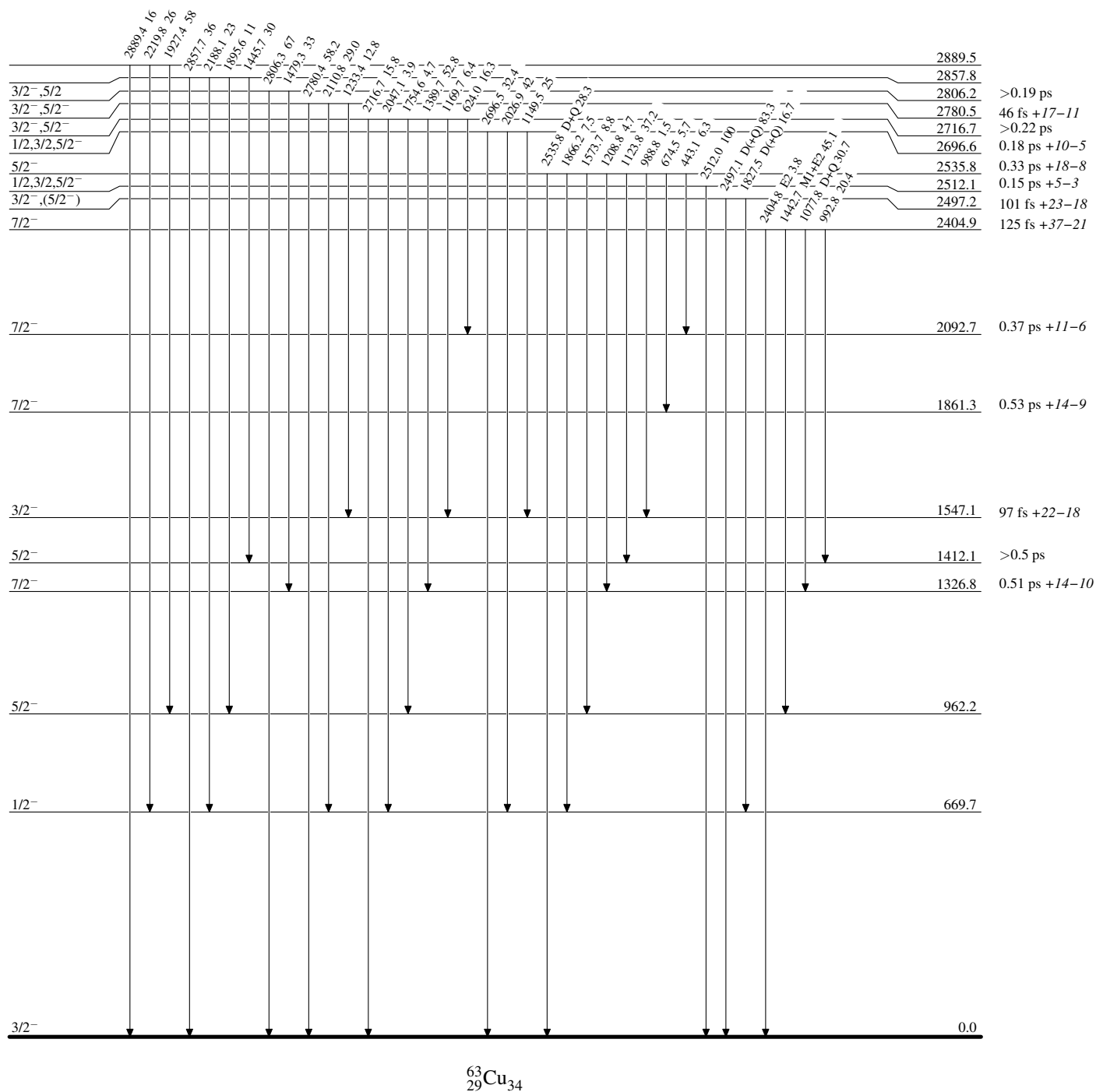
<sup>#</sup> Branching obtained by normalization on the basis of missing branches, seen in  $^{63}\text{Zn}$   $\varepsilon$  decay ([1978Ha27](#)).

<sup>@</sup> Branching obtained in [1978Ha27](#) by normalization to the value of  $(\alpha, \text{p}\gamma)$  in [1976Da01](#).

<sup>&</sup> Another  $\delta$  value from  $\gamma(\theta)$  analysis is omitted since it leads to unrealistic reduced transition probability ([1977Pa15](#)).

**$^{63}\text{Cu}(p,p'\gamma)$  1978Ha27,1977Pa15****Level Scheme**

Intensities: % photon branching from each level



$^{63}\text{Cu}(\text{p}, \text{p}'\gamma)$  1978Ha27, 1977Pa15

## Level Scheme (continued)

Intensities: % photon branching from each level

