

64Cu - Comments on evaluation of decay data
by R. G. Helmer

1 Decay Scheme

The only levels in 64Zn and 64Ni below the decay energies are those populated in this decay, so the decay scheme is complete.

The J^\pi values and half-lives for the excited levels are from Adopted Levels in Nuclear Data Sheets (1996Si12).

The decay scheme for the electron capture to 64Ni is consistent since the sum of the average energies of all of the radiations, as computed by RADLST, is 1020 (10) keV compared to the value of 1020 (8) from the Q_e value and the branching fraction.

2 Nuclear Data

Q values from 1995Au04 are for \beta^- decay 578.7 (9) and for e decay 1675.10 (20) keV.

The change in the half-life as a function of the chemical form or electron environment has been studied by several authors. These results are tallied after those used for the half-live evaluation.

The half-life values considered are, in hours:

<table>
<thead>
<tr>
<th>Hour</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>(1935Am01) omitted, no uncertainty</td>
</tr>
<tr>
<td>12.8 (1)</td>
<td>(1936Va02)</td>
</tr>
<tr>
<td>12.5</td>
<td>(1937He05) omitted, no uncertainty</td>
</tr>
<tr>
<td>12.8 (3)</td>
<td>(1938Ri ) as cited in 1968Ke12</td>
</tr>
<tr>
<td>12.8 (3)</td>
<td>(1939Sa02) as cited in 1968Ke12</td>
</tr>
<tr>
<td>11.9 (10)</td>
<td>(1943Hu03)</td>
</tr>
<tr>
<td>11.9 (10)</td>
<td>(1944Hu05) omitted, same data as 1943Hu03</td>
</tr>
<tr>
<td>12.80 (4)</td>
<td>(1950Ra62) as cited in 1968Ke12</td>
</tr>
<tr>
<td>12.74 (7)</td>
<td>(1951Sc56)</td>
</tr>
<tr>
<td>12.88 (3)</td>
<td>(1951Si91)</td>
</tr>
<tr>
<td>12.80 (3)</td>
<td>(1955To07) as cited in 1968Ke12</td>
</tr>
<tr>
<td>12.90 (6)</td>
<td>Rudstam as cited in 1968Ke12</td>
</tr>
<tr>
<td>12.87 (5)</td>
<td>(1957Wr37) superseded by 1972Em01</td>
</tr>
<tr>
<td>12.85 (5)</td>
<td>(1959Po64)</td>
</tr>
<tr>
<td>13.9</td>
<td>(1965He08) omitted, no uncertainty</td>
</tr>
<tr>
<td>12.86 (3)</td>
<td>(1965Pa18)</td>
</tr>
<tr>
<td>12.70 (3)</td>
<td>(1966Fu14)</td>
</tr>
<tr>
<td>12.86 (3)</td>
<td>(1966Li09)</td>
</tr>
</tbody>
</table>
The set of 23 unsuperseded values with uncertainties is inconsistent. The unweighted average is 12.73 (4) hours and the weighted average is 12.7029 with an internal uncertainty of 0.0015, a reduced-$\chi^2$ of 6.8, and an external uncertainty of 0.0039. It has been suggested that many of the older measurements give longer half-lives due to the presence of unidentified impurities. The value of 12.699 (2) given by 1973De56, and used here, differs slightly from the weighted average of 12.6973 (16) computed by the evaluator for their 22 measured values. The input value of 12.715 (7) is the evaluator's weighted average of the three values given in the paper of 1972Em01.

The adopted half-life was taken from the weighted average of the 6 values (those from 1968He20, 1972Em01, 1972MeZM, 1973De56, 1974Ry01, and 1980RuZY) with uncertainties less than 0.03 hours. This average is 12.7007 with internal and external uncertainties of 0.0015 and a reduced-$\chi^2$ of 1.04. As noted below, changes in this half-life of the order of 1 part in $10^4$ have been reported depending on the chemical form. Since these changes are comparable to the calculated uncertainty, the adopted uncertainty has been increased to 0.002.

This half-life has been measured, and reported, many times primarily to identify the radionuclide observed, for example, in the process of cross section measurements. Some of these values, which are not included above are: 13 (1948Mi12); 12.8 (1950Ho26); and 13.8 (14), 13.6 (7), and 12.4 (17) (1972Cr02).

Since $^{64}$Cu decays, in part, by electron capture, there have been several measurements of the variation in the decay constant with the chemical form or atomic environment. The results from 1968 to 1975 are tallied in 1976Ha66 and given in the following table.

<table>
<thead>
<tr>
<th>Reference and first author</th>
<th>Forms compared</th>
<th>$\Delta\lambda/\lambda \cdot 10^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972Au</td>
<td>Cu phtalocyanine in two forms</td>
<td>10.0 (16)</td>
</tr>
<tr>
<td>Auric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1972Em01</td>
<td>Cu metal</td>
<td>15 (15)</td>
</tr>
<tr>
<td>Emery</td>
<td>Cu(NO$_3$)$_2$</td>
<td></td>
</tr>
<tr>
<td>Reference and first author</td>
<td>Forms compared</td>
<td>$\Delta \lambda / \lambda \cdot 10^4$</td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>1973Ha60 Harbottle</td>
<td>Cu metal CuO</td>
<td>0 (3)</td>
</tr>
<tr>
<td>1973De56 Dema</td>
<td>Cu phtalocyanine in two forms</td>
<td>0.4 (20)</td>
</tr>
<tr>
<td>1974Je Jenschke</td>
<td>Cu metal Cu(H$_2$O)$_6$SO$_4$</td>
<td>1.12 (9)</td>
</tr>
<tr>
<td></td>
<td>Cu metal Cu(H$_2$O)$_6$(NO$_3$)$_2$</td>
<td>0.81 (10)</td>
</tr>
<tr>
<td></td>
<td>Cu metal Cu(2)</td>
<td>2.94</td>
</tr>
<tr>
<td></td>
<td>Cu metal Cu(3)</td>
<td>1.86</td>
</tr>
<tr>
<td>1974Jo17 Johnson</td>
<td>Cu phtalocyanine in two forms</td>
<td>1.4 (23)</td>
</tr>
<tr>
<td></td>
<td>Cu phtalocyanine in two forms</td>
<td>3.7(58)</td>
</tr>
<tr>
<td></td>
<td>Cu metal CuO</td>
<td>0.0 (23)</td>
</tr>
<tr>
<td>1975MaXN</td>
<td>Cu metal Cu$_2$S</td>
<td>2.3 (10)</td>
</tr>
<tr>
<td></td>
<td>Cu metal CuInS$_2$</td>
<td>1.5 (10)</td>
</tr>
<tr>
<td></td>
<td>Cu metal Cu$_2$SnS$_3$</td>
<td>1.5 (10)</td>
</tr>
<tr>
<td></td>
<td>CuInS$_2$Cu$_2$SnS$_3$</td>
<td>0 (1)</td>
</tr>
<tr>
<td>1979Eh01 Ehrhart</td>
<td>Cu metal atom % Cu in Ag</td>
<td>1.7 (3)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.7 (3)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.6 (4)</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.9 (4)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.7 (5)</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.2 (4)</td>
</tr>
<tr>
<td>1979Ko31 Koran</td>
<td>Cu metal atom % Cu in Au</td>
<td>3.1 (4)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.1 (4)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3.0 (4)</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1.4 (4)</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.7 (5)</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>-0.2 (9)</td>
</tr>
</tbody>
</table>

The earliest measurements gave larger values of $\Delta \lambda / \lambda$, but the values beginning in 1973 range from 0 to 0.00037 (6). These values are similar in magnitude to the uncertainty of 1.5 parts in $10^4$ assigned to the adopted value. A set of measurements is also given in 1968Ke12, but the units of the results are not clear.

### 2.1 $\beta^-$ Transitions

See comments in section 2.3.

### 2.2 $\beta^+$ Transitions

See comments in section 2.3.
2.3 Electron Capture Transitions

The probabilities of the $\beta^-$, $\beta^+$, and $\epsilon$ branches have been determined by a series of separate, but partially correlated, measurements by 1983Ch47 and 1986Ka03. These measurements include the $\beta^-$ spectrum, the $\beta^+$ spectrum, $4p\beta-\gamma$ coincidences, liquid scintillation counting, and the $\gamma$-ray spectrum. The analysis of 1983Ch47 included a least-squares fit to the various measured quantities and ratios of quantities. Since over 90% of the decays are to the ground states of $^{64}\text{Ni}$ and $^{64}\text{Zn}$, this set of data provides very accurate results. The results are: $\%\epsilon = 43.1 (5)$ [from 43.10 (46) (1983Ch47) and 43.2 (5) (1986Ka03)], $\%\beta^- = 39.0 (3)$ [from 1986Ch47, other: 38.3 (6) (1986Ka03)], and $\%\beta^+ = 17.86 (14)$ [from 1986Ch47, other: 17.93 (20) (1986Ka03)].

A recent, and unpublished, determination of $\%\beta^-$ has been made by mass spectrometric measurements of the number of atoms of $^{64}\text{Ni}$ and $^{64}\text{Zn}$ produced in the decay of a $^{64}\text{Cu}$ sample (2002We). Their results is 38.06 (3). This result suggests that future evaluations may result in a small decrease in this value and the corresponding increase in $\%\epsilon$.

From $\beta^-$ and $\beta^+$ spectra, the ratio of their emission rates is 2.181 (6) (1986Ch47) and 2.138 (32) (1986Ka03). (Earlier and less precise measurements of these quantities are tallied in 1983Ch47.) The average particle energies to the $^{64}\text{Ni}$ and $^{64}\text{Zn}$ ground states are 278.21 (9) and 190.4 (4), respectively, and are from the LOGFT code. The log ft values to the $^{64}\text{Ni}$ ground state and 1345 level are 4.973 (3) and 5.506 (10), respectively, and to the $^{64}\text{Zn}$ ground state 5.294 (4), all of which are consistent with being allowed transitions from the $1^+$ parent.

2.4 Gamma Transitions

The $\gamma$-ray energy is 1345.77 (16) from 1974HeYW and its emission intensity is 0.475% (10), a weighted average of 0.471% (11) (1983Ch47) and 0.487 (20) (1986Ka03).

The $J^\pi$ assignments are from the Adopted Levels in the Nuclear Data Sheets (1996Si12) and these imply the $\gamma$-ray has E2 multipolarity. The internal-conversion coefficients were interpolated from the tables of Band et al. (1976Ba63) and are $\alpha_K = 0.000112$, $\alpha_L = 0.0000108$, and $\alpha_T = 0.000126$.

The internal-pair-formation coefficient was interpolated from the theoretical values (1979Sc31) and is IPFC(1345) = 0.000034.

3 Atomic Data

The data are from 1996Sc06.

3.1 and 3.2

None

4 Radiation Emissions

4.1 Electron Emissions

Auger electron emission intensities are deduced from the evaluated data set.
4.2 Photon Emissions

See section 2.4.
X-ray emission intensities are deduced from the evaluated data set.

5 Main production modes

They are taken from : Table de Radionucléides, F; Lagoutine, N. Coursol, J. Legrand. ISBN 2 7272 0078-1

6 References

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