Energy Levels of Light Nuclei
\[ A = 9 \]

F. Ajzenberg-Selove

*University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396*

**Abstract:** An evaluation of \( A = 5–10 \) was published in *Nuclear Physics A413* (1984), p. 1. This version of \( A = 9 \) differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and Introductory tables have been omitted from this manuscript. Also, Reference key numbers have been changed to the NNDC/TUNL format.

(References closed June 1, 1983)

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\( ^9n \)
(Not illustrated)

Not observed: see (1977DE08).

\( ^9\text{He} \)
(Not illustrated)

\(^9\text{He}\) has been observed in the \(^9\text{Be}(\pi^-, \pi^+)\) reaction at \(E_{\pi^-} = 194\) MeV; the atomic mass excess is \(40.81 \pm 0.12\) MeV. \(^9\text{He}\) is then unstable with respect to decay into \(^{8}\text{He} + n\) by 1.14 MeV (1981SE1B, 1980NA1D, 1980SE1C, 1980SE1F). See also (1979AJ01) and (1982PO1C; hypernuclei) and (1982NG01; theor.).

\( ^9\text{Li} \)
(Figs. 15 and 18)

GENERAL: (See also (1979AJ01).)

Model calculations: (1979LA06).


Muon and neutrino capture and reactions: (1980MU1B).

Reactions involving pions and other mesons (See also reaction 3.): (1978FU09, 1979BO21, 1979PE1C, 1979WI1E, 1980NI03, 1980ST15, 1981YA1A).


Other topics: (1979BE1H, 1979LA06, 1982NG01).

Ground-state properties of \(^9\text{Li}\): (1981AV02, 1982NG01).

\[ \mu = 3.4391 \pm 0.0006 \text{ nm} \text{: see (1983CO1Q).} \]

\[ Q = 0.88 \pm 0.18 Q(^7\text{Li}) \text{: see (1983CO1Q).} \]

1. \(^9\text{Li}(\beta^-)^9\text{Be} \quad Q_m = 13.606\)
Table 9.1: Energy levels of $^9$Li

<table>
<thead>
<tr>
<th>$E_x$ (MeV ± keV)</th>
<th>$J^\pi; T$</th>
<th>$\tau_{1/2}$ or $\Gamma_{c.m.}$ (keV)</th>
<th>Decay</th>
<th>Reactions a</th>
</tr>
</thead>
<tbody>
<tr>
<td>g.s.</td>
<td>$\frac{1}{2}^-$ : $\frac{3}{2}^-$</td>
<td>$\tau_{1/2} = 178.3 \pm 0.4$ msec</td>
<td>$\beta^-$</td>
<td>1, 2, 3, 4, 5, 6</td>
</tr>
<tr>
<td>2.691 ± 5</td>
<td>($\frac{1}{2}^-$)</td>
<td>$\Gamma = 100 \pm 30$</td>
<td>(γ)</td>
<td>2, 6</td>
</tr>
<tr>
<td>4.31 ± 20</td>
<td></td>
<td>600 ± 100</td>
<td></td>
<td>2, 6</td>
</tr>
<tr>
<td>5.38 ± 60</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>6.43 ± 15</td>
<td>$\geq \frac{9}{2}^-$</td>
<td>40 ± 20</td>
<td></td>
<td>2, 6</td>
</tr>
</tbody>
</table>

a For other reactions on which no new work is reported, see (1979AJ01).

The half-life of $^9$Li is $178.3 \pm 0.4$ msec (1976AL02). See also (1979AJ01). $^9$Li decays to a number of states in $^9$Be: see reaction 12 in $^9$Be and Table 9.7. The nature of the decay to $^9$Be*(0, 2.43) with $J^\pi = \frac{3}{2}^-$, $\frac{5}{2}^-$ is evidence for $J^\pi = \frac{3}{2}^-$ for $^9$Li g.s.. The probability for delayed neutron decay, $P_n$, is $(49.5 \pm 5\%)$ (1981LA11): see Table 9.7.

2. $^7$Li(t, p)$^9$Li

Protons are observed to excited states at $E_x = 2.691 \pm 0.005$ MeV (1964MI04), 4.31 ± 0.03, 5.38±0.06 and 6.41±0.02 MeV (1971YO04) [$\Gamma_{c.m.} = 250\pm30, 600\pm100, < 100$ keV], 4.31±0.02 and 6.435 ± 0.020 MeV (1978AJ02) [$\Gamma_{c.m.} = 100 \pm 30, 40 \pm 20$ keV]. Angular distributions are reported at $E_t = 11.3$ (1964MI04; t0), 15 MeV (1971YO04: t0, t2, t4) and at 23 MeV (1978AJ02: t0, t1, t2, t4). They are consistent with $J^\pi = \frac{3}{2}^-$, ($\frac{1}{2}^-$) and $\geq \frac{9}{2}$ for $^9$Li*(0, 2.69, 6.43) (1978AJ02). See also (1979AB11, 1980AB16, 1983AB1A, 1983CO11) and $^{10}$Be.

3. $^9$Be(γ, π+)$^9$Li

At $E_\gamma = 175, 187$ and 200 MeV, the cross section for production of $^9$Li g.s. at $\theta_\pi = 90^\circ$ has been measured by (1982TE01). See also (1979BO21, 1980NI03).

4. $^9$Be(n, p)$^9$Li

$Q_m = -12.824$

See (1981BR1K) and (1979AJ01).

5. $^9$Be($^7$Li, $^7$Be)$^9$Li

$Q_m = -14.468$

4
See (1982AL1G: $E(^7\text{Li}) = 78 \text{ MeV}$).

6. $^{11}\text{B} (^6\text{Li}, ^8\text{B})^9\text{Li}$

\[ Q_m = -25.121 \]

At $E(^6\text{Li}) = 80 \text{ MeV}$ the angular distribution to $^9\text{Li}_{g.s.}$ has been measured. States at $E_x = 2.59 \pm 0.10, 4.36 \pm 0.10$ and $6.38 \pm 0.12 \text{ MeV}$ are also populated (1977WE03, 1977WE1B).
GENERAL: (See also (1979AJ01).)


Table 9.2: Energy levels of $^9$Be

<table>
<thead>
<tr>
<th>$E_x$ (MeV ± keV)</th>
<th>$J^\pi; T$</th>
<th>$\Gamma_{c.m.}$ (keV)</th>
<th>Decay</th>
<th>Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>g.s.</td>
<td>$^3_2^-; \frac{1}{2}$</td>
<td>stable</td>
<td></td>
<td>2, 3, 4, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45</td>
</tr>
<tr>
<td>1.685 ± 15</td>
<td>$^1_2^+$</td>
<td>$\approx 150$</td>
<td>$\gamma$, n</td>
<td>9, 10, 13, 16, 18, 19, 21, 23, 24, 32, 33, 36, 40, 41</td>
</tr>
<tr>
<td>2.4294 ± 1.3</td>
<td>$^5_2^-$</td>
<td>$0.77 \pm 0.15$</td>
<td>$\gamma$, n, $\alpha$</td>
<td>9, 10, 12, 16, 17, 18, 19, 21, 22, 23, 24, 26, 32, 35, 36, 39, 40, 41, 42, 43</td>
</tr>
<tr>
<td>2.78 ± 120</td>
<td>$^1_2^-$</td>
<td>1080 ± 110</td>
<td>n</td>
<td>9, 12, 42</td>
</tr>
<tr>
<td>3.049 ± 9</td>
<td>$^5_2^+$</td>
<td>282 ± 11</td>
<td>$\gamma$, n</td>
<td>9, 13, 16, 18, 19, 20, 21, 23, 24, 32, 36, 39, 40, 41</td>
</tr>
<tr>
<td>4.704 ± 25</td>
<td>$(\frac{3}{2})^+$</td>
<td>743 ± 55</td>
<td>$\gamma$, n</td>
<td>9, 16, 19, 20, 21, 23, 24, 34, 40, 42</td>
</tr>
<tr>
<td>6.76 ± 60</td>
<td>$^7_2^-$</td>
<td>1540 ± 200</td>
<td>$\gamma$, n</td>
<td>9, 16, 17, 18, 19, 20, 21, 23, 24, 35, 41</td>
</tr>
<tr>
<td>7.94 ± 80</td>
<td>$(\frac{1}{2}^-)$</td>
<td>$\approx 1000$</td>
<td></td>
<td>12, 19</td>
</tr>
<tr>
<td>11.283 ± 24</td>
<td>$(\frac{3}{2}^-)$</td>
<td>575 ± 50</td>
<td>n</td>
<td>9, 12, 19, 24, 35, 36</td>
</tr>
<tr>
<td>11.81 ± 20</td>
<td>$T = \frac{1}{2}$</td>
<td>400 ± 30</td>
<td>$\gamma$, n</td>
<td>9, 13, 39, 42</td>
</tr>
<tr>
<td>13.79 ± 30</td>
<td>$T = \frac{1}{2}$</td>
<td>590 ± 60</td>
<td>$\gamma$, n</td>
<td>9, 16, 39</td>
</tr>
<tr>
<td>14.3929 ± 1.8</td>
<td>$^3_2^-; \frac{3}{2}^-$</td>
<td>$0.381 \pm 0.033$</td>
<td>$\gamma$, n, $\alpha$</td>
<td>9, 16, 23, 36, 39</td>
</tr>
<tr>
<td>14.4 ± 300</td>
<td></td>
<td>$\approx 800$</td>
<td></td>
<td>19, 36</td>
</tr>
<tr>
<td>15.10 ± 50</td>
<td></td>
<td></td>
<td>$\gamma$</td>
<td>16, 39</td>
</tr>
<tr>
<td>15.97 ± 30</td>
<td>$T = \frac{1}{2}$</td>
<td>$\approx 300$</td>
<td>$\gamma$</td>
<td>16, 39</td>
</tr>
<tr>
<td>16.671 ± 8</td>
<td></td>
<td>41 ± 4</td>
<td>$\gamma$</td>
<td>9, 16, 19, 36</td>
</tr>
</tbody>
</table>
Table 9.2: Energy levels of $^9$Be (continued)

<table>
<thead>
<tr>
<th>$E_x$ (MeV ± keV)</th>
<th>$J^\pi; T$</th>
<th>$\Gamma_{c.m.}$ (keV)</th>
<th>Decay</th>
<th>Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.975 ± 2</td>
<td>$\frac{1^-}{2}; \frac{3}{2}$</td>
<td>&lt; 0.47</td>
<td>$\gamma$, n, p, d</td>
<td>4, 5, 6, 16</td>
</tr>
<tr>
<td>17.298 ± 7</td>
<td>$(\frac{5}{2})^-$</td>
<td>200</td>
<td>$\gamma$, n, p, d, $\alpha$</td>
<td>5, 6, 7, 13, 16, 19</td>
</tr>
<tr>
<td>17.493 ± 7</td>
<td>$\leq \frac{7}{2}^+$</td>
<td>47</td>
<td>$\gamma$, n, p, d, $\alpha$</td>
<td>5, 6, 7, 16, 19</td>
</tr>
<tr>
<td>18.02 ± 50</td>
<td></td>
<td></td>
<td>$\gamma$</td>
<td>16</td>
</tr>
<tr>
<td>18.58 ± 40</td>
<td></td>
<td></td>
<td>$\gamma$, n, p, d, $\alpha$</td>
<td>6, 16</td>
</tr>
<tr>
<td>19.20 ± 50</td>
<td></td>
<td>310 ± 80</td>
<td>n, p, d, t</td>
<td>1, 6, 19</td>
</tr>
<tr>
<td>19.51 ± 50</td>
<td></td>
<td></td>
<td>$\gamma$</td>
<td>13, 16</td>
</tr>
<tr>
<td>(19.9 ± 200)</td>
<td></td>
<td></td>
<td>$\gamma$, n</td>
<td>13, 19</td>
</tr>
<tr>
<td>(20.47 ± 40)</td>
<td></td>
<td></td>
<td>$\gamma$, p, d</td>
<td>13, 19</td>
</tr>
<tr>
<td>20.74 ± 30</td>
<td></td>
<td>≈ 1000</td>
<td>$\gamma$, n, p, t</td>
<td>1, 13, 16</td>
</tr>
<tr>
<td>(21.4 ± 200)</td>
<td></td>
<td></td>
<td>$\gamma$, n</td>
<td>13, 19</td>
</tr>
<tr>
<td>(22.4 ± 200)</td>
<td></td>
<td></td>
<td>$\gamma$, n</td>
<td>13, 19</td>
</tr>
<tr>
<td>(23.8 ± 200)</td>
<td></td>
<td></td>
<td>$\gamma$, n</td>
<td>13, 34</td>
</tr>
<tr>
<td>(27.0 ± 500)</td>
<td></td>
<td></td>
<td>$\gamma$, n</td>
<td>13</td>
</tr>
</tbody>
</table>

| b                 |                          |                      |                     |           |
| b                 |                          |                      |                     |           |

$^a$ See also reactions 14 and 16.

$^b$ See footnote $^i$ in Table 9.8.


$\mu = -1.1778 \pm 0.0009$ nm: see (1976WE17).

$Q = +53 \pm 3$ mb: see (1978LEZA).
1. (a) $^6\text{Li}(t, n)^8\text{Be}$ \hspace{1cm} $Q_m = 16.0223$ \hspace{1cm} $E_h = 17.6878$
(b) $^6\text{Li}(t, p)^8\text{Li}$ \hspace{1cm} $Q_m = 0.801$
(c) $^6\text{Li}(t, d)^7\text{Li}$ \hspace{1cm} $Q_m = 0.9929$
(d) $^6\text{Li}(t, \alpha)^5\text{He}$ \hspace{1cm} $Q_m = 15.22$
(e) $^6\text{Li}(t, n)^4\text{He}^4\text{He}$ \hspace{1cm} $Q_m = 16.1141$
(f) $^6\text{Li}(t, 2n)^7\text{Be}$ \hspace{1cm} $Q_m = -2.876$

The $0^\circ$ differential cross section for reaction (a) increases monotonically between $E_t = 0.10$ and 2.4 MeV except for a resonance at $E_t = 1.875$ MeV ($^9\text{Be}^* = 18.937$). The excitation function for $^8\text{Li}$ (reaction (b)) increases monotonically for $E_t = 0.275$ to 1.000 MeV. In the range $E_t = 2.0$ to 6.8 MeV, a broad peak [$\Gamma \approx 1.3$ MeV] is observed at $E_t = 4.57$ MeV [$E_x = 20.73$ MeV]: see (1974AJ01) for references. For reaction (d) see (1982CE1C). Cross sections for $^7\text{Be}$ production [reaction (f)] ($E_t = 4.4$ to 11.99 MeV) are reported by (1980GU26). For reactions (c) and (e) see (1966LA04).

2. $^6\text{Li}(^3\text{He}, \pi^+)^9\text{Be}$ \hspace{1cm} $Q_m = -121.898$


3. $^6\text{Li}(\alpha, p)^9\text{Be}$ \hspace{1cm} $Q_m = -2.1262$

Angular distributions of $p_0$ have been measured at $E_\alpha = 10.2$ to 14.7 MeV and at 30 MeV: see (1974AJ01). See also (1983BE1P; theor.).

4. $^7\text{Li}(d, \gamma)^9\text{Be}$ \hspace{1cm} $Q_m = 16.6950$

For $E_d = 0.1$ to 1.1 MeV, a resonance in the yield of capture $\gamma$-rays is observed at $E_d = 361 \pm 2$ keV, corresponding to $^9\text{Be}^*(16.975)$ with $\Gamma_{\text{c.m.}} < 0.47$ keV. The small width of this state and its energy correspondence with $^9\text{Li}^*(2.69)$ argue for $T = \frac{3}{2}$. The angular distribution of the $\gamma$-rays to $^9\text{Be}(0)$ is isotropic to within 7%: see (1974AJ01) for references.

5. (a) $^7\text{Li}(d, n)^8\text{Be}$ \hspace{1cm} $Q_m = 15.0296$ \hspace{1cm} $E_h = 16.6950$
(b) $^7\text{Li}(d, \alpha)^5\text{He}$ \hspace{1cm} $Q_m = 14.23$
(c) $^7\text{Li}(d, n)^4\text{He}^4\text{He}$ \hspace{1cm} $Q_m = 15.1213$
(d) $^7\text{Li}(d, 2n)^7\text{Be}$ \hspace{1cm} $Q_m = -3.869$
Table 9.3: Resonances in $^7\text{Li} + d$ \(^a\)

<table>
<thead>
<tr>
<th>$^7\text{Li}(d, n)$</th>
<th>$^7\text{Li}(d, \alpha)$</th>
<th>$^7\text{Li}(d, p)$</th>
<th>$E_x$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{res}}$ (keV)</td>
<td>$E_{\text{res}}$ (keV)</td>
<td>$E_{\text{res}}$ (keV)</td>
<td>$\Gamma_{\text{lab}}$ (keV)</td>
</tr>
<tr>
<td>361 ± 2 (^b)</td>
<td>750</td>
<td>360 ± 3 &lt; 0.5 (^b)</td>
<td>16.975</td>
</tr>
<tr>
<td>680</td>
<td>776 ± 7 (^c)</td>
<td>250</td>
<td>17.298</td>
</tr>
<tr>
<td>980</td>
<td>1027 ± 7 (^c)</td>
<td>60</td>
<td>17.493</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>broad</td>
<td>(18.5)</td>
</tr>
<tr>
<td></td>
<td>2375 ± 50</td>
<td></td>
<td>18.54</td>
</tr>
<tr>
<td></td>
<td>3220 ± 50</td>
<td>400 ± 100</td>
<td>19.20</td>
</tr>
<tr>
<td></td>
<td>≈ 4800</td>
<td></td>
<td>20.4</td>
</tr>
</tbody>
</table>

\(^a\) For references and additional information see Tables 9.3 in (1974AJ01, 1979AJ01).

\(^b\) $E_{\text{res}}$ from $^7\text{Li}(d, \gamma)$: $\Gamma_{\text{no}}/\Gamma_{\gamma} \approx 1.5$, $\Gamma_{\text{do}}/\Gamma_{\gamma} < 400$, $\Gamma_{\text{no}}/\Gamma_{\gamma} < 20$.

\(^c\) (1976SC14, 1979MI1E).

The yield of neutrons has been measured for $E_d = 0.2$ to 23 MeV; observed resonances are displayed in Table 9.3. For polarization measurements [$E_d = 0.64$ MeV and 2.5 to 3.7 MeV] see (1974AJ01). See also (1979SE04; theor.).

The yields of $\alpha$-particles have been measured for $E_d = 0.25$ to 0.75 MeV (1977RO1C; $\alpha_1$) and 0.2 to 3.0 MeV; see Table 9.3. For reaction (c) see (1974AJ01) and $^5\text{He}$. The $^7\text{Be}$ production cross section (reaction (d)) has been studied for $E_d = 5.38$ to 11.94 MeV (1980GU26). See also (1978BA1F, 1979JO1B; applications).

6. $^7\text{Li}(d, p)^8\text{Li}$

\[ Q_m = -0.192 \quad E_b = 16.6950 \]

Excitation functions have been measured for $E_d = 0.29$ to 7 MeV [see (1974AJ01, 1979AJ01)] and 0.60 to 1.2 MeV (1982EL03, 1982FI03; $\sigma_t$) and 0.7 to 3.4 MeV (1979MI1E; $\sigma_t$): observed resonances are displayed in Table 9.3. Recent measurements of the total cross section at the $E_d = 0.78$ MeV resonance are $181 \pm 8$ mb (1976SC14), $174 \pm 16$ mb (1979MI1E), $146 \pm 13$ mb (1982EL03) and $148 \pm 12$ mb (1982FI03): we adopt 147 ± 9 mb. See also (1983FI01). For earlier values see (1974AJ01). This cross section serves as normalization for the $^7\text{Be}(p, \gamma)^8\text{B}$ data and to calculations of the $S$-factor. The new value predicts that the neutrino-capture rate in $^{37}\text{Cl}$ should be decreased by about 15%.

Polarization measurements are reported at $E_d = 4$ MeV (1982WAZS). See also (1980HU1D, 1982AB1D) and $^8\text{Li}$. 

---

\(^a\) For references and additional information see Tables 9.3 in (1974AJ01, 1979AJ01).

\(^b\) $E_{\text{res}}$ from $^7\text{Li}(d, \gamma)$: $\Gamma_{\text{no}}/\Gamma_{\gamma} \approx 1.5$, $\Gamma_{\text{do}}/\Gamma_{\gamma} < 400$, $\Gamma_{\text{no}}/\Gamma_{\gamma} < 20$.

\(^c\) (1976SC14, 1979MI1E).
<table>
<thead>
<tr>
<th>$E_x$ (MeV ± keV)</th>
<th>$\Gamma_{c.m.}$ (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.64</td>
<td>&lt; 8</td>
</tr>
<tr>
<td>2.4292 ± 1.7</td>
<td>1000 ± 250</td>
</tr>
<tr>
<td>2.9 ± 250</td>
<td>289 ± 22</td>
</tr>
<tr>
<td>3.076 ± 15</td>
<td>743 ± 55</td>
</tr>
<tr>
<td>4.704 ± 25</td>
<td>2000 ± 200</td>
</tr>
<tr>
<td>6.7 ± 100</td>
<td>620 ± 70</td>
</tr>
<tr>
<td>11.29 ± 30</td>
<td>400 ± 30</td>
</tr>
<tr>
<td>11.81 ± 20</td>
<td>590 ± 60</td>
</tr>
<tr>
<td>13.78 ± 30</td>
<td>0.38 ± 0.03</td>
</tr>
<tr>
<td>14.396 ± 5</td>
<td>41 ± 4</td>
</tr>
<tr>
<td>16.671 ± 8</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ See also Tables 9.4 in (1974AJ01, 1979AJ01) for references.

$^b$ See also Table 9.6.

---

7. $^7$Li(d, d)$^7$Li

The elastic scattering [$E_d = 0.4$ to $1.8$ MeV] shows a marked increase in cross section for $E_d = 0.8$ to $1.0$ MeV (perhaps related to $^9$Be*($17.30$)) and a conspicuous anomaly at $E_d = 1.0$ MeV, due to p-wave deuterons [$^9$Be*($17.50$)]. The elastic scattering has also been studied for $E_d = 1.0$ to $2.6$ MeV and $10.0$ to $12.0$ MeV: see (1974AJ01). See also (1982AB1D) and $^7$Li.

8. (a) $^7$Li(d, t)$^6$Li

```
| $Q_m$ = −0.993 | $E_b = 16.6950$
```

(b) $^7$Li(d, $^3$He)$^6$He

```
| $Q_m$ = −4.481 |
```

The cross section for reaction (a) rises steeply from threshold to $95$ mb at $E_d = 2.4$ MeV and then more slowly to $\approx 165$ mb at $E_d = 4.1$ MeV. The $t_0$ yield curve ($\theta_{lab} = 155^\circ$) decreases monotonically for $E_d = 10.0$ to $12.0$ MeV: see (1974AJ01). See also $^6$Li. For reaction (b) see $^6$He.

9. $^7$Li($^3$He, p)$^9$Be

```
| $Q_m = 11.2015$
```

---

11
Table 9.5: Neutron decay of $^9$Be states

<table>
<thead>
<tr>
<th>$^9$Be state (MeV)</th>
<th>$l_n$</th>
<th>Decay (in %) to $^8$Be(0)</th>
<th>$^8$Be*(2.9)</th>
<th>$\theta^2$ (%) b</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.43</td>
<td>3</td>
<td>7.0 ± 1.0 a</td>
<td>2.1 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>2.78</td>
<td>1</td>
<td>mainly</td>
<td>0.48 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>3.05</td>
<td>2</td>
<td>87 ± 13</td>
<td>81 ± 13</td>
<td></td>
</tr>
<tr>
<td>4.70</td>
<td>2</td>
<td>13 ± 4</td>
<td>6.0 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>6.76</td>
<td>3</td>
<td>$\leq$ 2</td>
<td>$\leq$ 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>55 ± 14</td>
<td>37 ± 10</td>
<td></td>
</tr>
<tr>
<td>11.28</td>
<td>1</td>
<td>$\leq$ 2</td>
<td>$\leq$ 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>14 ± 4</td>
<td>0.93 ± 0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>4.0 ± 1.2</td>
<td></td>
</tr>
<tr>
<td>11.81</td>
<td>1</td>
<td>$\leq$ 3</td>
<td>$\leq$ 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>12 ± 4</td>
<td>0.48 ± 0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>1.8 ± 0.6</td>
<td></td>
</tr>
</tbody>
</table>

a For references see Table 9.5 in (1979AJ01).  
b Expressed in units of $h^2/mR^2 = 2.47$ MeV (1968CO08, 1970CH07).  
c See Table 9.6.

Observed proton groups are listed in Table 9.4. The parameters for the particle and $\gamma$-decay of observed states are displayed in Tables 9.5 and 9.6. Angular distributions have been reported in the range $E(^3\text{He}) = 0.9$ to 14 MeV: see (1974AJ01, 1979AJ01). See also (1981SL03), (1981VI1B) and $^{10}$B.

The $\gamma$-decay of $^9$Be*($14.39$) [$J^\pi = \frac{3}{2}^-; T = \frac{3}{2}$] has been measured by (1978DI08) and compared with the decay from the mirror state in $^9$B: see Table 9.6. No evidence is found for violation of the selection rule for $\Delta T = 1$ mirror $\gamma$ transitions (1978DI08).

10. $^7$Li($\alpha$, d)$^9$Be $Q_m = -7.1517$

Angular distributions of d$_0$, d$_1$ and d$_2$ are reported at $E_\alpha = 30$ MeV: see (1974AJ01). See also (1980ZE05, 1983BE1P; theor.).

11. $^7$Li($^6$Li, $\alpha$)$^9$Be $Q_m = 15.220$
Angular distributions of $\alpha_0$ have been studied at $E(\gamma) = 3.78$ to 5.95 MeV: see (1974AJ01).

12. $^9\text{Li}(\beta^-)^8\text{Be}$  

$^9\text{Li}$ decays by $\beta^-$ emission with $\tau_{1/2} = 178.3 \pm 0.4$ msec to several $^9\text{Be}$ states: see $^9\text{Li}$, reaction 1 and Table 9.7. Measurement of $\beta - \alpha$ coincidences involving $^9\text{Be}^*(11.28)$ show contributions from the direct $n + 2\alpha$ breakup process as well as the sequential $n$-emission to $^8\text{Be}^*(2.9) [J^\pi = 2^+]$, followed by breakup into $2\alpha$ (1981LA11, 1981NY1A). The branching ratio for the $^9\text{Be}^*(2.43) \rightarrow ^8\text{Be}_{g.s.} + n$ decay is $(6.4 \pm 1.2)\%$. $^9\text{Be}^*(2.78) [J^\pi = \frac{1}{2}^-]$ decays mainly to $^8\text{Be}_{g.s.} + n$ presumably by p-wave neutron emission: see reaction 13 in (1979AJ01). See also (1981JOZV) and (1979DE15; theor.).

13. (a) $^9\text{Be}(\gamma, n)^8\text{Be}$  
(b) $^9\text{Be}(\gamma, \alpha)^7\text{He}$  
(c) $^9\text{Be}(\gamma, n)^4\text{He}^4\text{He}$  

The photoneutron cross section has been measured from threshold to 320 MeV: see Table 9.6 in (1966LA04) and (1979AJ01). A pronounced peak occurs $\approx 29$ keV above threshold with $\sigma_{\text{max}} = 1.33 \pm 0.24$ mb. The shape of the resonance has been measured very accurately for $E_\gamma = 1675$ to 2168 keV. The FWHM of the peak is estimated to be 100 keV (1982FU11). See also (1983BA52; theor.). The cross section then decreases slowly to 1.2 mb at 40 keV above threshold. From bremsstrahlung studies, peaks in the $(\gamma, \text{Tn})$ cross section are observed corresponding to $E_\gamma = 1.80$ and 3.03 MeV. At higher energies, using monoenergetic photons, the $(\gamma, \text{Tn})$ cross section is found to be relatively smooth from $E_\gamma = 17$ to 37 MeV with weak structures which correspond to $E_\gamma = 17.1, 18.8, 19.9, 21.4, 22.4, 23.8 [\pm 0.2]$ MeV and $27 \pm 0.5$ MeV (broad). In the range $E_\gamma = 18$ to 26 MeV the integrated $(\gamma, n_0)$ cross section is $< 0.1$ MeV · mb, that for $(\gamma, n_1) = 2.4 \pm 0.4$ MeV · mb and the combined integrated cross section for $(\gamma, n)$ to $^8\text{Be}^*(16.6)$ and $(\gamma, \alpha_0)$ to $^3\text{He}_{g.s.}$ is $13.1 \pm 2$ MeV · mb.

The total absorption cross section has been measured for $E_\gamma = 10$ to 210 MeV: it rises to $\approx 5$ mb at $\approx 21$ MeV, decreases to about 0 at 160 MeV and then increases to $\approx 1.5$ mb at 210 MeV. An integrated cross section of $156 \pm 15$ MeV · mb is reported for $E_\gamma = 10$ to 29 MeV as is resonant structure at $E_\gamma = 11.8, (13.5), 14.8, 917.3, (19.5), 21.0, (23.0)$ and (25.0) MeV. Fine structure is also reported at $E_\gamma = 20.47 \pm 0.04$ and $20.73 \pm 0.04$ MeV. See (1979AJ01) for references. See also (1978CH1E, 1979ZI1A, 1980AH1A, 1982DE1H), (1982BA1T; applications) and (1979BA60, 1979KI1D, 1980TA1D, 1981DE18, 1981DE33, 1981IS11; theor.).

14. (a) $^9\text{Be}(\gamma, p)^8\text{Li}$  
(b) $^9\text{Be}(\gamma, np)^7\text{Li}$  

$$Q_m = -16.887$$  
$$Q_m = -18.920$$
Table 9.6: Parameters of the first $T = \frac{3}{2}^-$ states in $^9$Be and $^9$B, $J^\pi = \frac{3}{2}^-$

<table>
<thead>
<tr>
<th></th>
<th>$^9$Be</th>
<th>$^9$B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_x$ (keV)</td>
<td>14392.9 ± 1.8</td>
<td>14655.0 ± 2.5</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_0}$ (eV)</td>
<td>6.9 ± 0.5</td>
<td>(6.9 ± 0.5) b</td>
</tr>
<tr>
<td>$\Gamma$ (eV)</td>
<td>381 ± 33 c</td>
<td>395 ± 42 d</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_0}$ (to $\frac{3}{2}^-$)/$\Gamma$ (%)</td>
<td>1.81 ± 0.09 d</td>
<td>1.85 ± 0.15 d</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_1}$ (to $\frac{1}{2}^+$)/$\Gamma$ (%)</td>
<td>0.03 ± 0.04 d</td>
<td>0.00 ± 0.08 d</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_2}$ (to $\frac{5}{2}^-$)/$\Gamma$ (%)</td>
<td>2.05 ± 0.11 d</td>
<td>1.93 ± 0.22 d</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_3}$ (to $\frac{1}{2}^-$)/$\Gamma$ (%)</td>
<td>&lt; 0.2 d</td>
<td></td>
</tr>
<tr>
<td>$\Gamma_{\gamma_4}$ (to $\frac{5}{2}^-$)/$\Gamma$ (%)</td>
<td>0.33 ± 0.07 d</td>
<td></td>
</tr>
<tr>
<td>$\Gamma_{\gamma_5}$ (to $\frac{3}{2}^+$)/$\Gamma$ (%)</td>
<td>0.23 ± 0.05 d</td>
<td></td>
</tr>
<tr>
<td>$\Gamma_{\gamma_2}/\Gamma_{\gamma_0}$</td>
<td>1.13 ± 0.05 d</td>
<td>1.03 ± 0.11 d</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_0}/\Gamma$</td>
<td>0.028 ± 0.021</td>
<td>$\Gamma_{\gamma_0}/\Gamma$</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_1}/\Gamma$</td>
<td>0.50 ± 0.11</td>
<td>$\Gamma_{\gamma_1}/\Gamma$</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_0}$ (eV)</td>
<td>9 ± 8</td>
<td>$\Gamma_{\gamma_0}$ (eV)</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_1}$ (eV)</td>
<td>147 ± 28</td>
<td>$\Gamma_{\gamma_1}$ (eV)</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_1}/\Gamma_{\gamma_0}$</td>
<td>18 ± 14</td>
<td>$\Gamma_{\gamma_1}/\Gamma_{\gamma_0}$</td>
</tr>
<tr>
<td>$\gamma_{\gamma_1}/\Gamma_{\gamma_0}$</td>
<td>22 ± 17</td>
<td>$\gamma_{\gamma_1}/\Gamma_{\gamma_0}$</td>
</tr>
<tr>
<td>$\Gamma_{\gamma_0}/\Gamma_{\gamma_0}$</td>
<td>31.2 ± 9.8</td>
<td></td>
</tr>
</tbody>
</table>

a See Table 9.6 in (1979AJ01) for references.
b Assumed identical to $^9$Be.
c Calculated from $\Gamma_{\gamma_0}/\Gamma$ and $\Gamma_{\gamma_0}$ (1978DI08).
d (1978DI08): $\Gamma(^9\text{B}/\Gamma(^9\text{Be}) = 1.04 ± 0.10.$
Table 9.7: Branching parameters in $^9\text{Li}$ $\beta$-decay (1981LA11)

<table>
<thead>
<tr>
<th>$E_x$ in $^9\text{Be}$ (MeV)</th>
<th>$J^\pi; T$</th>
<th>Branching ratio (%)</th>
<th>log $ft$ a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$^2_2^-$; $^1_2^+$</td>
<td>50.5 ± 5 c</td>
<td>5.31</td>
</tr>
<tr>
<td>2.43</td>
<td>$^2_2^-$; $^1_2^+$</td>
<td>34 ± 4</td>
<td>5.07</td>
</tr>
<tr>
<td>2.78 b</td>
<td>$^1_2^-$; $^1_2^+$</td>
<td>10 ± 2</td>
<td>5.54</td>
</tr>
<tr>
<td>7.94</td>
<td>$^1_2^-$ d; $^3_2^+$</td>
<td>1.5 ± 0.5</td>
<td>5.04</td>
</tr>
<tr>
<td>11.28</td>
<td>$^1_2^-$ d; $^3_2^+$</td>
<td>4 ± 0.5</td>
<td>2.87 e</td>
</tr>
<tr>
<td>11.81</td>
<td>&lt; 0.1</td>
<td>&gt; 4.0</td>
<td></td>
</tr>
</tbody>
</table>

a M.J. Martin, private communication.
b 2.78 ± 0.12 MeV, $\Gamma_{\text{c.m.}} = 1.10 ± 0.12$ MeV; $\theta^2_p = 0.48 ± 0.06$: see Table 9.7 in (1979AJ01).
c $P_n = (50 ± 4)$% (1981BJ01); $P_n = (49.5 ± 5)$% (1981LA11).
d Suggested by (1981LA11) on the basis of the branching ratios.
e (1981LA11) suggest that the very low log $ft$ value implies that $^9\text{Be}*(11.28)$ is the anti-analog to $^9\text{Li}_{g.s.}$.

(c) $^9\text{Be}(\gamma, \text{d})^7\text{Li}$          $Q_m = -16.6950$
(d) $^9\text{Be}(\gamma, \text{t})^6\text{Li}$          $Q_m = -17.6878$

The yield shows structure in the energy region corresponding to the $^9\text{Be}$ levels at 17–19 MeV followed by the giant resonance at $E_\gamma \approx 23$ MeV ($\sigma = 2.64 ± 0.30$ mb). Structure attributed to eleven states of $^9\text{Be}$ with $18.2 < E_x < 32.2$ MeV has also been reported. Integrated cross sections have been obtained for each of these resonances, and over different energy intervals for protons leading to $^8\text{Li}^*(0 + 0.98, 2.26 + 3.21, 9.0, 17.0)$. Angular and energy distributions of photoprotons in various energy intervals have been studied by many groups: see (1974AJ01) for references. See also (1976MA34). For momentum spectra using tagged photons with $E_\gamma = 180 – 420$ MeV and 360–600 MeV, see (1980HO22) and (1982BA32), respectively. See also (1981AR04, 1981TA1T, 1983ST1G).

The integrated cross sections are reported to be $1.0 ± 0.5$ MeV · mb ($E_\gamma = 21 \rightarrow 33$ MeV) for reaction (c) to $^7\text{Li}^*(0 + 0.4)$ and $0.6 ± 0.3$ MeV · mb ($E_\gamma = 25 \rightarrow 33$ MeV) for reaction (d) to $^6\text{Li}(0)$. The total integrated cross section for $[(\gamma, \text{p}) + (\gamma, \text{pn}) + (\gamma, \text{d}) + (\gamma, \text{t})]$ is given as $33 ± 3$ MeV · mb by (1966DE13), who also report resonances in the $(\gamma, \text{d})$ and $(\gamma, \text{t})$ cross sections corresponding to $^9\text{Be}^*(26.0 ± 0.2)$ and $^9\text{Be}^*(32.2 ± 0.3)$, respectively. See also (1974AJ01), (1980IS1E, 1982AV06, 1983HO01, 1983LI1J) and (1981IS11, 1982SU09; theor.).

15. $^9\text{Be}(\gamma, \gamma)^9\text{Be}$
See (1980IS1E, 1982NO1C). See also (1979AJ01) and (1983ZH1D; theor.).

16. (a) $^9$Be(e, e)$^9$Be
(b) $^9$Be(e, en)$^8$Be $Q_m = -1.6655$
(c) $^9$Be(e, ep)$^8$Li $Q_m = -16.887$
(d) $^9$Be(e, eα)$^5$He $Q_m = -2.46$
(e) $^9$Be(e, eπ$^+$)$^9$Li $Q_m = -153.174$

$$\langle r^2 \rangle^{1/2} = 2.519 \pm 0.012 \text{ fm, } Q = 6.5^{+0.9}_{-0.6} \text{ fm}^2,$$
$$b = 1.5^{+0.3}_{-0.2} \text{ fm } [b = \text{ oscillator parameter}]$$
$$\langle r^2 \rangle_M^{1/2} = 3.2 \pm 0.3 \text{ fm, } \Omega = 6 \pm 2 \mu_N \cdot \text{ fm}^2 [\text{this value of the magnetic octupole moment implies a deformation of the average nuclear potential}].$$

The elastic scattering of electrons has been studied for $E_e$ up to 700 MeV. Magnetic elastic scattering gives indications of both M1 and M3 contributions. See also (1978DE32). Inelastic scattering populates a number of levels: Table 9.8 displays the parameters of the states. See (1974AJ01, 1979AJ01) for other work and for references.

At $E_e = 134.7$ and 237 MeV (1979BU11) have determined transverse and longitudinal form factors for electrodisintegration in the region of the quasielastic scattering peak. They report the observation of E1 and E2 giant resonance peaks: see Table 9.8. The quasielastic process has been studied in the range 250–580 MeV/c by (1978KU06). For reaction (c) see $^8$Li. For reaction (e) see (1980ST15). (1979JE04) have measured the ratio $\pi^- / \pi^+$ in the electroproduction of 10 MeV pions. See also (1979SC1E) and the “General” section here.


17. $^9$Be($\pi^\pm$, $\pi^\pm$)$^9$Be (See also the “General” section here.)

The elastic scattering, and inelastic scattering to $^9$Be*(2.43, 6.76), have been studied at $E_{\pi^\pm} = 162$ MeV (1978GE11) and 291 MeV (1981GE03). Quadrupole contributions appear to be quite important for the elastic scattering at 162 MeV (1978GE11), but are much less so at higher energy (1981GE03). The inelastic scattering suggest the importance of radial localization effects (1981GE03). For a study of the ($\pi^+$, $\pi^0$) reaction see (1981BO06). For measurements of inclusive charged pion scattering yields see (1981MC09).
Table 9.8: Levels of $^9$Be from $^9$Be(e, $e'$)$^9$Be* a

<table>
<thead>
<tr>
<th>$E_x$ in $^9$Be (MeV ± keV)</th>
<th>$\Gamma_{\text{c.m.}}$ (keV)</th>
<th>Transition</th>
<th>$J^\pi$</th>
<th>$\Gamma_{\gamma_0}$ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.78 ± 30</td>
<td>150 ± 50</td>
<td>E1</td>
<td>$\frac{1}{2}^+$</td>
<td>0.30 ± 0.12</td>
</tr>
<tr>
<td>2.44 ± 20</td>
<td>&lt; 30</td>
<td>M1</td>
<td>$\frac{5}{2}^-$</td>
<td>0.089 ± 0.010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E2</td>
<td></td>
<td>(1.89 ± 0.14) $\times 10^{-3}$ b</td>
</tr>
<tr>
<td>3.04 ± 20</td>
<td>450 ± 150</td>
<td>E1 c</td>
<td>$\frac{5}{2}^+$</td>
<td>0.30 ± 0.25 d</td>
</tr>
<tr>
<td>4.7 ± 200</td>
<td>700 ± 300</td>
<td>E(1)</td>
<td></td>
<td>2.4 ± 1.2 e</td>
</tr>
<tr>
<td>6.4 ± 100</td>
<td>1000 ± 300</td>
<td>E2</td>
<td>$\frac{7}{2}^-$</td>
<td>0.082 ± 0.035</td>
</tr>
<tr>
<td>13.84 ± 50 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.388 ± 15 h</td>
<td>&lt; 70</td>
<td>M1</td>
<td>$\frac{3}{2}^-$</td>
<td>6.9 ± 0.5 f</td>
</tr>
<tr>
<td>15.10 ± 50 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.97 ± 30 g</td>
<td>≈ 300</td>
<td>M1</td>
<td></td>
<td>3.7 ± 0.8 e</td>
</tr>
<tr>
<td>16.631 ± 15 h</td>
<td>&lt; 70</td>
<td>M2 i</td>
<td>$\leq \frac{7}{2}^+$</td>
<td>0.26 ± 0.02 e</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M1</td>
<td>$\leq \frac{5}{2}^-$</td>
<td>2.0 ± 0.5 e</td>
</tr>
<tr>
<td>16.961 ± 15 h</td>
<td>&lt; 70</td>
<td>M1</td>
<td>$\frac{1}{2}^-$</td>
<td>11.5 ± 1.4 f</td>
</tr>
<tr>
<td>17.28</td>
<td></td>
<td>M1</td>
<td>$\leq \frac{5}{2}^-$</td>
<td>7.3 ± 1.3 e</td>
</tr>
<tr>
<td>17.480 ± 20 h</td>
<td>≈ 100</td>
<td>M2 i</td>
<td>$\leq \frac{7}{2}^+$</td>
<td>0.40 ± 0.03 e</td>
</tr>
<tr>
<td>18.02 ± 50 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.62 ± 50 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.51 ± 50 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.76 ± 50 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>j</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a For references see Table 9.8 in (1979AJ01).

b $B(C2, \omega) \uparrow = 45.7 ± 3.5 \text{ e}^2 \cdot \text{fm}^4$.

c Assumed.

d The group may consist of two unresolved states, the second one reached by an M1 transition $[J^\pi = (\frac{1}{2})^-]$ with $\Gamma_{\gamma_0} = 0.18 ± 0.09 \text{ eV}$. I am indebted to Dr. L.W. Fagg for his help in understanding this point.

e $\Gamma_{\gamma_0}$; where $g = (2J_f + 1)/(2J_i + 1)$.

f See (1974AJ01) and Table 9.6 here.

g Weak transition.

h (1983LO11, 1983LOZZ) report transverse form factors for this state ($0.9 \leq q \leq 2.5 \text{ fm}^{-1}$).

i Or pure spin-flip E1.

j States belonging to the E1 and E2 giant resonances are reported at $E_x = 19.2 ± 0.2 [4.0 ± 0.6], 28.7 ± 0.5 [8.9 ± 1.7], 36.3 ± 0.5 [2.8 ± 1.3], 41 ± 1 [7.2 ± 2.0] and 58.0 ± 0.4 \text{ MeV [3.1 ± 0.5 MeV (1979BU11)] [\Gamma in brackets]}. See also (1974AJ01) for other reported states.
18. (a) $^9\text{Be}(n, n)^9\text{Be}$

(b) $^9\text{Be}(n, 2n)^8\text{Be}$

$$Q_m = -1.6655$$

The population of $^9\text{Be}^*(0, 1.7, 2.4, 3.1, (6.8))$ has been reported in this reaction: see (1974AJ01). For the neutron decay of these states see Table 9.5. Angular distributions have been measured at $E_n = 5.9$ to 14.2 MeV [see (1974AJ01, 1979AJ01)] and at 3.5 to 7.1 MeV (1980CO1U; n$_0$, n$_2$), 6.97 to 14.93 MeV (1978HO23; n$_0$, n$_2$) and at 14.6 MeV (1982HAZK; n$_0$). See also (1981DA1K, 1983ANZY), (1979BY01, 1980AK01; theor.) and $^{10}\text{Be}$.

19. $^9\text{Be}(p, p)^9\text{Be}$

Elastic and inelastic scattering angular distributions have been studied at many energies in the range $E_p = 5$ to 1000 MeV [see (1974AJ01, 1979AJ01)] and at $E_p = 2.31$ to 2.73 MeV (1980BO1L; p$_0$), 35.2 MeV (1980FA07; p$_0$), 72 MeV (1982AU1B; p$_0$), 225 MeV (1981RO1F; p$_0$) and 1 GeV (1979AL26; p$_0$). The elastic distributions show pronounced diffraction maxima characteristic of the optical model. A quadrupole-deformed optical model potential is necessary to obtain a good fit to the p$_0$ and p$_2$ angular distributions: see (1974AJ01).

The structure corresponding to $^9\text{Be}^*(1.7)$ is asymmetric: the line shape peaks 25$^{+15}_{-11}$ keV above the threshold for $^8\text{Be} + n$. The population of $^9\text{Be}^*(1.7)$ has been studied for $E_p = 4.2$ to 5.5 MeV: it is consistent with a scattering length of about $-20$ fm between a neutron and $^8\text{Be}$. The weighted mean of the values of $E_x$ for $^9\text{Be}^*(2.4)$ listed in (1974AJ01) is 2432$\pm$3 keV. $^9\text{Be}^*(3.1)$ has $E_x = 3.03 \pm 0.03$ MeV, $\Gamma = 250 \pm 50$ keV, $J^\pi = \frac{3}{2}^+, \frac{5}{2}^+$. Higher states are observed at $E_x = 4.8 \pm 0.2, 6.76 \pm 0.06$ [for $J^\pi = \frac{1}{2}^+, \frac{5}{2}^+, \frac{7}{2}^+$ (but see below), $\Gamma = 1.2 \pm 0.2$ MeV], $7.94 \pm 0.08$ (for $\Gamma \approx 1$ MeV), $11.3 \pm 0.2$ MeV (for $\Gamma \approx 1$ MeV), $14.4 \pm 0.3$ (for $\Gamma \approx 1$ MeV), $16.7 \pm 0.3, 17.4 \pm 0.3, 19.0 \pm 0.4, 21.1 \pm 0.5$ and $22.4 \pm 0.7$ MeV [the five highest states are all broad]. For $^9\text{Be}^*(2.4, 6.8)$ $B(E2)$ = 49$\pm$6 and 24$\pm$4 fm$^4$ and $\Gamma(E2)$ = 0.0025 and 0.10 eV, respectively. The strong population of $^9\text{Be}^*(2.4, 6.8)$ is consistent with the assumption that they have $J^\pi = \frac{5}{2}^-$ and $\frac{7}{2}^-$, respectively, and are members of the ground-state $K = \frac{3}{2}^-$ band. See (1966LA04, 1974AJ01) for references.

The elastic scattering studied at $E_p = 25$ MeV (1974BI14) and 225 MeV (1981RO1F) shows that the depolarization parameter, $D$, deviates from unity and thus that a spin-spin term must be included in the optical parameter. The spin-flip probability at $E_{p-bar} = 31$ MeV is $\approx 0$ for the $p_2$ group, which is expected in view of the collective nature of the transition (1981CO08). See also (1978AL1G) and (1979BY01, 1980KO1V, 1981BA50, 1981CO08, 1981GU1B, 1981GU1F, 1981KR17, 1982BA1X, 1982BA14, 1982GU1E; theor.).

20. (a) $^9\text{Be}(p, 2p)^8\text{Li}$

(b) $^9\text{Be}(p, pd)^7\text{Li}$

$$Q_m = -16.887$$

$$Q_m = -16.6950$$
(c) $^9\text{Be}(p, p\alpha)^5\text{He}$  \hspace{1cm} Q_m = -2.46

(d) $^9\text{Be}(p, pn)^8\text{Be}$  \hspace{1cm} Q_m = -1.6655

(e) $^9\text{Be}(p, d^3\text{He})^5\text{He}$  \hspace{1cm} Q_m = -20.82

The summed proton spectrum (reaction (a)) shows two peaks with $Q = -16.4 \pm 0.3$ and $-25.4 \pm 0.5$ MeV, corresponding to removal of a p-proton and an s-proton respectively, and a third peak of uncertain assignment (perhaps due to unresolved states) with $Q = -32.3 \pm 0.6$ MeV. See (1974AJ01). See also (1979KO21; also for (p, pX)), (1979KR1A, 1981FR24). For reaction (b) see (1974AJ01). Reactions (c) and (f) are dominated by quasi-free processes at $E_p = 101.5$ MeV: $S_{\alpha}(L = 0) = 0.45$, $S_{\alpha}(L = 2) = 0.55$ (1980NA09). See also (1982NA1N). Reaction (d) at $E_p = 10 - 24$ MeV involves the $\frac{3}{2}^+$ state $[3.01 \pm 0.02$ MeV]. $^9\text{Be}*(4.7)$ is also involved (1978JE01). See also (1982PE1F). For pion production see (1979BU1D). See also (1979BA28) and (1978WO1A, 1979BO27, 1979DO03, 1979KI10, 1979MA1M, 1980BO12, 1981IS11; theor.).

21. $^9\text{Be}(d, d)^9\text{Be}$

Angular distributions have been reported in the range 1.0 to 410 MeV [see (1974AJ01, 1979AJ01)] and at $E_{d-\text{bar}} = 2.0$ to 2.8 MeV (1982DE1P; d$_0$) and $E_d = 12.17$ to 14.43 MeV (1978TA12; d$_0$, d$_1$, d$_2$).

Inelastic groups have been reported to $^9\text{Be}*(1.7)$, to states with $E_x = 2431.9 \pm 7.0$ keV and $3040 \pm 15$ keV ($\Gamma = 294 \pm 20$ keV), and to $^9\text{B}*(4.7, 6.8)$: see (1974AJ01). See also (1978ZE03, 1979DO03; theor.) and $^{11}\text{B}$ in (1985AJ01).

22. (a) $^9\text{Be}(t, t)^9\text{Be}$

(b) $^9\text{Be}(t, nt)^9\text{Be}$  \hspace{1cm} Q_m = -1.6655

Angular distributions of elastically scattered tritons have been measured at $E_t = 2.10$ MeV [see (1974AJ01)] and at $E_t = 15$ and 17 MeV (1978SC02). Reaction (b) at $E_t = 4.2$ and 4.6 MeV proceeds via $^9\text{Be}*(2.4)$: see (1974AJ01). See also (1981ME1D; theor.).

23. (a) $^9\text{Be}(^3\text{He}, ^3\text{He})^9\text{Be}$

(b) $^9\text{Be}(^3\text{He}, 2\alpha)^4\text{He}$  \hspace{1cm} Q_m = 19.0041

Angular distributions have been studied for $E(^3\text{He}) = 1.6$ to 32.6 MeV and at 217 MeV [see (1974AJ01, 1979AJ01)] and at $E(^3\text{He}) = 46.1$ MeV (1979GO07; elastic). For optical model parameters see references in (1979AJ01). At $E(^3\text{He}) = 39.8$ MeV, $^9\text{Be}*(1.7, 2.4, 3.1, 4.7, 6.8,
14.4) are populated. In a study of reaction (b) the \(^{(3}\text{He} + \alpha)\) system is found to be mainly in an S-state: the probability of finding such a cluster in \(^9\text{Be}\) is \(N_{\text{eff}} = 0.05\) (1975KA05). At \(E^{(3}\text{He}) = 2.1\) to 2.7 MeV quasifree processes are reported by (1978AR21); see \(^8\text{Be}\). See also (1981DE1X) and (1979KA1G).

24. (a) \(^9\text{Be}(\alpha, \alpha)^9\text{Be}\)
   (b) \(^9\text{Be}(\alpha, 2\alpha)^5\text{He}\)
   \[ Q_m = -2.46 \]
   (c) \(^9\text{Be}(\alpha, \alpha\text{n})^8\text{Be}\)
   \[ Q_m = -1.6655 \]

Angular distributions have been studied at many energies in the range \(E_\alpha = 5.0\) to 104 MeV [see (1974AJ01)] and at \(E_\alpha = 35.5\) MeV (1982PE03; \(\alpha_0, \alpha_1, \alpha_2, \alpha_4, \alpha_5\) and \(\alpha\) to \(^9\text{Be}^*\)(11.28)) and 65 MeV (1980HA33; \(\alpha_0, \alpha_2, \alpha_5\)). See (1972DE01) for a discussion of optical model parameters. The structure \(^{(3}\text{He} + \alpha)\) for \(^9\text{Be}\) is found to be much more probable than \(^{(4}\text{Li} + \alpha)\): the ratio of spectroscopic factors is about 30 (1972DE01).

At \(E_\alpha = 35.5\) MeV, states belonging to the \(K = \frac{3}{2}^-\) ground-state band are strongly excited \([{}^9\text{Be}^*(0, 2.43, 6.76, 11.28)\); it is suggested that the latter has \(J^\pi = (\frac{5}{2}^-)\); see, however, reaction 12]. The first three states belonging to the \(K = \frac{1}{2}^+\) band are also excited \([{}^9\text{Be}^*(1.68, 3.05, 4.70)\]) (1982PE03; coupled channels analysis). For reaction (b) see (1974AJ01) and (1980ZH1A; 18 MeV) and (1980WA07; 140 MeV). \(S_\alpha = 0.96\) (1976WO11). For reaction (c) see (1974AJ01). See also (1978ZE03, 1981BA20, 1982BU1D; theor.).

25. (a) \(^9\text{Be}({}^6\text{Li}, {}^6\text{Li})^9\text{Be}\)
   (b) \(^9\text{Be}({}^7\text{Li}, {}^7\text{Li})^9\text{Be}\)

Elastic angular distributions have been measured at \(E({}^6\text{Li}) = 4, 6\) and 24 MeV and at \(E({}^7\text{Li}) = 24\) and 34 MeV: see (1979AJ01).

26. \(^9\text{Be}({}^{9}\text{Be}, {}^{9}\text{Be})^9\text{Be}\)

Elastic angular distributions have been obtained at \(E({}^{9}\text{Be}) = 5, 9, 12\) and 16 MeV [see (1979AJ01)], at 14, 20 and 26 MeV (1979UN01) and at 40 to 55 MeV (1983OMZZ; also to \(^{9}\text{Be}^*(2.43)\); \(\sigma\) (fusion)).

27. \(^9\text{Be}({}^{10}\text{B}, {}^{10}\text{B})^9\text{Be}\)
Elastic angular distributions are reported at $E(^{10}\text{B}) = 20.1$ and 30 MeV (1980BO14).

28. (a) $^9\text{Be}(^{12}\text{C}, ^{12}\text{C})^9\text{Be}$
(b) $^9\text{Be}(^{13}\text{C}, ^{13}\text{C})^9\text{Be}$

Elastic angular distributions have been measured for reaction (a) at $E(^{12}\text{C}) = 12, 15, 18$ and $21$ MeV and $E(^9\text{Be}) = 14, 20, 26$ and $43$ MeV [see (1979AJ01)] and at $E(^9\text{Be}) = 14, 20$ and $26$ MeV (1979UN01), 20 MeV (1979BO1K), 20 and 26.1 MeV (1979JA04), 50 MeV (1977ST20), 69.7 and 76.6 MeV (1979MA21) and 158.4 MeV (1983FUZY). For yield and fusion cross-section measurements see (1978MA44, 1979MA21, 1981JA09, 1982DEZL, 1982HU06). Elastic angular distributions for reaction (b) are reported at $E(^9\text{Be}) = 14, 20$ and 26 MeV (1979UN01) and 19.5 and 25.0 MeV (1979JA04). See also (1978TA1B, 1982JA1E) and (1978GR22, 1980BR05, 1980OH1B, 1981GR17, 1981HU07, 1982LO13, 1983DE1U; theor.).

29. $^9\text{Be}(^{14}\text{N}, ^{14}\text{N})^9\text{Be}$

Elastic angular distributions have been measured at $E(^{14}\text{N}) = 25$ and 27.3 MeV: see (1974AJ01). For fusion studies see (1981MA1V, 1982MAZA).

30. (a) $^9\text{Be}(^{16}\text{O}, ^{16}\text{O})^9\text{Be}$
(b) $^9\text{Be}(^{18}\text{O}, ^{18}\text{O})^9\text{Be}$

Elastic angular distributions have been reported in the range $E(^{16}\text{O}) = 15$ to 30 MeV [see (1979AJ01)] and at $E(^9\text{Be}) = 14, 20$ and 26 MeV (1979UN01) and 158.4 MeV (1983FUZY), as well as at $E(^{18}\text{O}) = 12.1, 16$ and 20 MeV [see (1974AJ01)]. See also (1981ST1P, 1982BE54), (1979HU1B, 1979MA30, 1979PA1B, 1981GR17, 1981GU1B; theor.).

31. (a) $^9\text{Be}(^{24}\text{Mg}, ^{24}\text{Mg})^9\text{Be}$
(b) $^9\text{Be}(^{26}\text{Mg}, ^{26}\text{Mg})^9\text{Be}$
(c) $^9\text{Be}(^{27}\text{Al}, ^{27}\text{Al})^9\text{Be}$
(d) $^9\text{Be}(^{28}\text{Si}, ^{28}\text{Si})^9\text{Be}$
(e) $^9\text{Be}(^{29}\text{K}, ^{30}\text{K})^9\text{Be}$
(f) $^9\text{Be}(^{40}\text{Ca}, ^{40}\text{Ca})^9\text{Be}$
(g) $^9\text{Be}(^{44}\text{Ca}, ^{44}\text{Ca})^9\text{Be}$
Elastic angular distributions have been measured at $E(^{9}\text{Be}) = 14, 20$ and $26 \text{ MeV}$ for reactions (a), (c), (d) and at $14$ and $17 \text{ MeV}$ for reaction (d): see (1979AJ01). Recent measurements are at $E(^{9}\text{Be}) = 12$ to $30 \text{ MeV}$ (1980BO11, 1981HU08; reaction (d)), $14, 20$ and $26 \text{ MeV}$ (1978UN02, 1979UN01; reactions (a) (nat. Mg), (c), (d), (f)), $20 \text{ MeV}$ (1978JA07; reaction (d)), $27$ and $40 \text{ MeV}$ (1981GL03; reaction (d)), $40 \text{ MeV}$ (1981HN04; reactions (e), (f), (g)), $45$ and $60 \text{ MeV}$ (1980EC01; reactions (d), (f)), $50 \text{ MeV}$ (1977ST20; reactions (d), (f)), $158.4 \text{ MeV}$ (1983FUZY; reactions (b), (c)) and $121$ and $201.6 \text{ MeV}$ (1980ZI02; reaction (d)). For fusion studies see (1980EC03, 1983EC01). See also (1980EC04) and (1979SA1E, 1980HU09; theor.).

32. $^{10}\text{Be}(d, t)^{9}\text{Be}$ \hspace{1cm} $Q_m = -0.5548$

Forward angular distributions have been obtained at $E_d = 15.0 \text{ MeV}$ for the tritons to $^{9}\text{Be}^*(0, 1.7, 2.4, 3.1)$. The ground-state transition is well fitted by $l = 1$. The transition to $^{9}\text{Be}^*(1.7)$ [$\approx 165 \pm 25 \text{ keV}$] is consistent with $J^\pi = \frac{1}{2}^+$, that to $^{9}\text{Be}^*(2.4)$ is quite well fitted with $l = 3$ [$J^\pi = \frac{5}{2}^-$], and that to $^{9}\text{Be}^*(3.1)$ [$\Gamma = 280 \pm 25 \text{ keV}$] is consistent with $l = 2$. No other narrow states are seen up to $E_x = 5.5 \text{ MeV}$ (1970AU02).

33. $^{10}\text{B}(n, d)^{9}\text{Be}$ \hspace{1cm} $Q_m = -4.3620$

Angular distributions of the d$_0$ and d$_1$ groups have been measured at $E_n = 14.4 \text{ MeV}$: see (1974AJ01). See also $^{11}\text{B}$ in (1980AJ01).

34. $^{10}\text{B}(p, 2p)^{9}\text{Be}$ \hspace{1cm} $Q_m = -6.5865$

The summed proton spectrum at $E_p = 460 \text{ MeV}$ yields $Q = -6.7 \pm 0.5, -11.9 \pm 0.5, -17.1 \pm 0.6$ (all $l \neq 0$) and $Q = -30.5 \pm 0.6 \text{ MeV}$ ($l = 0$): see (1974AJ01).

35. $^{10}\text{B}(d, ^3\text{He})^{9}\text{Be}$ \hspace{1cm} $Q_m = -1.0930$

Angular distributions of the $^3\text{He}$ groups corresponding to $^{9}\text{Be}^*(0, 2.4)$ have been studied at $E_d = 11.8, 28$ and $52 \text{ MeV}$ [the latter also to $^{9}\text{Be}^*(6.7)$], and at $E_d = 15 \text{ MeV}$: $S = 0.72$ and $0.82$ for $^{9}\text{Be}^*(0, 2.4)$. At $E_{d-\text{bar}} = 52 \text{ MeV}$ $^{9}\text{Be}^*(11.3)$ appears to be strongly populated: see (1979AJ01).

36. $^{10}\text{B}(t, \alpha)^{9}\text{Be}$ \hspace{1cm} $Q_m = 13.2275$
At $E_t = 12.9$ MeV $\alpha$-groups are observed to the ground state of $^{9}$Be and to excited states at $E_x = 1.75 \pm 0.03$, 2.43, 3.02 $\pm$ 0.04 ($\Gamma = 320 \pm 60$ keV), 11.27 $\pm$ 0.04 ($\Gamma = 530 \pm 70$ keV), (14.4) [$\Gamma \approx 800$ keV], 14.39 and 16.67 MeV. The $T = 3/2$ state $^{9}$Be*(14.39) is very weakly populated [ $\approx 5\%$ of intensity of $\alpha_2$]. The angular distribution of the $\alpha_2$ group shows sharp forward and backward peaking. The $\alpha_0$ group is not peaked in the backward direction: see (1979AJ01). Angular distributions are also reported at $E_t = 0.9$ and 1.1 MeV to $^{9}$Be*(2.4) (1980CI1B). A study at $E_t = 1.0$ to 3.2 MeV finds $E_x = 1.750 \pm 0.025$ MeV, $\Gamma = 220 \pm 8$ keV: see (1974AJ01). See also (1978KR16; theor.) and $^{13}$C in (1981AJ01).

37. $^{10}$B($\alpha$, $^5$Li)$^9$Be

$Q_m = -8.551$

See $^5$Li.

38. $^{11}$B(n, t)$^9$Be

$Q_m = -9.5589$

The angular distribution of t$_0$ has been measured at $E_n = 14.4$ MeV: see (1974AJ01).

39. $^{11}$B(p, $^3$He)$^9$Be

$Q_m = -10.3227$

At $E_p = 45$ MeV angular distributions are reported for the $^3$He ions corresponding to $^9$Be*(0, 2.4, 11.8, 13.8, 14.39 [$T = 3/2$], 15.96 $\pm$ 0.04 [$T = 1/2$]). In addition one or more states may be located at $^9$Be*(15.13). It is suggested that $^9$Be*(11.8, 13.8, 15.96) are the $J = 3^-$, $T = 1/2$ analogs to $^9$B*(12.06, 14.01, 16.02). Angular distributions are also reported at $E_p = 40$ MeV. The intensity of the group to $^9$Be*(3.1) is $\approx 1\%$ of the ground-state group at that energy: see (1974AJ01). The excitation energy of the first $T = 3/2$ state is $E_x = 14392.9 \pm 1.8$ keV (1974KA15), using $Q_m$. See also (1981CO2D) and $^{12}$C in (1985AJ01).

40. (a) $^{11}$B(d, $\alpha$)$^9$Be

$Q_m = 8.031$

(b) $^{11}$B(d, n$\alpha$)$^4$He$^4$He

$Q_m = 6.457$

Alpha groups reported corresponding to $^9$Be*(0, 1.7, 2.4, 3.1). The width of $^9$Be*(1.7) [$E_x = 1.70 \pm 0.01$ MeV] is $\Gamma_{c.m.} = 220 \pm 20$ keV. The weighted mean of the values of $E_x$ of $^9$Be*(2.4), reported in (1974AJ01), is 2425 $\pm$ 3 keV. The $3^+$ state is at $E_x = 3.035 \pm 0.025$ MeV; $\Gamma_{c.m.} = 257 \pm 25$ keV. The ratio $\Gamma_x / \Gamma$ of $^9$Be*(1.7) $\leq 2.4 \times 10^{-5}$, that for $^9$Be*(2.4) is reported to be $(1.16 \pm 0.14) \times 10^{-4}$. Since $\Gamma_x$ is known from (e, e') [see Table 9.8: 0.089 $\pm$ 0.010 eV], $\Gamma = 0.77 \pm 0.15$ keV. See (1974AJ01, 1979AJ01) for references.
Angular distributions for \( \alpha_0 \) and \( \alpha_2 \) are reported at \( E_d = 0.39 \) to 3.9 MeV and at 12 MeV [see (1974AJ01, 1979AJ01)]. Reaction (b), at \( E_d = 10.4 \) and 12.0 MeV, proceeds via \(^9\text{Be*}(2.4)\) and to some extent via \(^9\text{Be*}(3.1, 4.7)\) and possibly some higher excited states. The dominant decay of \(^9\text{Be*}(2.4)\) is to \(^5\text{He}(0) + \alpha\) while \(^9\text{Be*}(3.1, 4.7)\) decay to \(^8\text{Be}(0) + n\). It should be noted, however, that the peaks corresponding to \(^9\text{Be*}(3.1)\) have a FWHM of \( \approx 1 \) MeV, which may imply that \(^9\text{Be*}(2.8)\) is involved.

41. (a) \(^{12}\text{C}(n, \alpha)^9\text{Be}\)  \( Q_m = -5.7010 \)
(b) \(^{12}\text{C}(n, n\alpha)^4\text{He}^4\text{He}\)  \( Q_m = -7.2747 \)

Angular distributions of the \( \alpha_0 \) group have been measured at \( E_n = 13.9 \) to 18.8 MeV [see (1974AJ01)] and at 14 MeV (1981HA1K). \(^9\text{Be*}(1.7, 2.4, 3.1)\) are also populated. At \( E_n = 14.7 \) MeV (1981GU12) report the involvement of \(^9\text{Be*}(6.76)\) which subsequently decays by n-emission. Reaction (b) at \( E_n = 13 \) to 18 MeV populates \(^9\text{Be*}(2.4)\). See also (1979SU1C) and \(^{12}\text{C}, ^{13}\text{C}\) in (1980AJ01, 1981AJ01).

42. \(^{13}\text{C}(^3\text{He}, 7\text{Be})^9\text{Be}\)  \( Q_m = -9.060 \)

Angular distributions have been obtained at \( E(^3\text{He}) = 70 \) MeV for the transitions to \(^9\text{Be*}(0, 2.4)\) and \(^7\text{Be*}(0, 0.43)\). Broad states at 2.9, 4.8 \( \pm 0.2\), 7.3 \( \pm 0.2\) and 11.9 \( \pm 0.4\) MeV are also populated (1976ST11).

43. \(^{13}\text{C}(\alpha, 8\text{Be})^9\text{Be}\)  \( Q_m = -10.7392 \)

At \( E_\alpha = 65 \) MeV angular distributions have been measured for the transitions to \(^9\text{Be*}(0, 2.4)\) (1976WO11). See also (1979BE1J).

44. \(^{19}\text{F}(d, ^{12}\text{C})^9\text{Be}\)  \( Q_m = 0.3009 \)


45. \(^{23}\text{Na}(d, ^{16}\text{O})^9\text{Be}\)  \( Q_m = -3.0059 \)

See (1981RU09; \( E_d = 13.6 \) MeV).
GENERAL: (See also (1979AJ01).)


Special states: (1981KO1Q).


Other topics: (1979BE1H, 1979LA06, 1982NG01).

Ground state of $^9B$: (1982NG01).

1. (a) $^6Li(^3He, \gamma)^9B$  
   $Q_m = 16.601$  
   $E_b = 16.601$

(b) $^6Li(^3He, n)^8B$  
   $Q_m = -1.975$

(c) $^6Li(^3He, p)^8Be$  
   $Q_m = 16.7861$

(d) $^6Li(^3He, d)^7Be$  
   $Q_m = 0.112$

(e) $^6Li(^3He, t)^6Be$  
   $Q_m = -4.307$

(f) $^6Li(^3He, ^3He)^6Li$

(g) $^6Li(^3He, \alpha)^9Li$  
   $Q_m = 14.91$

(h) $^6Li(^3He, p)^4He^4He$  
   $Q_m = 16.8779$

The $90^\circ$ yields of $\gamma_0$ and of $\gamma$ to $^9Be^*(2.36)$ (reaction (a)) has been measured for $E(^3He) = 0.6$ to 1.2 MeV [as have the 2 $\alpha$-particles from the decay of $^8Be^*(16.6)$ (reaction (c))]: they are reported to show a resonance at $E(^3He) = 765 \pm 5$ keV [$^9B^*(17.111)$], attributed to $^9B^*(17.076)$ [$T = \frac{3}{2}$] (1978AL37). The total cross section for reaction (b) increases monotonically from threshold to $\approx 7$ mb at 3.8 MeV. It then decreases monotonically from $\approx 20$ mb at $E(^3He) = 5.5$ to 7.6 MeV and also from 8.9 to 26.5 MeV: see (1979AJ01), and $^8B$.

Absolute cross sections for protons (reaction (c)) to $^8Be^*(0, 2.9, 16.6, 16.9)$ as well as for the continuum protons (reaction (h)) have been measured for $E(^3He) = 0.5$ to 1.85 MeV. Reaction rate parameters, $\langle \sigma \nu \rangle$, have been calculated for $kT = 0.01$ to 10.0 MeV (1980EL02). Excitation functions for $p_0$ and $p_1$ have been measured for $E(^3He) = 0.9$ to 17 MeV, and polarization measurements are reported at $E(^3He) = 14$ MeV. Resonances are reported at $E(^3He) = 1.6$ and 3.0 MeV [$\Gamma = 0.25$ and 1.5 MeV]: see (1974AJ01, 1979AJ01), and $^8Be$. See also (1979SL01). Polarization measurements are also reported at $E(^6Li) = 21$ MeV (1983KO04; VAP; $p_0$). A resonance in the excitation function for deuterons (reaction (d)) is observed corresponding to $^9B^*(17.6)$ (1979BU1E) [$E(^3He) = 0.7$ to 2.0 MeV]. Polarization measurements at $E(^3He) = 33.3$ MeV for
Table 9.9: Energy levels of $^9$B

<table>
<thead>
<tr>
<th>$E_x$ (MeV ± keV)</th>
<th>$J^\pi; T$</th>
<th>$\Gamma_{\text{c.m.}}$ (keV)</th>
<th>Decay</th>
<th>Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>g.s.</td>
<td>$\frac{3}{2}^-; \frac{3}{2}$</td>
<td>0.54 ± 0.21</td>
<td>p, $\alpha$</td>
<td>1, 2, 3, 4, 6, 7, 8, 10, 11, 12, 13, 14, 16, 17, 18, 19</td>
</tr>
<tr>
<td>(1.6)</td>
<td>$\frac{5}{2}^-; \frac{1}{2}$</td>
<td>≈ 700</td>
<td>(p, $\alpha$)</td>
<td>4, 13</td>
</tr>
<tr>
<td>2.361 ± 5</td>
<td>$\frac{7}{2}^-; \frac{1}{2}$</td>
<td>81 ± 5</td>
<td>$\alpha$</td>
<td>1, 2, 4, 6, 7, 8, 11, 12, 13, 14, 16, 18</td>
</tr>
<tr>
<td>2.788 ± 30</td>
<td>($\frac{3}{2}, \frac{5}{2}$)$^+; \frac{1}{2}$</td>
<td>550 ± 40</td>
<td>p</td>
<td>4, 6, 11, 13, 16, 18</td>
</tr>
<tr>
<td>(4.8 ± 100)</td>
<td></td>
<td>1000 ± 200</td>
<td></td>
<td>4, 9</td>
</tr>
<tr>
<td>6.97 ± 60</td>
<td>$\frac{7}{2}^-; \frac{1}{2}$</td>
<td>2000 ± 200</td>
<td>p</td>
<td>4, 6, 9, 11, 14, 16</td>
</tr>
<tr>
<td>11.70 ± 70</td>
<td>($\frac{7}{2}^-; \frac{1}{2}$)</td>
<td>800 ± 50</td>
<td>p</td>
<td>9, 11, 13</td>
</tr>
<tr>
<td>12.06 ± 60</td>
<td>$\frac{1}{2}^-$; $\frac{1}{2}^-$</td>
<td>800 ± 200</td>
<td>p</td>
<td>4, 9, 14</td>
</tr>
<tr>
<td>14.01 ± 70</td>
<td>$\frac{3}{2}^-; \frac{1}{2}^-$</td>
<td>390 ± 110</td>
<td></td>
<td>4, 14</td>
</tr>
<tr>
<td>14.6550 ± 2.5</td>
<td>$\frac{3}{2}^-; \frac{3}{2}^-$</td>
<td>0.395 ± 0.042</td>
<td>$\gamma$, p</td>
<td>4, 7, 14</td>
</tr>
<tr>
<td>14.7 ± 180</td>
<td>($\frac{5}{2}^-; \frac{1}{2}^-$)</td>
<td>1350 ± 200</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>15.29 ± 40</td>
<td>$\frac{1}{2}^-$; $\frac{1}{2}^-$</td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>15.58 ± 40</td>
<td>$\frac{1}{2}^-$; $\frac{1}{2}^-$</td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>16.024 ± 25</td>
<td>($\frac{1}{2}^-; \frac{1}{2}^-$)</td>
<td>180 ± 16</td>
<td></td>
<td>4, 14</td>
</tr>
<tr>
<td>17.076 ± 4</td>
<td>$T = \frac{3}{2}$</td>
<td>22 ± 5</td>
<td>($\gamma$, $^3$He)</td>
<td>1, 14</td>
</tr>
<tr>
<td>17.190 ± 25</td>
<td></td>
<td>120 ± 40</td>
<td>p, d, $^3$He</td>
<td>4, 5, 14</td>
</tr>
<tr>
<td>17.637 ± 10</td>
<td></td>
<td>71 ± 8</td>
<td>p, d, $^3$He, $\alpha$</td>
<td>1, 4, 5, 14</td>
</tr>
<tr>
<td>(18.6)</td>
<td></td>
<td>1000</td>
<td>p, $^3$He</td>
<td>1, 11</td>
</tr>
</tbody>
</table>

The $d_0$ and $d_1$ groups are reported by (1981BA38). See also (1979AJ01), and $^7$Be. Excitation functions for $t_0$ (reaction (e)) have been measured for $E(3^\text{He}) = 10$ to 16 and 23.3 to 25.4 MeV: see (1974AJ01). Polarization measurements are reported at $E(3^\text{He}) = 33.3$ MeV for the $t_0$ group as well as for the $^3$He ions to $^6$Li*(0, 2.19) (1981BA37) (reaction (f)). The elastic scattering has also been studied for $E(3^\text{He}) = 0.7$ to 2.0 MeV (1979BU1E). See also $^6$Li and $^6$Be.

The $\alpha - \alpha$ coincidences from the $^5$Li,g.s. decay (reaction (g)) have been measured for $E(^3\text{He}) = 1.4$ to 1.8 MeV: a resonance is observed at $1.57 \pm 0.02$ MeV [$^9$B*(17.63)], $\Gamma = 70 \pm 20$ keV (1978GU15). Polarization measurements of the $\alpha$-particles to $^5$Li*(0, 16.7) are reported at $E(^3\text{He}) = 33.3$ MeV (1981BA38). For reaction (h) see also (1979AJ01). See also (1982LA20), (1979KA1G, 1981HO1E) and (1980LE06, 1982HI02, 1982LE10; theor.).
2. $^6\text{Li}(\alpha, \text{n})^9\text{B}$

\[ Q_m = -3.977 \]

At $E_\alpha = 14.4$ MeV, neutron groups are observed to $^9\text{B}^*(0, 2.4)$: the upper limit of the cross section to a state at $\approx 1.7$ MeV is 100 $\mu$b/sr or $< 0.1$ of the n$_0$ group: see (1974AJ01). See also $^{10}\text{B}$.

3. $^6\text{Li}(^6\text{Li}, \text{t})^9\text{B}$

\[ Q_m = 0.805 \]

Angular distributions of the t$_0$ group have been measured for $E(^6\text{Li}) = 4.0$ to 5.5 MeV and at 7.35 and 9.0 MeV. No evidence was observed for a group, corresponding to $^9\text{B}^*(1.6)$: see (1974AJ01).

4. (a) $^7\text{Li}(^3\text{He}, \text{n})^9\text{B}$

\[ Q_m = 9.351 \]

(b) $^7\text{Li}(^3\text{He}, \text{np})^8\text{Be}$

\[ Q_m = 9.5360 \]

For $E(^3\text{He})$ to 12.5 MeV this reaction populates $^9\text{B}^*(0, 1.6, 2.4, 2.8, 7.0)$, and states at $E_x = 4.8 \pm 0.1$ MeV [1.0 \pm 0.2 MeV], 12.06 \pm 0.06 [0.8 \pm 0.2], 14.01 \pm 0.07 [0.39 \pm 0.11], 14.657 \pm 0.005 (based on $Q_m$) [\text{\textless} 0.045], 16.024 \pm 0.025 [0.180 \pm 0.016], 17.19 and 17.63 MeV [$\Gamma$ in brackets]: see (1974J01). $^9\text{B}^*(14.66)$ is the first $T = \frac{3}{2}$ state in $^9\text{B}$. Its decay properties are displayed in Table 9.6 and compared with those of $^9\text{Be}^*(14.40)$: see reaction 9 in $^9\text{Be}$ and (1974AJ01). Angular distributions have been measured at $E(^3\text{He}) = 1.56$ to 5.27 MeV: see (1974AJ01).

5. $^7\text{Be}(\text{d}, \text{p})^8\text{Be}$

\[ Q_m = 16.6738 \quad E_b = 16.489 \]

For $E_\text{d} = 0.75$ to 1.70 MeV, resonances in the yields of protons are observed at $E_\text{d} = 0.900 \pm 0.025$ MeV ($p_0$, $p_1$) and 1.475 \pm 0.010 MeV ($p_1$ only) with $\Gamma_{\text{c.m.}} = 120 \pm 40$ and 71 \pm 8 keV, respectively [$^9\text{B}^* = 17.19$ and 17.64 MeV] (1960KA17).

6. (a) $^9\text{Be}(\text{p}, \text{n})^9\text{B}$

\[ Q_m = -1.851 \]

(b) $^9\text{Be}(\text{p}, \text{pn})^8\text{Be}$

\[ Q_m = -1.6655 \]

At $E_\text{p} = 20$ MeV, $^9\text{B}^*(0, 2.4)$ are populated. The results are consistent with the excitation of $^9\text{B}^*(2.8)$ [$\Gamma \approx 0.3$ MeV] and $^9\text{B}^*(7.0)$ [$\Gamma > 1$ MeV]. No other states are excited for $E_x < 7.1$ MeV (1970AN07). Additional states have been reported: see (1979AJ01) and the comments in (1978JE01). See also (1983BY01). The width of the ground state is $540 \pm 210$ eV (1964TE01).
Angular distributions have been reported at many energies in the range \( E_p = 3.5 \) to 49.3 MeV [see (1979AJ01)] and at 8.15 to 16.98 MeV (1983BY01; \( n_0 \)). At \( E_p = 10 \) to 24 MeV reaction (b) does not appear to involve states of \(^9\text{B}\) (1978JE01) [see \(^9\text{Be}\): see, however, (1979AJ01). For polarization and yield measurements see \(^{10}\text{B}\). See also (1978BA1F, 1979WA1E, 1979WA1F; applications) and (1979BY01, 1980BA2H, 1983GU1G; theor.).

7. \(^{9}\text{Be}(^3\text{He}, \text{t})^9\text{B}\)  \( Q_m = -1.087 \)

Angular distributions have been measured for \( E(^3\text{He}) = 3.0 \) to 25 MeV and at 217 MeV; see (1974AJ01, 1979AJ01). At \( E(^3\text{He}) = 39.8 \) MeV, \(^9\text{B}_{\text{g.s.}}\) is strongly populated and \(^9\text{B}^*(2.4, 14.7)\) are also observed (1969BA06). See also \(^{12}\text{C}\) in (1980AJ01).

8. \(^{9}\text{Be}(^6\text{Li}, ^6\text{He})^9\text{B}\)  \( Q_m = -4.575 \)

At \( E(^6\text{Li}) \approx 31 \) MeV \(^9\text{B}_{\text{g.s.}}\) is strongly excited. \(^9\text{B}^*(2.4)\) is also populated: see (1974AJ01).

9. \(^9\text{C}(\beta^+)\text{B} \rightarrow ^8\text{Be} + \text{p}\)  \( Q_m = 16.682 \)
\[ \rightarrow ^5\text{Li} + \alpha \]  \( Q_m = 14.81 \)

Several groups of delayed protons are observed indicating the involvement of a number of \(^9\text{B}\) states: see Table 9.10 (1972ES05). It is not possible to determine \( f_t \) values since some of the \(^9\text{B}\) states involved decay via \(^5\text{Li} + \alpha\): (1972ES05).

10. \(^{10}\text{B}(\gamma, \text{n})^9\text{B}\)  \( Q_m = -8.437 \)

See \(^{10}\text{B}\).

11. \(^{10}\text{B}(\text{p, d})^9\text{B}\)  \( Q_m = -6.212 \)

See Table 9.11. See also (1979AJ01).

12. \(^{10}\text{B}(\text{d, t})^9\text{B}\)  \( Q_m = -2.180 \)

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Table 9.10: Delayed protons following the $\beta^+$ decay of $^9$Ca

<table>
<thead>
<tr>
<th>$E_p$ (c.m.) (MeV)</th>
<th>$\Gamma_{c.m.}$ (keV)</th>
<th>Corresponding state in $^9$B (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>if decay is to $^8$Be* (2.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>if decay is to $^8$Be_g.s.</td>
</tr>
<tr>
<td>3.45 ± 0.25</td>
<td>200 ± 100</td>
<td>3.26 ± 0.25 d</td>
</tr>
<tr>
<td>(4.2 ± 0.3)</td>
<td>1000 ± 200</td>
<td>4.0 ± 0.3</td>
</tr>
<tr>
<td>(5.0 ± 0.2)</td>
<td>400 ± 200</td>
<td>4.8 ± 0.2</td>
</tr>
<tr>
<td>6.10 ± 0.10</td>
<td>400 ± 100</td>
<td>5.91 ± 0.10</td>
</tr>
<tr>
<td>9.28 ± 0.24 b</td>
<td>1800 ± 200</td>
<td>9.09 ± 0.24</td>
</tr>
<tr>
<td>12.30 ± 0.10 b</td>
<td>450 ± 100</td>
<td>12.11 ± 0.10</td>
</tr>
</tbody>
</table>

- $a$ (1972ES05).
- $b$ Ratio of the intensities $I_{9.28}/I_{12.30} = 1.2 ± 0.2$.
- $c$ The relatively narrow width of the proton group does not permit this option.
- $d$ By analogy with the $^9$Li decay, this decay may involve a $J^\pi = \sqrt{1}/2^−$ analog of $^9$Be*(2.78). Such a state in $^9$B has not been reported in any other reaction.

Table 9.11: Levels of $^9$B from $^{10}$B(p, d)$^9$B

<table>
<thead>
<tr>
<th>$E_x$ (MeV ± keV)</th>
<th>$\Gamma_{c.m.}$ (MeV)</th>
<th>$l_a$</th>
<th>$J^\pi$ b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>1</td>
<td>$3/2^-$</td>
</tr>
<tr>
<td>2.35 ± 20</td>
<td></td>
<td>1</td>
<td>$5/2^-$</td>
</tr>
<tr>
<td>(2.8) c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.1 ± 140</td>
<td>2.15 ± 0.15</td>
<td>1</td>
<td>$7/2^-$</td>
</tr>
<tr>
<td>11.70 ± 70</td>
<td>0.80 ± 0.05</td>
<td>1</td>
<td>($7/2$)$^-$</td>
</tr>
<tr>
<td>14.7 ± 180</td>
<td>1.35 ± 0.2</td>
<td>1</td>
<td>($7/2$)$^-$</td>
</tr>
<tr>
<td>(18.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- $a$ For references see Table 9.11 in (1974AJ01).
- $b$ $J$ from best fit to theoretical spectroscopic factor (1968KU04).
- $c$ Weak group.
Angular distributions have been measured at $E_d = 11.8$ to 28 MeV. $S$ for $^9\text{B}^*(0, 2.4)$ are 0.66 and 0.58, respectively. See ($1974\text{AJ01}$, $1979\text{AJ01}$).

13. (a) $^{10}\text{B}(^3\text{He}, \alpha)^9\text{B}$ \hspace{1cm} $Q_m = 12.141$

(b) $^{10}\text{B}(^3\text{He}, \alpha)^8\text{Be}$ \hspace{1cm} $Q_m = 12.3258$

Alpha-particle spectra show the excitation of $^9\text{B}^*(0, 2.4, 2.8, 11.8)$: see ($1966\text{LA04}$). Measurements by ($1968\text{KR02}$) determine $E_x = 2.361 \pm 0.005$ and $2.788 \pm 0.030$ MeV, $\Gamma = 81 \pm 5$ and $548 \pm 40$ keV, respectively. There is some evidence for a state with $E_x \approx 1.6$ MeV, $\Gamma \approx 0.7$ MeV, but it is not conclusive, in agreement with the older work. No evidence is found for any narrow levels in $^9\text{B}$ with $\Gamma \leq 100$ keV and $4 < E_x < 7$ MeV: the upper limit to the intensity of the corresponding $\alpha$-group is 1% of the intensity of the group to $^9\text{B}^*(2.4)$ ($1968\text{KR02}$). Angular distributions have been determined at $E(^3\text{He}) = 5.5$ and 33.7 MeV.

In reaction (b) study of the decays of $^9\text{B}^*(2.4, 2.8)$ shows that $^9\text{B}^*(2.4)$ decays < 0.5% by proton emission to $^8\text{Be}(0)$ [$\theta_2^2 < 5.1 \times 10^{-3}$] [it decays to $^5\text{Li}(0)$ by $\alpha$-emission] while the second state, $E_x = 2.71 \pm 0.03$ MeV [$\Gamma = 0.71 \pm 0.06$ MeV] decays almost 100% by that channel [$\theta_d^2 = 0.74$] ($1966\text{WI08}$). No other excited states of $^9\text{B}$ with $3.5 < E_x < 9.5$ MeV decay by proton emission to $^8\text{Be}(0)$ ($1968\text{KR02}$). See also ($1974\text{AJ01}$).

14. $^{11}\text{B}(p, t)^9\text{B}$ \hspace{1cm} $Q_m = -11.409$

At $E_p = 45$ MeV angular distributions have been obtained for the triton groups to $^9\text{B}^*(0, 2.36, 12.06, 14.01, 14.66, 16.02)$. In addition the spectra show some indication of the groups corresponding to $^9\text{B}^*(7.0, 17.19, 17.64)$. $T = \frac{1}{2}$ states are reported at $E_x = 15.29 \pm 0.04$ and $15.58 \pm 0.04$ MeV ($1971\text{HA10}$). The first two $T = \frac{3}{2}$ states have been observed at $E_x = 14.6550 \pm 0.0025$ ($1974\text{KA15}$) and $17.076 \pm 0.004$ MeV [$\Gamma = 22 \pm 5$ keV] ($1974\text{BE66}$).

15. $^{12}\text{C}(\pi^+, \pi^+ t)^9\text{B}$ \hspace{1cm} $Q_m = -27.366$

See ($1979\text{EL12}$).

16. (a) $^{12}\text{C}(p, \alpha)^9\text{B}$ \hspace{1cm} $Q_m = -7.552$

(b) $^{12}\text{C}(p, p)^4\text{He}^4\text{He}$ \hspace{1cm} $Q_m = -7.2747$
Angular distributions have been measured for the $\alpha_0$ group at $E_p = 14.0$ to 54.1 MeV. Alpha groups are also observed to $^9B^*(2.3, 2.9 \pm 0.2, 6.97 \pm 0.06)$. The angular distribution to $^9B^*(6.97)$ at $E_p = 54.1$ MeV is consistent with $J^\pi = \frac{7}{2}^-$, $\Gamma \approx 2$ MeV: see (1974AJ01). Angular distributions involving the $\alpha_0$ and $\alpha^*$ groups [to $^4He^*(20.1)$, $0^+$] to $^9B_{g.s.}$ have been studied at $E_p = 45.2$ MeV (1980DA07). At $E_p = 72.4$ MeV, a study of the inclusive $(p, dX)$ reaction shows a structure which, if attributed to $^9B$, would correspond to $E_x \approx 20.7$ MeV (1981KO28). See also $^{13}N$ (1981AJ01) and (1978GO14, 1981KA04; theor.).

17. $^{12}C(^3He, ^6Li)^9B$  

$Q_m = -11.570$

Angular distributions of $^6Li$ ions have been obtained at $E(^3He) = 30.0$ and 40.7 MeV: see (1974AJ01).

18. $^{12}C(\alpha, ^7Li)^9B$  

$Q_m = -24.898$

At $E_\alpha = 65$ MeV, $^9B_{g.s.}$ and possibly $^9B^*(2.36, 2.79)$ are populated (1978SA26).

19. $^{12}C(^{16}O, ^{19}F)^9B$  

$Q_m = -15.665$

See (1982LE1N).

$^9C$  
(Figs. 17 and 18)

GENERAL: (See also (1979AJ01) for other references in this category and for some reactions on which no new work has been done.)

*Model calculations:* (1979LA06).


*Other topics:* (1979BE1H, 1979LA06, 1982NG01).

*Mass of $^9C$:* The recent $Q_0$ value for the $^{12}C(^3He, ^6He)^9C$ reaction (see reaction 3) has not been published. We therefore adopt the Wapstra mass excess: $28913.1 \pm 2.5$ keV.
1. \(^{9}\text{C}(\beta^+)^{9}\text{B} \rightarrow ^{8}\text{Be} + p\) \(Q_m = 16.682\)
   \(\rightarrow ^{5}\text{Li} + \alpha\) \(Q_m = 14.81\)

The half-life of \(^{9}\text{C}\) is 126.5 ± 0.9 msec: see (1974AJ101). Several groups of delayed protons are observed indicating the involvement of a number of \(^{9}\text{B}\) states: see Table 9.10 (1972ES05). See also (1978RA2A).

Table 9.12: Energy levels of \(^{9}\text{C}\)

<table>
<thead>
<tr>
<th>(E_x) (MeV ± keV)</th>
<th>(J^\pi; T)</th>
<th>(\tau_{1/2}) or (\Gamma)</th>
<th>Decay</th>
<th>Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>g.s.</td>
<td>((\frac{3}{2}^-), \frac{3}{2})</td>
<td>(\tau_{1/2} = 126.5 \pm 0.9) msec</td>
<td>(\beta^+)</td>
<td>1, 2, 3 (^{a})</td>
</tr>
<tr>
<td>2.218 ± 11</td>
<td>(\beta^+)</td>
<td>(\Gamma = 100 \pm 20) keV</td>
<td>(\beta^+)</td>
<td>(3)</td>
</tr>
</tbody>
</table>

\(^{a}\) See also (1974AJ01, 1979AJ01).

2. \(^{9}\text{Be}(\pi^+, \pi^-)^{9}\text{C}\) \(Q_m = -3.959\)

\(^{9}\text{C}_{g.s.}\) has been observed at \(E_{\pi^+} = 180\) MeV (1980BU15). See also (1979NA1E).

3. \(^{12}\text{C}(^3\text{He}, ^6\text{He})^{9}\text{C}\) \(Q_m = -31.574\)
   \(Q_0 = -31.5762 \pm 0.0032\): see (1980KA1J).

At \(E(^3\text{He}) = 74.1\) MeV a \(^6\text{He}\) group is observed to the first excited state of \(^{9}\text{C}\) (1974BE66).

Based on \(Q_m\), \(E_x = 2218 \pm 11\) keV and \(\Gamma = 100 \pm 20\) keV.

\(^{9}\text{N}\)
(Not illustrated)

Not observed: see (1979AJ01). See also (1982NG01; theor.).

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(Closed 1 June 1983)

References are arranged and designated by the year of publication followed by the first two letters of the first-mentioned author’s name and then by two additional characters. Most of the references appear in the National Nuclear Data Center files (Nuclear Science References Database) and have NNDC key numbers. Otherwise, TUNL key numbers were assigned with the last two characters of the form 1A, 1B, etc. In response to many requests for more informative citations, we have, when possible, included up to ten authors per paper and added the authors’ initials.

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