# Energy Levels of Light Nuclei
# $A = 5$

F. Ajzenberg-Selove

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

**Abstract:** An evaluation of $A = 5$–10 was published in *Nuclear Physics A*413 (1984), p. 1. This version of $A = 5$ 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 TUNL/NNDC format.

(References closed June 1, 1983)

The original work of Fay Ajzenberg-Selove was supported by the US Department of Energy [DE-FG02-86ER40279]. Later modification by the TUNL Data Evaluation group was supported by the US Department of Energy, Office of High Energy and Nuclear Physics, under: Contract No. DEFG05-88-ER40441 (North Carolina State University); Contract No. DEFG05-91-ER40619 (Duke University).

# Table of Contents for $A = 5$

*Below is a list of links for items found within the PDF document. Figures from this evaluation have been scanned in and are available on this website or via the link below.*

## $^{5}$n
(Not illustrated)

$^{5}$n has not been observed. It is suggested that it is unbound by 10 MeV (1981BE25; theor.). See also (1979AJ01).

## $^{5}$H
(Not illustrated)

Attempts to study this nucleus is the $^{3}$H(t, p), $^{7}$Li($^{6}$Li, $^{8}$B) and $^{9}$Be($\alpha$, $^{8}$Be) reactions, as well as in $^{7}$Li $+ \pi^{-}$ have been unsuccessful: no sharp states are observed [see (1974AJ01, 1979AJ01)]. A recent study of the spectrum of $\pi^{+}$ from $^{7}$Li $+ \pi^{-}$ suggests that $^{5}$H may be nearly stable to decay into $^{3}$H $+$ 2n (1981SE1J). The work of (1967AD05) on the $^{3}$He($^{3}$He, n)$^{5}$Be reaction suggested, on the basis of analog considerations, that $^{5}$H is unstable by more than 2.1 MeV to decay into $^{3}$H$+$2n. See also (1981SE1B) and (1981AV02, 1981BE10; theor.).

## $^{5}$He
(Figs. 1 and 3)

GENERAL: (See also (1979AJ01).)

*Model calculations:* (1978RE1A, 1979JA31, 1979KA06, 1979LU1A, 1979MA1J, 1980HA1M, 1981BE10, 1981KR1J, 1982FI13).

*Special states (The first $T = \frac{5}{2}$ state of $^{5}$He is predicted to lie at $E_{x} \approx 40$ MeV (1981BE25; theor.).):* (1979JA31, 1981BE10, 1981KU1H, 1982EM1A, 1982FI13, 1982FR1D).

*Complex reactions involving $^{5}$He:* (1979BR02, 1979RU1B).

*Reactions involving pions:* (1978FI1D, 1979BA16, 1981WH1D, 1982WH1A, 1983HUZZ).

*Reactions involving antiprotons:* (1981YA1B, 1981YA1C).

*Hypernuclei:* (1978PO1A, 1978SO1A, 1979BU1C, 1979ZO1A, 1980BA1X, 1980IW1A, 1980SC1H, 1981BA2N, 1981BA2Q, 1981KU1H, 1981LY1B, 1981RA18, 1981RE1B, 1981WA1J, 1982BA1P, 1982DA1H, 1982FI1K, 1982JO1C, 1983GI1C, 1983JO1E).

*Applied topics:* (1982GO1R).

*Other topics:* (1978BE2J, 1978RO17, 1979KA06, 1980AM1B, 1982BA1P, 1982LA11, 1982NG01).

*Ground state of $^{5}$He:* (1979BR02, 1981AV02, 1981BE10, 1982EM1A, 1982FI13, 1982KU1C, 1982NG01).

1. $^{3}$H(d, $\gamma$)$^{5}$He $\qquad Q_{\rm m} = 16.70$

Table 5.1: Energy levels of $^5$He [a]

| $E_x$ (MeV) | $J^\pi; T$ | $\Gamma_{c.m.}$ (MeV) | Decay | Reactions |
|---|---|---|---|---|
| g.s. | $\frac{3}{2}^-; \frac{1}{2}$ | $0.60 \pm 0.02$ [a] | n, $\alpha$ | 1, 4, 6, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 |
| $4 \pm 1$ | $\frac{1}{2}^-; \frac{1}{2}$ | $4 \pm 1$ | n, $\alpha$ | 4, 6, 11, 17, 18, 21 |
| $16.76 \pm 0.13$ | $\frac{3}{2}^+; \frac{1}{2}$ | $0.10 \pm 0.05$ | $\gamma$, n, d, t, $\alpha$ | 1, 2, 5, 6, 8, 9, 12, 13, 14, 20, 21 |
| $19.8 \pm 0.4$ [b] | $(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$ | $2.5 \pm 0.5$ | n, d, t, $\alpha$ | 2, 3, 5, 8, 9, 11, 13, 14, 16, 20, 21 |
| $24 - 25$ [b] | | broad | | 20, 21 |

[a] See Table 5.2 in (1966LA04) and reaction 20 here.

[b] See (1974AJ01), p. 7-8.

At low energies the reaction is dominated by a resonance at $E_d = 107$ keV; the mirror reaction shows resonance at $E_d = 430$ keV. The cross section for emission of 16.7 MeV $\gamma$-rays for $E_d = 25$ to 100 keV has been measured: the ratio $\sigma$(d, $\gamma$)/$\sigma$(d, n) is approximately constant at $(2.1 \pm 0.6) \times 10^{-4}$, leading to $\Gamma_\gamma = 14 \pm 4$ eV, where $\Gamma_n$ is taken as 66 keV. The cross sections derived from thick target yields from $E_d = 150$ to 1300 keV are analyzed into resonant and direct-capture contributions: there is disagreement about the cross section at resonance: see (1979AJ01). At $E_d = 1.03 \pm 0.05$ MeV, the differential cross section is $0.44 \pm 0.12$ $\mu$b/sr $(90°)$ and the $\gamma$ to n branching ratio is an order of magnitude smaller: $2.3 \times 10^{-5}$. The angular distribution of the $\gamma$-rays is forward peaked and the total cross section is estimated to be 4.8 $\mu$b: see (1979AJ01).

2. (a) $^3$H(d, n)$^4$He $\quad Q_m = 17.5894 \quad E_b = 16.70$

   (b) $^3$H(d, 2n)$^3$He $\quad Q_m = -2.9883$

   (c) $^3$H(d, pn)$^3$H $\quad Q_m = -2.2246$

Below $E_d = 100$ keV, the cross section for reaction (a) follows the Gamow function, $\sigma = (A/E)$ exp $(-44.40E^{-1/2})$. A strong resonance, $\sigma$(peak) $= 5.0$ b, appears at $E_d = 107$ keV: see Table 5.2. From $E_d = 10$ to 500 keV, the cross section is well fitted with the assumption of s-wave formation of a $J^\pi = \frac{3}{2}^+$ state. Excitation curves and angular distributions for reaction (a) have been measured from $E_d = 8$ keV to 21 MeV and at $E_t = 20.00$ MeV [see (1974AJ01, 1979AJ01) foir the earlier references] and at $E_t = 12.5$ to 117 keV (1983BR1G; $\sigma_t$), 7.49 to 16.65 MeV (0° excitation function; $\pm 1.0 \rightarrow 4.4\%$) and $E_d = 7$, 10, 13.36 and 16.5 MeV (angular distributions) (1978DR08) [see also for a review of other work on this reaction].

Table 5.2: Resonance parameters for the $\frac{3}{2}^+$ states observed in $^3$H(d, n)$^4$He and $^3$He(d, p)$^4$He [a]

| $E_r$ (keV) | $\Gamma_{lab}$ (keV) | $l_d$ | $J^\pi$ | $l_{n,p}$ | $R$ (fm) | $E_\lambda$ (keV) | $\gamma^2_d$ (keV) | $\gamma^2_{n,p}$ (keV) | $\theta^2_d$ [d] | $\theta^2_{n,p}$ [d] | $E_x$ (MeV) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 107 [b] | 135 | 0 | $\frac{3}{2}^+$ | 2 | 5.0 | $-464$ | $2000 \pm 500$ | $50 \pm 10$ | 1.0 | 0.018 | 16.76 |
| | | | | | 7.0 | $-126$ | 715 | 17 | 0.7 | 0.011 | |
| 450 [c] | $\approx 450$ | 0 | $\frac{3}{2}^+$ | 2 | 5.0 | $-391$ | 2930 | 42 | 1.4 | 0.013 | 16.66 |
| | | | | | 7.0 | 129 | 780 | 12 | 0.7 | 0.008 | |

[a] See references in (1979AJ01).
[b] $^3$H(d, n)$^4$He.
[c] $^3$He(d, p)$^4$He.
[d] Units of $3\hbar^2/2MR^2$.

A study of reaction (a) with polarized deuterons at $E_d = 0.2$ to 1.0 MeV indicates intervention of the s-wave, $J^\pi = \frac{1}{2}^+$ channel, as well as possible p-waves above $E_d = 0.3$ MeV. At higher energies, the neutron polarization $P_1(\theta_1)$ shows an angular distribution that peaks typically at $\theta_1 = 30°$ lab, then goes negative with increasing angle and has a minimum between $90°$ and $130°$, depending upon energy. (1971MU04) have made an extensive study of $P_1(30°)$ for $E_d = 5$ to 15 MeV and, with deuterium as target, for $E_t = 4.5$ to 19.5 MeV (neutrons near $135°$ lab). The polarization increases monotonically from 0.03 at $E_d = 3$ MeV to $\approx 0.5$ at $E_d = 6.5$ MeV and then with a lower slope to 0.69 at $E_d = 13$ MeV. The change in the slope may be caused by excited states of $^5$He near 20 MeV. Comparison with the $^3$He(d, p)$^4$He mirror reaction at corresponding c.m. energies shows excellent agreement between the polarization values in the two reactions up to $E_d = 6$ MeV, but then the proton polarization becomes $\approx 15$% higher, converging back to the neutron values at $E_d \approx 12 - 13$ MeV. This may be due to experimental factors (1971MU04). The tensor analyzing power of $A_{zz}(0°)$ has been measured for $E_{\vec{d}} = 0.24$ to 6.75 MeV: large differences in $A_{zz}(0°)$ for this reaction and for $^3$He(d, p) are reported for $E_{\vec{d}} < 1.65$ and $> 4$ MeV (1980DR01). See however (1980GR14). See also (1981CL1B, 1981DE2E; prelim.). For other polarization studies see (1974AJ01, 1979AJ01) and (1982SA05: $E_d = 37.1$ MeV).

(1981JA1F) suggests that errors of as much as 50% are possible in the reactivity values for $E_d = 10$ to 100 keV, probably because of energy-scale errors: this will affect the fusion probability errors in reactor calculations. The astrophysical $S$ function has been obtained by (1983BR1G) for the equivalent $E_d = 8.3$ to 78.1 keV.

Reaction (b) has been studied for $E_d = 10.9$ to 83 MeV: see (1974AJ01, 1979AJ01). A reanalysis of the work of (1963PO02) on reaction (c) by (1974SC04) leads to the suggestion of a resonance at $E_{c.m.} = 2.9 \pm 0.3$ MeV [$E_x = 19.6$ MeV], $\Gamma_{c.m.} = 1.9 \pm 0.2$ MeV, consistent with $J^\pi = \frac{3}{2}^-$ [see, however, Table 5.1]. For muon catalysis see (1981BY1E, 1982BE1P, 1982BR1R, 1983JO1F).

See also (1979BA2X, 1979OH1B, 1981HA1P), (1980DR1C, 1981DR05, 1982RA1A), (1978BA1F, 1979FO1R, 1979GR1P, 1979GR2D, 1979HA2C, 1980BR1D, 1980PE1J, 1981HA1N, 1982HE1F, 1982MI1E, 1982RA1F; applications) and (1978FI1D, 1981BE1P, 1981BO2C, 1981BR1G, 1981GE1C; theor.).

3. $^3$H(d, d)$^3$H $E_b = 16.70$

The elastic scattering has been studied for $E_d = 2.6$ to 11.0 MeV [see (1979AJ01)] and at $E_t = 0.6$ to 3.4 MeV (1979KA33). The excitation curves show an interference at $E_x \approx 19$ MeV and a broad ($\Gamma > 1$ MeV) resonance corresponding to $E_x = 20.0 \pm 0.5$ MeV, similar to that seen in $^3$He(d, d) [see $^5$Li]. Together with data from $^3$H(d, n)$^4$He, this work favors an assignment $D_{3/2}$ or $D_{5/2}$ with a mixture of doublet and quartet components (channel spin $\frac{1}{2}$ and $\frac{3}{2}$) if only one state is involved [any appreciable doublet component would, however, be in conflict with results from $^7$Li(p, $^3$He)$^5$He]. Measurements of differential cross section and analyzing power using polarized deuterons with $E_d = 3.2$ to 12.3 MeV show resonance-like behavior in the vector analyzing power near $E_d = 5$ MeV. The anomaly appears in the odd Legendre coefficients and is interpreted in terms of a $(\frac{1}{2}, \frac{3}{2})^-$ excited state of $^5$He with $E_x \approx 19.6$ MeV. Broad structure in the differential cross section near 6 MeV, principally in the even Legendre coefficients, corresponds to an even-parity state $^5$He*(20.0). For other polarization measurements (and for references) see (1979AJ01). See also (1978TA1A, 1981BO2C; theor.).

4. (a) $^3$H(t, n)$^5$He $Q_m = 10.44$
(b) $^3$H(t, 2n)$^4$He $Q_m = 11.3322$

At $E_t = 0.5$ MeV, the reaction appears to proceed via three channels: (i) direct breakup into $^4$He$+$2n, the three-body breakup shape being modified by the n-n interaction; (ii) sequential decay via $^5$He(0); (iii) sequential decay via a broad excited state of $^5$He. The width of $^5$He(0) is estimated to be $0.74 \pm 0.18$ MeV. Some evidence is also shown for $^5$He* at $E_x \approx 2$ MeV, $\Gamma \approx 2.4$ MeV: see (1979AJ01). For reaction (b), see $^6$He.

5. (a) $^3$He(t, p)$^5$He $Q_m = 11.21$
(b) $^3$He(t, pn)$^4$He $Q_m = 12.0959$

Some evidence is reported at $E_t = 22.25$ MeV in reaction (a) for a broad state of $^5$He at $E_x \approx 20$ MeV, in addition to a sharp peak corresponding to $^5$He*(16.7): see (1979AJ01). For reaction (b) see $^6$Li.

6. $^4$He(n, n)$^4$He $E_b = -0.89$

Thye coherent scattering length (thermal, bound) is $3.07 \pm 0.02$ fm, $\overline{\sigma_s} = 0.76 \pm 0.01$ b (1981MUZQ). Total cross sections for $E_n = 4 \times 10^{-4}$ eV to 150.9 MeV and at 10 GeV/$c$ are summarized in (1974AJ01, 1976GAYV). For polarization measurements see (1974AJ01, 1979AJ01) and (1983YO01; $E_n = 50.4$ MeV).

The total cross section has a peak of 7.6 b at $E_n = 1.15 \pm 0.05$ MeV, $E_{c.m.} = 0.92 \pm 0.04$ MeV, with a width of about 1.2 MeV. A second resonance is observed at $E_n = 22.15 \pm 0.12$ MeV, corresponding to the 16.7 MeV $J^\pi = \frac{3}{2}^+$ state: $\Gamma_{c.m.} = 100 \pm 50$ keV [see (1979AJ01) for references]. $\Gamma_n = \Gamma_d = 45 \pm 10$ keV (1981MUZQ). [(1966HO07) find that the data are fitted best by $\Gamma_n < \Gamma_d$ although $\Gamma_n > \Gamma_d$ is not excluded]. Attempts to detetct additional resonances in the total cross section have been unsuccessful: see (1966LA04).

The $P_{3/2}$ phase shift shows strong resonance behavior near 1 MeV, while the $P_{1/2}$ shift changes more slowly, indicating a broad $P_{1/2}$ level at several MeV excitation. (1966HO07) have constructed a set of phase shifts for $E_n = 0$ to 31 MeV, $l = 0$, 1, 2, 3 using largely p-$\alpha$ phase shifts. At the $\frac{3}{2}^+$ state the best fit to all data is given by $E_{res} = 17.669$ MeV $\pm$ 10 keV, $\gamma_d^2 = 2.0$ MeV $\pm$ 25%, $\gamma_n^2 = 50$ keV $\pm$ 25% (see Table 5.2). The work of (1976LI15) indicates some discepancies with the results of (1966HO07) [below $E_n = 22$ MeV].

An $R$-function analysis of the $^4$He + n data below 21 MeV (including the absolute neutron analyzing power measurement of (1976BO05) and the accurate cross-section measurements of (1973GO38) has led to a set of phase shifts and analyzing powers which are based on the $^4$He + n data alone (rather than also including the $^4$He + p data). At $r = 3.3$ fm the values obtained for the $P_{1/2}$ and $P_{3/2}$ resonances are, respectively, $E_{c.m.} = 1.97$ and 0.77 MeV, $\Gamma_{c.m.} = 5.22$ and 0.64 MeV (1977BO24). See also (1982FR11; theor.).

See also (1978TA1A, 1978TH1A, 1979FO16, 1979KA17, 1979LE1B, 1980DM1A, 1980FU1G, 1980LA20, 1980PE1K, 1980VI01, 1981FR20, 1982AV02, 1982AZ01, 1982FR14, 1982LE1G, 1982OR03; theor.).

7. $^4$He(n, d)$^3$H $Q_m = -17.5894$ $E_b = -0.89$

For a study of the polarization at $E_{\vec{n}} = 50$ MeV see (1982SA05). See also (1979AJ01) and reaction 7 in $^5$Li.

8. $^4$He(p, $\pi^+$)$^5$He $Q_m = -141.24$

See (1981WI1F, 1982LE1L).

9. (a) $^4$He(d, p)$^5$He $Q_m = -3.11$

(b) $^4$He(d, pn)$^4$He $Q_m = -2.2246$

A typical proton spectrum consists of a peak corresponding to formation of the ground state of $^5$He, plus a lower continuum of protons ascribed to deuteron breakup (reaction (b)). Ground-state protons show pronounced azimuthal asymmetry when the reaction is induced by 8.5, 10 and 11 MeV vector polarized deuterons. Reaction (b) has been studied for $E = 6.8$ to 165 MeV: see (1979AJ01). See also $^6$Li.

At $E_\alpha = 70$ MeV, a kinematically complete experiment (reaction (b)) shows evidence for sequential decay, proceeding through excited states of $^5$He. Peaks in the coincident yield of protons and deuterons are ascribed to narrow states at $E_{\rm x} = 16.7 \pm 0.1$ MeV, $\Gamma = 80 \pm 30$ keV, at $E_{\rm x} = 18.6 \pm 0.1$, $18.8 \pm 0.1$ and $19.2 \pm 0.1$ MeV, all with $\Gamma = 180 \pm 60$ keV (1973TR04). The fine structure near 19 MeV is not confirmed in other experiments [see, however, reaction 13]. Polarization studies are reported at $E_{\vec{\rm d}} = 12$ and 17 MeV (1983SL01), 12.0 and 21 MeV (1982IS06) and at 18 MeV (1981OS02). See also reaction 5 in $^6$Li, (1980BR20, 1980BR28, 1982LA14) and (1978NA12, 1980KO04; theor.).

10. $^4$He(t, nd)$^4$He $\qquad Q_{\rm m} = -6.2573$

The results displayed in (1979AJ01) have not been published.

11. $^6$Li($\gamma$, p)$^5$He $\qquad Q_{\rm m} = -4.59$

At $E_\gamma = 60$ MeV, the proton spectrum shows two prominent peaks attributed to $^5$He*($0 + 4.0$, $20 \pm 2$) (1976MA34). See also (1979AJ01) and $^6$Li.

12. $^6$Li(e, ep)$^5$He $\qquad Q_{\rm m} = -4.59$

At $E_{\rm e} = 1180$ MeV, the exciation of $^5$He*(0, 16.7) is reported: the latter state is formed with the ejection of an s-proton: see (1979AJ01) and reaction 5 in $^6$Li.

13. (a) $^6$Li(n, d)$^5$He $\qquad Q_{\rm m} = -2.37$
(b) $^6$Li(n, nd)$^4$He $\qquad Q_{|rmm} = -1.4753$

Angular distributions of ground-state deuterons have been studied at $E_{\rm n} = 6.57$, 6.77, 14.4 and 56.3 MeV and recently at 14.1 MeV (1982HI06). At $E_{\rm n} = 56.3$ MeV angular distributions have also been obtained to $^5$He*(16.7, $18.5 \pm 0.5$, $20.5 \pm 0.5$). The observation of the two highest states is not certain: if they exist their widths are less than the instrumental width, 1.6 MeV (1977BR17). See also (1974AJ01, 1979AJ01).

14. $^{6}$Li(p, 2p)$^{5}$He $Q_{\rm m} = -4.59$

At $E_{\rm p} = 100$ MeV the population of $^{5}$He*(0, 16.7) and possibly of a broad structure at $E_{\rm x} \approx 19$ MeV is observed: momentum distributions for $^{5}$He*(0, 16.7) and angular correlation measurements are also reported. The main features of the data are reasonably well described by DWIA: see (1974AJ01, 1979AJ01). See also (1981PA25, 1982GO1H).

15. (a) $^{6}$Li(d, $^{3}$He)$^{5}$He $Q_{\rm m} = 0.90$
(b) $^{6}$Li(d, n$^{3}$He)$^{4}$He $Q_{\rm m} = 1.794$

$^{5}$He$_{\rm g.s.}$ has been observed in reaction (a) at $E_{\rm d} = 14.5$ MeV: see (1979AJ01) [the $E_{\rm d} = 80$ MeV work has not been published]. For reaction (b) see (1979HO04) and $^{8}$Be.

16. $^{6}$Li($\alpha$, $\alpha$p)$^{5}$He $Q_{\rm m} = -4.59$

At $E_{\alpha} = 140$ MeV, $^{5}$He*(0, 20.0) are populated: DWIA calculations provide a good fit to the data (1979NA06). See also (1979AJ01).

17. $^{7}$Li($\gamma$, d)$^{5}$He $Q_{\rm m} = -9.62$

Differential cross sections have been measured at $E_{\gamma} = 100$ and 150 MeV to $^{5}$He*(0, 4.0) by (1982KIZW).

18. (a) $^{7}$Li($\pi^{+}$, 2p)$^{5}$He $Q_{\rm m} = 128.51$
(b) $^{7}$Li($\pi^{-}$, 2n)$^{5}$He $Q_{\rm m} = 126.95$

Reaction (a) shows broad structures attributed to the ground state of $^{5}$He, to the excited state at 4 MeV (1981WH1C) and to p$^{-1}$s$^{-1}$ and s$^{-2}$ states at $\approx 20$ and $(\approx 35)$ MeV excitation: see (1979AJ01). For reaction (b) see (1977BA1M).

19. (a) $^{7}$Li(n, t)$^{5}$He $Q_{\rm m} = -3.36$
(b) $^{7}$Li(n, tn)$^{4}$He $Q_{\rm m} = -2.468$

The angular distribution of $t_0$ has been measured at $E_\mathrm{t} = 14.4$ MeV. Reaction (b) at the same energy involves $^7$Li*(4.63) and $^5$He$_\mathrm{g.s.}$: see (1979AJ01) and $^8$Li. See also (1979BE1K; theor.).

20. (a) $^7$Li(p, $^3$He)$^5$He $\qquad Q_\mathrm{m} = -4.12$
    (b) $^7$Li(p, pd)$^5$He $\qquad Q_\mathrm{m} = -9.62$

At $E_\mathrm{p} = 43.7$ MeV, angukar distributions of the $^3$He groups to the ground state of $^5$He ($\Gamma = 0.80 \pm 0.04$ MeV; $L = 0{+}2$) and to levels at 16.7 MeV $(L = 1)$ and $19.9 \pm 0.4$ MeV ($\Gamma = 2.7$ MeV) have been studied. Since no transitions are observed in the $^7$Li(p, t)$^5$Li reaction to the analogue 20 MeV state in $^5$Li [see $^5$Li], the transition is presumably $S$-forbidden and the states in $^5$He–$^5$Li near 20 MeV are $^4D_{3/2}$ or $^4D_{5/2}$ [compare $^3$H(d, d)]. Particle-particle coincidence data have been obtained at $E_\mathrm{p} = 43.7$ MeV. They suggest the existence of $^5$He*(20.0) with $\Gamma = 3.0 \pm 0.6$ MeV and of a broad state at $\approx 25$ MeV. No $T = \frac{3}{2}$ states decaying via $T = 1$ states in $^4$He were observed: see (1979AJ01). In reaction (b) (1981ER10; 670 MeV), $^5$He*($0 + 4$, 16.7, 25) appear to be involved.

21. (a) $^7$Li(d, $\alpha$)$^5$He $\qquad Q_\mathrm{m} = 14.23$
    (b) $^7$Li(d, n)$^4$He$^4$He $\qquad Q_\mathrm{m} = 15.121$

At $E_\mathrm{d} = 24$ MeV, the $\alpha$-particle spectrum from reaction (a) shows structures corresponding to the ground and 16.7 MeV states and to states at $E_\mathrm{x} \approx 20.2$ and 23.8 MeV with $\Gamma \approx 2$ MeV and $\approx 1$ MeV respectively: see (1979AJ01). See also (1977RO1C).

Reaction (b) proceeds mainly via excited states of $^8$Be and $^5$He$_\mathrm{g.s.}$. Spectra suggest the involvement of the $P_{1/2}$ state: the values suggested are inconsistent with each other because of the difficulty of evaluating the contribution to other reactions: see (1974AJ01) for the earlier values and see (1976FO21) for a discussion of some of the problems involved in these. (1976FO21) suggest a width for $^5$He$_\mathrm{g.s.} = 0.6$ MeV and $E_\mathrm{x} = 4.1 \pm 0.2$, $\Gamma_\mathrm{c.m.} = 4.4 \pm 0.2$ MeV for the $P_{1/2}$ state. See also (1980NE1B, 1982LA21), and $^7$Li, $^8$Be and $^9$Be.

22. (a) $^9$Be(p, p$\alpha$)$^5$He $\qquad Q_\mathrm{m} = -2.46$
    (b) $^9$Be(p, d$^3$He)$^5$He $\qquad Q_\mathrm{m} = -20.82$

Reaction (a) has been studied for $E_\mathrm{p} = 26.0$ to 100 MeV [see (1979AJ01)] and at 101.5 MeV (1980NA09). Reaction (b) has also been studied at the latter energy. DWIA calculations show that the reactions are dominated by quasifree processes (1980NA09). The continuum has been studied by (1983DE14) at $E_\mathrm{p} = 30$, 50 and 75 MeV. See also $^9$Be.

23. $^{9}$Be($^{3}$He, $^{7}$Be)$^{5}$He $\qquad Q_{\rm m} = -0.88$

The continuum has been studied by (1983DE14, 1981DE1X; $E(^{3}{\rm He}) = 45$ MeV): the ground state is also strongly populated.

24. (a) $^{9}$Be($\alpha$, $2\alpha$)$^{5}$He $\qquad Q_{\rm m} = -2.46$

(b) $^{9}$Be($\alpha$, $^{8}$Be)$^{5}$He $\qquad Q_{\rm m} = -2.56$

Reaction (a) has been studied at $E_{\alpha} = 28$ to 37.4 MeV [see (1974AJ01)] and at 18 MeV (1980ZH1A). Reaction (b) has been studied at $E_{\alpha} = 65$ MeV: only $^{5}{\rm He}_{\rm g.s.}$ is observed for $E_{\rm x} \leq 25$ MeV (1976WO11). See also (1981BA20; theor.).

25. $^{10}$B(d, $^{7}$Be)$^{5}$He $\qquad Q_{\rm m} = -1.97$

See (1982DO1E).

26. $^{11}$B(d, n)$^{4}$He$^{4}$He$^{4}$He $\qquad Q_{\rm m} = 6.4568$

At $E_{\rm d} = 3.8$ to 12 MeV this reaction involves $^{5}{\rm He}_{\rm g.s.}$ and states in $^{8}$Be, $^{9}$Be and $^{12}$C: see (1979AJ01).

# $^5$Li

(Figs. 2 and 3)

GENERAL: (See also (1979AJ01).)

*Model calculations:* (1978RE1A, 1979MA1J, 1980HA1M, 1981BE10, 1982FI13).

*Special states:* (1981BE10, 1981KU1H, 1982EM1A, 1982FI13, 1982FR1D).

*Complex reactions involving* $^5$*Li:* (1979BR02, 1979RU1B).

*Reactions involving pions:* (1978BR1V, 1979SA1W, 1983AS02).

*Reactions involving antiprotons:* (1981YA1B).

*Hypernuclei:* (1980IW1A, 1981KO1V, 1981KU1H, 1983GI1C).

*Other topics:* (1978BE2J, 1982NG01).

*Ground state of* $^5$*Li:* (1979BR02, 1981BE10, 1982EM1A, 1982FI13, 1982KU1C, 1982NG01).

1. $^3$He(d, $\gamma$)$^5$Li $\qquad Q_{\rm m} = 16.39$

Excitation curves and angular distributions have been measured for $E_{\rm d} = 0.2$ to 5 MeV and $E(^3{\rm He}) = 2$ to 26 MeV. A broad maximum in the cross section is observed at $E_{\rm d} = 0.45 \pm 0.04$ MeV [$^5$Li*(16.66)]. $\sigma_{\gamma_0} = 21 \pm 4$ $\mu$b, $\Gamma_{\gamma_0} = 5 \pm 1$ eV. The radiation at resonance is isotropic, consistent with s-wave capture. Study of $\gamma_0$ and $\gamma_1$ yield $\Gamma = 2.6 \pm 0.4$ MeV for the ground-state width, and $E_{\rm x} = 7.5 \pm 1.0$ MeV, $\Gamma = 6.6 \pm 1.2$ MeV for the $\frac{1}{2}^-$ state: see (1974AJ01).

An excess in the cross section at higher bombarding energies is interpreted as being due to a state at $E_{\rm x} \approx 18$ MeV: even parity is deduced from the relative intensity of $\gamma_0$ and $\gamma_1$. It is presumed to be the $\frac{1}{2}^+$ state reported in reactions 2 and 6. A broad peak is also observed at $E_{\rm x} \approx 20.7$ MeV in the $\gamma_0$ cross section. The cross section for $\gamma_1$ is $\approx 0$. The observations are consistent with $J^\pi = \frac{5}{2}^+$: angular distributions appear to require at least one other state with significant strength near 19 MeV: see (1974AJ01).

2. (a) $^3$He(d, p)$^4$He $\qquad Q_{\rm m} = 18.3532 \qquad E_{\rm b} = 16.39$

(b) $^3$He(d, np)$^3$He $\qquad Q_{\rm m} = -2.2246$

(c) $^3$He(d, 2p)$^3$H $\qquad Q_{\rm m} = -1.4608$

(d) $^3$He(d, 2d)$^1$H $\qquad Q_{\rm m} = -5.4936$

Below 100 keV the cross section follows the simple Gamow form: $\sigma = (18.2 \times 10^3/E)$ exp $(-91E^{-1/2})$ b ($E$ in keV). The zero-energy cross-section factor $S_0 = 6700$ kev $\cdot$ b. [However

Table 5.3: Energy levels of $^5$Li [a]

| $E_x$ (MeV) | $J^\pi; T$ | $\Gamma_{c.m.}$ (MeV) | Decay | Reactions |
|---|---|---|---|---|
| g.s. | $\frac{3}{2}^-; \frac{1}{2}$ | $\approx 1.5$ | p, $\alpha$ | 1, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20 |
| $5 - 10$ | $\frac{1}{2}^-; \frac{1}{2}$ | $5 \pm 2$ | p, $\alpha$ | 1, 6, 9, 11, 13, 15, 17 |
| $16.66 \pm 0.07$ | $\frac{3}{2}^+; \frac{1}{2}$ | $\approx 0.3$ | $\gamma$, p, d, $^3$He, $\alpha$ | 1, 2, 3, 6, 11, 13, 14 |
| $(18 \pm 1)$ | $(\frac{1}{2}^+); \frac{1}{2}$ | broad | $\gamma$, p, d, $^3$He, $\alpha$ | 1, 2 |
| $(20.0 \pm 0.5)$ [a] | $(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$ | $\approx 5$ | $\gamma$, p, d, $^3$He, $\alpha$ | 1, 2, 3, 4, 11, 13 |

[a] See also discussion in reactions 2, 3, 6, 15.

(1981JA1F) suggest that the cross section below 100 keV may be in error by as much as 50%.] A pronounced resonance occurs at $E_d = 430$ keV, $\Gamma \approx 450$ keV. The peak cross section is $695 \pm 14$ mb: see Table 5.2. Excitation functions for ground-state protons have also been reported for $E(^3\text{He}) = 0.39$ to 1.46 MeV and 18.7 to 44.1 MeV, for $E_d = 2.8$ to 17.8 MeV [see (1974AJ01)], and at $E(^3\text{He}) = 0.20$ to 2.15 MeV (1980MO03). Angular distributions have been measured for $E_d = 0.25$ to 27 MeV and $E(^3\text{He}) = 18.7$ to 44.1 MeV [see Table 5.6 in (1974AJ01) and (1979AJ01)]. Resonance-like behavior is suggested at $E_x = 16.6$, 17.5, 20.0, 20.9 and 22.4 MeV: see (1979AJ01).

Tensor analyzing power measurements are reported for $E_{\vec{d}} = 0.48$ to 6.64 MeV (1980DR01). [See, however, (1980GR14) for a discussion of the (1980DR01) results and for a summary of $T_{20}(0^\circ)$ for $E_{\vec{d}} = 0$ to 40 MeV]. (1981RO13) report measurements of angular distributions, of $\sigma_t$ and of the VAP for $E_{\vec{d}} = 14.6$ to 39.9 MeV: the results are consistent with the presence of an f-wave $\frac{7}{2}^-$ state and suggest the importance of d-wave amplitudes. Measurements of angular distributions and analyzing powers at $E(^3\vec{\text{He}}) = 27$ and 33 MeV suggest the presence of a broad resonance(s) at $E_x \approx 28$ MeV (1979OK03). For other recent polarization studies see (1980ST1A) and (1979BUZO, 1981CL1B, 1981DE1G, 1981DE2E, 1981WO1C, 1982COZO; all preliminary). The earlier polarization work is summarized in Tables 5.6 (1974AJ01) and 5.4 (1979AJ01).

Reactions (b), (c) and (d) have been studied at $E_d = 22.3$ and 35 MeV and at $E(^3\text{He}) = 30$, 33.5 and 52.5 MeV and analyzed with a PWIA: Fourier transforms of the wave functions were obtained. At $E(^3\text{He}) = 35.9$ MeV, the spectra in reactions (b) and (c) are dominated by the nucleon-nucleon FSI: the results were fitted with a fully antisymmetrized PWBA and with DWBA. Polarization measurements for reactions (b) and (c) are reported at $E_{\vec{d}} = 15$ MeV (1976ME13) and at $E(^3\vec{\text{He}}) = 33$ MeV (1980OK04). (1976SC26) have studied the excitation function for reaction

(c) for $E_d = 2.2$ to 6 MeV in a kinematically complete experiment. They have extracted the p + t FST going via $^4$He*(20.1) [$J^\pi = 0^+$] and suggest that the reaction goes primarily via a $J^\pi = \frac{3}{2}^-$, $T = \frac{1}{2}$ state of $^5$Li located $0.8 \pm 0.2$ MeV above threshold [i.e. $E_x = 18.9 \pm 0.2$ MeV]. This suggests that the attraction of a $p_{3/2}$ nucleon to $^4$He*($0^+$) is stronger than is the attraction of such a nucleon to $^4He_{g.s.}$ (1976SC26). (1981FU11) have studied the deuteron breakup (reactions (b), (c), (d)) at $E(^3He) = 89.4$ and 118.9 MeV.

See also (1981TO1G), (1974AJ01, 1982DA1K), (1979DI1C, 1983BL1C; applications) and (1978FI1D, 1979SE04, 1981NE1B, 1983DU1C; theor.).

3. $^3$He(d, d)$^3$He $\qquad E_b = 16.39$

In the range $E_d = 380$ to 570 keV, the scattering cross section is consistent with s-wave formation of the $J^\pi = \frac{3}{2}^+$ state at 16.66 MeV. The excitation curves for $E_d = 1.96$ to 10.99 MeV show a broad resonance ($\Gamma > 1$ MeV) corresponding to $E_x = 20.0 \pm 0.5$ MeV. From the behavior of the angular distributions an assignment of $^2D_{3/2}$ or $(^2D, ^4D)_{5/2}$ is favored, if only one state is involved: see (1979AJ01). A phase-shift analysis by (1980JE01) of the angular distribution and VAP data below 5 MeV suggests several MeV broad states [$^2P_{3/2}$, $^4D_{7/2}$, $^4D_{5/2}$, $^4D_{3/2}$ and, possibly, $^4D_{1/2}$].

Angular distributions and analyzing powers have been measured at many energies to $E = 44$ MeV: see (1979AJ01) for the earlier work, (1979JE02: $E_{\vec{d}} = 1.5$ to 11.5 MeV; $\sigma(\theta)$ and VAP, $T_{20}(\theta)$, $T_{21}(\theta)$, $T_{22}(\theta)$) and (1981RO13: $E_{\vec{d}} = 14.6$ to 40 MeV; $\sigma(\theta)$, $\sigma_t$ and VAP). See also (1983BR1E) and (1978TA1A, 1979SE04, 1980ZE1D, 1981SA1N; theor.).

4. (a) $^3$He(t, n)$^5$Li $\qquad Q_m = 10.13$
(b) $^3$He(t, np)$^4$He $\qquad Q_m = 12.0959$

At $E(^3He) = 14$ to 26 MeV, the spectra show the $n_0$ group and a broad resonance with $E_x = 20.5 \pm 0.8$ MeV (1974CH15). For reaction (b) see (1979AJ01). See also $^6$Li.

5. (a) $^3$He($^3$He, p)$^5$Li $\qquad Q_m = 10.90$
(b) $^3$He($^3$He, 2p)$^4$He $\qquad Q_m = 12.8596$
(c) $^3$He($^3$He, 3p)$^3$H $\qquad Q_m = -6.9544$

The spectrum of protons shows a pronounced peak at $E(^3He) = 3$ to 18 MeV corresponding to $^5Li_{g.s.}$ superposed on a continuum: see (1974AJ01). Searches for three-proton enhancement (reaction (c)) have been unsuccessful: see (1974AJ01). See also (1979AJ01) and $^6$Be.

6. $^4$He(p, p)$^4$He $E_b = -1.96$

Differential cross sections and polarization measurements have been carried out at many energies: see Tables 5.5 in (1966LA04), 5.7 in (1974AJ01) and 5.5 in (1979AJ01). Recent studies include those of (1978HO17; $E_p = 21.85$ to 47.65 MeV), (1983RI01; $E_{\vec{p}} = 28.8$, 29.77 and 30.40 MeV), (1979IM01; $E_{\vec{p}} = 45.0$, 52.3, 59.6 and 64.9 MeV), (1980MO09; $E_{\vec{p}} = 200$, 350 and 500 MeV), (1979GR08; $E_{\vec{p}} = 222$, 325 and 518 MeV; analyzing powers at $\theta_{lab} = 15°$), (1982VE03; $E_p = 992$ MeV) and (1979CO01; $E_{\vec{p}} = 0.56$, 0.80, 1.03, 1.24, 1.73 GeV). See also (1981KH1C, 1981RO1J). For work at GeV energies (to $E_{c.m.} = 88$ GeV) see (1978BR1V, 1978DU15, 1978NA13, 1979VA1L, 1980AB1C, 1982BE1X, 1982FA1B).

Phase shifts below $E_p = 18$ MeV have been determined by (1977DO01) based on all the available cross-section and polarization measurements, using an $R$-matrix analysis program. The $P_{3/2}$ phase shift shows a pronounced resonance corresponding to $^5$Li$_{g.s.}$ while $P_{1/2}$ shift changes slowly over a range of several MeV, suggesting that the first excited state is very broad and located 5–10 MeV above the ground state. The reduced widths of the P-wave resonance states are nearly the same. The $D_{5/2}$, $D_{3/2}$, $F_{7/2}$ and $F_{5/2}$ phase shifts become greater than $1°$ at $E_p \approx 11$, 13, 14 and 16 MeV, respectively (1977DO01).

A phase-shift analysis for $E_p = 21.8$ to 55 MeV is presented by (1978HO17) [see also for analyzing power contour diagram for $E_p = 20$ to 65 MeV]. A striking anomaly is seen in the analyzing power at $E_p = 23$ MeV and the $^2D_{3/2}$ phase shift clearly shows the $\frac{3}{2}^+$ state at $E_x = 16.7$ MeV [see also (1979AJ01)]. The other phase shifts $^2S_{1/2}$, $^2P_{3/2}$, $^2P_{1/2}$, $^2D_{5/2}$, $^2F_{7/2}$, $^2F_{5/2}$, $^2G_{9/2}$ and $^2G_{7/2}$ are smooth functions of energy. Both the $^2P_{3/2}$ and $^2P_{1/2}$ inelastic parameters show a somewhat anomalous behavior at $E_p \approx 30$ MeV: the absorption first increases then decreases to stay rather constant at $E_p > 40$ MeV. These results are consistent with broad and overlapping states with $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$ at $E_x \approx 22$ MeV. There is very little splitting of the real parts of the F-wave phase shifts up to 40 MeV. There is some indication (from the $^2G_{7/2}$ phase shifts) of a $\frac{7}{2}^+$ level around $E_p = 29$ MeV [$E_x \approx 21$ MeV]. The G-waves are necessary to fit the detailed shape of the angular distributions for $E_p = 20$ to 55 MeV (1978HO17). For a contour diagram of the analyzing power for $E_p = 130$ to 1800 MeV see (1980MO09). For the earlier work see (1979AJ01). See also (1982FR11; theor.).

(1982HE1C) have studied parity non-conservation (PNC) by comparing the cross sections $\sigma^+$ and $\sigma^-$ (positive and negative helicities) for longitudinally polarized 46 MeV protons. The longitudinal polarizing power $A_z = (0.3 \pm 1.3) \times 10^{-7}$ [see (1982HE1C) for a discussion of the weak pion-nucleon coupling constant].

A search for $\gamma$-ray transitions within the broad ground state of $^5$Li has been unsuccessful (1983SC10; $E_p = 1.5$ to 7.0 MeV). For a measurement of the spin rotation parameter $R$ at $E_p = 500$ MeV see (1983MO01). For total cross-section measurements see (1979SC07; $224 \rightarrow 563$ MeV), (1981KH1C; 992 MeV) and (1978JA16; 0.87 and 2.1 GeV/nucleon). See also (1980FA08; inelastic interactions at $E_\alpha = 1.74$ and 2.57 GeV).

See also (1977BO40, 1982BE1T), (1982GO1A), (1978AL1G, 1978BR1A, 1980CA1A, 1980LE19, 1981IG1A, 1982FA1F, 1982IG2A, 1983YO01) and (1978AH03, 1978AU11, 1978GR1G, 1978GR1H, 1978HA2F, 1978HE2A, 1978LE2E, 1978MA2M, 1979AL12, 1979AR02, 1979AR06, 1979DY07,

1979GH01, 1979KA17, 1979KOZV, 1979LE1T, 1979LU1A, 1979SA09, 1979SA35, 1979SH1V, 1979WI1B, 1980AR08, 1980AU09, 1980DM1A, 1980DY1A, 1980FU1G, 1980GO1K, 1980LA20, 1980PE1K, 1980RO1L, 1980VI01, 1980WA06, 1981AU07, 1981FE02, 1981FR20, 1981GU1F, 1981KH07, 1981LY1B, 1981NI1E, 1981RO1G, 1981SH04, 1981TE01, 1981VA1L, 1981ZH03, 1982AV02, 1982AZ01, 1982FR14, 1982PA1B, 1982PR1E, 1982PR1F, 1982PR1G, 1982WA1H, 1983SA1H, 1983SH12, 1983VI1D; theor.).

| | | |
|---|---|---|
| 7. (a) $^4$He(p, d)$^3$He | $Q_m = -18.3532$ | $E_b = -1.96$ |
| (b) $^4$He(p, pn)$^3$He | $Q_m = -20.5778$ | |
| (c) $^4$He(p, 2p)$^3$H | $Q_m = -19.8140$ | |
| (d) $^4$He(p, pd)$^2$H | $Q_m = -23.8467$ | |

Angular distributions of $^3$He ions (reaction (a)) have been measured for $E_p = 27.9$ to 770 MeV and at $E_\alpha = 3.98$ GeV/$c$ [see (1979AJ01)] and at $E_p = 200$ and 400 MeV (1981LI1B). Excitation functions are reported at $E_p = 38.5$ to 44.6 MeV [see (1979AJ01)] and 200 to 500 MeV (1978KA2A). For polarization measurements to 500 MeV see (1979AJ01) and (1981LI1B, 1982SA05, 1983RI01). At $E_{\vec{p}} = 50$ MeV the analyzing power angular distributions for this reaction and for $^4$He($\vec{n}$, d) are the same, which is expected from charge symmetry (1982SA05; also measurements at $E_{\vec{p}} = 32$, 40 and 52.5 MeV). See also (1982KA21). For reaction (b) see (1974AJ01).

Reaction (c) has been studied at $E_p = 250$, 350 and 500 MeV: energy-sharing spectra, coplanar symmetric angular distributions and quasi-free angular distributions have been obtained. The results are in good agreement with DWIA calculations dor $q \lesssim 150$ MeV/$c$ but a spin-orbit term has to be included in the optical potential used to generate the DW for larger recoil momenta (1982VA01, 1980EP01). For polarization measurements at $E_{\vec{p}} = 250$ and 500 MeV see (1982MA19). See (1979AJ01) for the earlier work. For inclusive scattering at $E_p = 500$ MeV see (1981RO1J). For breakup processes see (1980WE1C, 1981AL1J). See also (1980MC1C, 1982DA1K), (1977GO1V; applications) and (1978BA1C, 1978BL1C, 1978TA1A, 1979KA19, 1979MI1K, 1979SH21, 1979TE07, 1980DM1A, 1981FE02, 1981TE01, 1982LE28; theor.).

| | |
|---|---|
| 8. (a) $^4$He(d, n)$^5$Li | $Q_m = -4.19$ |
| (b) $^4$He(d, np)$^4$He | $Q_m = -2.2246$ |

Reaction (b) has been studied at $E_d = 14.2$ MeV and at $E_\alpha = 18.0$ to 42 MeV [see (1979AJ01)] and at $E_{\vec{d}} = 12$ and 17 MeV (1983SL01) and $E_\alpha = 28.3$ MeV (1979AN24, 1981BE1G) and 140 MeV (1982LA14). $^5$Li$_{g.s.}$ is formed. Tensor moments are derived by (1979AN24, 1981BE1G). See also (1978NA12, 1980KO04; theor.) and reaction 5 in $^6$Li.

9. (a) $^4$He($^3$He, d)$^5$Li $\quad Q_{\rm m} = -7.46$
   (b) $^4$He($^3$He, pd)$^4$He $\quad Q_{\rm m} = -5.4936$

At $E_\alpha = 26.3$ MeV, $^5$Li$_{\rm g.s.}$ is reported to have a width of $1.9 \pm 0.25$ MeV, while the first excited state is reported at $E_{\rm x} = 2.82 \pm 0.35$ MeV, $\Gamma = 1.64 \pm 0.25$ MeV (1982NE09) [reaction (b)]. See also (1979KU08; theor.) and (1979AJ01).

10. $^6$Li($\pi^+$, p)$^5$Li $\quad Q_{\rm m} = 134.69$

Differential cross sections have been measured at $E_\pi = 75$ and 150 MeV for the transition to $^5$Li$_{\rm g.s.}$ (1980KA11).

11. (a) $^6$Li(p, d)$^5$Li $\quad Q_{\rm m} = -3.44$
    (b) $^6$Li(p, pd)$^4$He $\quad Q_{\rm m} = -1.4753$
    (c) $^6$Li(p, pn)$^5$Li $\quad Q_{\rm m} = -5.66$

Angular distributions have been measured at $E_{\rm p} = 18.6$ to 156 MeV [see (1974AJ01)] and at $E_{\rm p} = 185$ MeV (1976FA03, 1974KA28). In the latter experiment the spectra are characterized by a broad, asymmetric peak corresponding to $^5$Li$_{\rm g.s.}$, a narrow peak [$^5$Li*(16.7)] and a broad peak at $E_{\rm x} \approx 20$ MeV. DWBA analysis leads to $C^2S = 0.64$ and 0.57 for $^5$Li*(0, 16.7) (1976FA03). The first excited state of $^5$Li is reported to be populated by (1969BA05; $E_{\rm p} = 156$ MeV).

Reaction (b) has been studied at $E_{\rm p} = 9$ to 50 MeV: the p-$\alpha$FSI corresponding to $^5$Li$_{\rm g.s.}$ is observed: see (1979AJ01). For reaction (c) see (1977WA05).

12. (a) $^6$Li(d, t)$^5$Li $\quad Q_{\rm m} = 0.59$
    (b) $^6$Li(d, pt)$^4$He $\quad Q_{\rm m} = 2.5574$

Angular distributions of the t$_0$ group have been measured at $E_{\rm d} = 15$ and 20 MeV: see (1974AJ01). reaction (b) has been studied at $E_{\rm d} = 0.47$ MeV and 7.5 to 10.5 MeV [see (1979AJ01)] and at $E_{\rm d} = 117$ to 772 keV (1979HO04; differential cross sections and energy spectra). See also $^8$Be.

13. (a) $^6$Li($^3$He, $\alpha$)$^5$Li $\quad Q_{\rm m} = 14.91$
    (b) $^6$Li($^3$He, p$\alpha$)$^4$He $\quad Q_{\rm m} = 16.8779$

At $E(^3\text{He}) = 25.5$ MeV, the spectra show $^5$Li*(0, 16.7) and two broad peaks at $E_x \approx 19.8$ and 22.7 MeV with $\Gamma_{\text{c.m.}} = 2$ and 1 MeV, respectively. At $E(^3\vec{\text{He}}) = 33.3$ MeV, angular distributions and analyzing powers have been studied for $^5$Li*(0, 16.7) [$\Gamma \approx 1.6$ and $\approx 0.4$ MeV] (1981BA38). In reaction (b) the $E_x$ and $\Gamma$ of the first excited state are reported to be 7.5 MeV and $5 \pm 1$ MeV, respectively (1982LA20). See also (1979AJ01), (1981DU1F; theor.) and $^8$Be.

14. $^7$Li($\pi^+$, d)$^5$Li $\qquad Q_m = 129.66$

At $E_\pi = 65$ MeV, $^5$Li*(0, 16.7) are populated (1982DO01).

15. (a) $^7$Li(p, t)$^5$Li $\qquad Q_m = -4.43$

(b) $^7$Li(p, nd)$^5$Li $\qquad Q_m = -10.69$

At $E_p = 43.7$ MeV, a triton group is observed to $^5$Li(0) ($\Gamma = 1.55 \pm 0.15$ MeV): the angular distribution is consistent with a substantial mixing of $L = 0$ and 2 transfer. There is some evidence also for a very broad excited state between $E_x = 2$ and 5 MeV. $^5$Li*(16.7, 20.0) were not observed. The formation of $^5$Li*(16.7) ($^4S_{3/2}$) would be $S$-forbidden: the absence of $^5$Li*(20.0) would indicate that this state(s) is also of quartet character [see reaction 19 in $^5$He]. Weak, broad states at $E_x = 22.0 \pm 0.5$ MeV and $25.0 \pm 0.5$ MeV and possibly 34 MeV are reported in a coincidence experiment in which three- and four-particle breakup was analyzed: see (1979AJ01). For reaction (b) at $E_p = 670$ MeV see (1979AL11). See also (1980CA13).

16. $^9$Be($^3$He, $^7$Li)$^5$Li $\qquad Q_m = -0.31$

See (1983DE14).

17. $^9$Be($\alpha$, $^8$Li)$^5$Li $\qquad Q_m = -18.85$

At $E_\alpha = 90$ MeV differential cross sections have been measured for the tranisitions to $^5\text{Li}_{\text{g.s.}} + {}^8\text{Li}_{\text{g.s.}}$ (1981DA03).

18. $^{10}$B(d, $^7$Li)$^5$Li $\qquad Q_m = -1.40$

See (1982DO1E; $E_d = 13.6$ MeV).

19. $^{10}$B($^{3}$He, p$\alpha$)$^{4}$He$^{4}$He $\qquad Q_{\rm m} = 12.4175$

See (1979AJ01).

20. $^{10}$B($\alpha$, $^{9}$Be)$^{5}$Li $\qquad Q_{\rm m} = -8.55$

See (1982DO1F; $E_{\alpha} = 27.2$ MeV).

## $^{5}$Be
(Fig. 3)

The absence of any group structure in the neutron spectrum in the reaction $^{3}$He($^{3}$He, n)$^{5}$Be at $E$($^{3}$He) $= 18.0$ to 26.0 MeV indicates that $^{5}$Be(0) is at least 4.2 MeV unstable with respect to $^{3}$He + 2p [$(M - A) > 33.7$ MeV]. With Coulomb corrections adjusted to match the 16.7 MeV states of $^{5}$He–$^{5}$Li, this observation places the first $T = \frac{3}{2}$ level in these nuclei above $E_{\rm x} = 21.4$ MeV (1967AD05). See also (1981BE10, 1982NG01; theor.).

## References

(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.


1963PO02 C.H. Poppe, C.H. Holbrow and R.R. Borchers, Phys. Rev. 129 (1963) 733

1966HO07 B. Hoop, Jr. and H.H. Barschall, Nucl. Phys. 83 (1966) 65

1966LA04 T. Lauritsen and F. Ajzenberg-Selove, Nucl. Phys. 78 (1966) 1

1967AD05 E.G. Adelberger, A.B. McDonald, T.A. Tombrello, F.S. Dietrich and A.V. Nero, Phys. Lett. B25 (1967) 595

1969BA05 D. Bachelier, M. Bernas, I. Brissaud, C. Detraz and P. Radvanyi, Nucl. Phys. A126 (1969) 60

1971MU04 G.S. Mutchler, W.B. Broste and J.E. Simmons, Phys. Rev. C3 (1971) 1031

1973GO38 C.A. Goulding, P. Stoler and J.D. Seagrave, Nucl. Phys. A215 (1973) 253

1973TR04 P.A. Treado, J.M. Lambert, R.J. Kane, L.A. Beach, E.L. Petersen and R.B. Theus, Phys. Rev. C7 (1973) 1742

1974AJ01 F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. A227 (1974) 1

1974CH15 C.C. Chang and E. Ventura, Phys. Rev. C9 (1974) 1671

1974KA28 J. Kallne, B. Fagerstrom, O. Sundberg and G. Tibell, Phys. Lett. B52 (1974) 313

1974SC04 H. Schroder, K.K. Kern and D. Fick, Phys. Lett. B48 (1974) 206

1976BO05 J.E. Bond and F.W.K. Firk, Nucl. Phys. A258 (1976) 189

1976FA03 B. Fagerstrom, J. Kallne, O. Sundberg and G. Tibell, Phys. Scr. 13 (1976) 101

1976FO21 C.-M. Fou, Y.-C. Liu, C.-C. Hsu and S.-L. Huang, J. Phys. G2 (1976) 847

1976GAYV D.I. Garber and R.R. Kinsey, BNL 325 (1976)

1976LI15 P.W. Lisowski, R.L. Walter, G.G. Ohlsen and R.A. Hardekopf, Phys. Rev. Lett. 37 (1976) 809

1976MA34 J.L. Matthews, D.J.S. Findlay, S.N. Gardiner and R.O. Owens, Nucl. Phys. A267 (1976) 51

1976ME13 H.O. Meyer, G.G. Ohlsen, R.A. Hardekopf, R.V. Poore and J.W. Sunier, Nucl. Phys. A265 (1976) 280

1976SC26 H. Schroder, K.K. Kern, K. Schmidt, D. Fick, Nucl. Phys. A269 (1976) 74

1976WO11 G.J. Wozniak, D.P. Stahel, J. Cerny and N.A. Jelley, Phys. Rev. C14 (1976) 815

1977BA1M Bassalleck et al, in Proc., Zurich-Sin (1977) p. 35

1977BO24 J.E. Bond and F.W.K. Firk, Nucl. Phys. A287 (1977) 317

1977BO40 A.E. Borzakovskij, S.V. Romanovskij, Ukr. Fiz. Zh. (USSR) 22 (1977) 2056

1977BR17 F.P. Brady, N.S.P. King, B.E. Bonner, M.W. McNaughton, J.C. Wang and W.W. True, Phys. Rev. C16 (1977) 31

1977DO01 D.C. Dodder, G.M. Hale, N. Jarmie, J.H. Jett, P.W. Keaton, Jr., R.A. Nisley and K. Witte, Phys. Rev. C15 (1977) 518

1977GO1V Goldberg, Faiziev and Chechetkin, Sov. At. Energy 43 (1977) 929

1977RO1C Robaye and Delbrouck-Habaru, Bull. Soc. R. Sci. Liege (Belgium) 46 (1977) 375

1977WA05 C.N. Waddell, E.M. Diener, R.G. Allas, L.A. Beach, R.O. Bondelid, E.L. Petersen, A.G. Pieper, R.B. Theus, C.C. Chang and N.S. Chant, Nucl. Phys. A281 (1977) 418

1978AH03 I. Ahmad, J. Phys. G4 (1978) 1695

1978AL1G Alkhazov, Belostotsky and Vorobyov, Phys. Rep. C42 (1978) 89

1978AU11 J.P. Auger, R.J. Lombard, Ann. Phys. (New York) 115 (1978) 442

1978BA1C Balashov, in Clustering, Winnipeg 1978, AIP Conf. Proc. 47 (1978) 252

1978BA1F Barschall, Ann. Rev. Nucl. Part. Sci. 28 (1978) 207

1978BE2J Bevelacqua, Can. J. Phys. 56 (1978) 1382

1978BL1C Blokhintsev and Safronov, Izv. Akad. Nauk SSSR Ser. Fiz. 42 (1978) 739

1978BR1A Brown, in Clustering, Winnipeg 1978, AIP Conf. Proc. 47 (1978) 90

1978BR1V Bruton et al, Nucl. Phys. B142 (1978) 365

1978DR08 M. Drosg, Nucl. Sci. Eng. 67 (1978) 190

1978DU15 Dubna-Warsaw-Leningrad Collaboration, Yad. Fiz. 27 (1978) 710; Sov. J. Nucl. Phys. 27 (1978) 380

1978FI1D Fick, in Few Body Syst. & Nucl. Forces, Graz 1978, Springer Lecture Notes 87 (1978) 414

1978GR1G Grigoryan and Shakhbazyan, Yad. Fiz. 27 (1978) 256

1978GR1H Grigoryan and Shakhbazyan, Yad. Fiz. 27 (1978) 1046

1978HA2F Hahn and Rule, Phys. Rev. C18 (1978) 2447

1978HE2A E.M. Henley and L. Wolfenstein, Nucl. Phys. A300 (1978) 265

1978HO17 A. Houdayer, N.E. Davison, S.A. Elbakr, A.M. Sourkes, W.T.H. van Oers and A.D. Bacher, Phys. Rev. C18 (1978) 1985

1978JA16 J. Jaros, A. Wagner, L. Anderson, O. Chamberlain, R.Z. Fuzesy, J. Gallup, W. Gorn, L. Schroeder, S. Shannon, G. Shapiro et al, Phys. Rev. C18 (1978) 2273

1978KA2A J. Kallne, D.A. Hutcheon, W.J. McDonald, A.N. Anderson, J.L. Beveridge and J. Rogers, Phys. Rev. Lett. 41 (1978) 1638

1978LE2E Lesniak and Lesniak, Acta Phys. Pol. B9 (1978) 419

1978MA2M Malyarov, Pivovarchik, Poplavsky and Popushoy, Yad. Fiz. 27 (1978) 1128

1978NA12 H. Nakamura and H. Noya, Nucl. Phys. A309 (1978) 115

1978NA13 M.A. Nasser, M.M. Gazzaly, J.V. Geaga, B. Hoistad, G. Igo, J.B. McClelland, A.L. Sagle, H. Spinka, J.B. Carroll, V. Perez-Mendez et al, Nucl. Phys. A312 (1978) 209

1978PO1A B. Povh, Ann. Rev. Nucl. Part. Sci. 28 (1978) 1

1978RE1A Redish, in Few Body Syst. and Nucl. Forces, Graz 1978, Springer Lecture Notes 87 (1978) 427

1978RO17 D. Robson, Nucl. Phys. A308 (1978) 381

1978SO1A Sokol, Izv. Akad. Nauk SSSR Ser. Fiz. 42 (1978) 1829

1978TA1A Tang, Lemere and Thompson, Phys. Rept. 47 (1978) 167

1978TH1A Thompson, in Clustering, Winnipeg 1978, AIP Conf. Proc. 47 (1978) 69

1979AJ01 F. Ajzenberg-Selove, Nucl. Phys. A320 (1979) 1

1979AL11 D. Albrecht, J. Ero, Z. Fodor, I. Hernyes, Hong Sung Mu, B.A. Khomenko, N.N. Khovanskij, P. Koncz, Z.V. Krumstein, Y.P. Merekov et al, Nucl. Phys, A322 (19179) 512

1979AL12 Y. Alexander, R.H. Landau, Phys. Lett. B84 (1979) 292

1979AN24 B. Anders, U. Berghaus, H. Bruckmann, P. Lara, C. Pegel, H. Salehi, A. Schutte, K. Sinram and K. Wick, Phys. Lett. B87 (1979) 346

1979AR02 L.G. Arnold, B.C. Clark, R.L. Mercer, Phys. Rev. C19 (1979) 917

1979AR06 L.G. Arnold and B.C. Clark, Phys. Lett. B84 (1979) 46

1979BA16 B. Bassalleck, H.-D. Engelhardt, W.D. Klotz, F. Takeutchi, H. Ullrich and M. Furic, Nucl. Phys. A319 (1979) 397

1979BA2X Barker et al, Bull. Amer. Phys. Soc. 24 (1979) 822

1979BE1K Beynon and Oastler, Ann. Nucl. Energy 6 (1979) 537

1979BR02 D.R. Brown, J.M. Moss, C.M. Rozsa, D.H. Youngblood and J.D. Bronson, Nucl. Phys. A313 (1979) 157

1979BU1C Bunyatov et al, Yad. Fiz. 30 (1979) 1054

1979BUZO H.R. Buergi, K. Stephenson and W. Haeberli, Bull. Amer. Phys. Soc. 24 (1979) 838, ED4

1979CO01 H. Courant, K. Einsweiler, T. Joyce, H. Kagan, Y.I. Makdisi, M.L. Marshak, B. Mossberg, E.A. Peterson, K. Ruddick, T. Walsh, Phys. Rev. C19 (1979) 104

1979DI1C Dieumegard, Dubreuil and Amsel, Nucl. Instrum. Meth. Phys. Res. 166 (1979) 431

1979DY07 R. Dymarz, A. Malecki, J. Phys. (Paris) Lett. 40 (1979) L425

1979FO16 A.C. Fonseca, J. Revai and A. Matveenko, Nucl. Phys. A326 (1979) 182

1979FO1R Fowler et al, Bull. Amer. Phys. Soc. 24 (1979) 651

1979GH01 J. Ghosh, V.S. Varma, Pramana 12 (1979) 427

1979GR08 L.G. Greeniaus, D.A. Hutcheon, C.A. Miller, G.A. Moss, G. Roy, R. Dubois, C. Amsler, B.K.S. Koene, B.T. Murdoch, Nucl. Phys. A322 (1979) 308

1979GR1P Grabmayr et al, Bull. Amer. Phys. Soc. 24 (1979) 878

1979GR2D Greenwood, Bull. Amer. Phys. Soc. 24 (1979) 886

1979HA2C Haight, Bull. Amer. Phys. Soc. 24 (1979) 869

1979HO04 R.E. Holland, A.J. Elwyn, C.N. Davids, F.J. Lynch, L. Meyer-Schutzmeister, J.E. Monahan, F.P. Mooring and W. Ray, Jr., Phys. Rev. C19 (1979) 592

1979IM01 K. Imai, K. Hatanaka, H. Shimizu, N. Tamura, K. Egawa, K. Nisimura, T. Saito, H. Sato and Y. Wakuta, Nucl. Phys. A325 (1979) 397

1979JA31 V.K. Jain and B.B. Srivastava, Indian J. Pure Appl. Phys. 17 (1979) 810

1979JE02 B. Jenny, W. Gruebler, V. Konig, P.A. Schmelzbach, R. Risler, H.R. Burgi and D.O. Boerma, Nucl. Phys. A324 (1979) 99

1979KA06 N.I. Kassis, S.K. Khalil, Nucl. Phys. A315 (1979) 381

1979KA17 H. Kanada, T. Kaneko, S. Nagata and M. Nomoto, Prog. Theor. Phys. 61 (1979) 1327

1979KA19 J. Kallne and P.C. Gugelot, Phys. Rev. C20 (1979) 1085

1979KA33 M. Kaoua, M. Allab, C. Gerardin and R. Seltz, Nuovo Cim. A54 (1979) 321

1979KOZV R.D. Koshel and P.J. Griffin, Bull. Amer. Phys. Soc. 24 (1979) 611, DL15

1979KU08 P.D. Kunz, A. Saha and H.T. Fortune, Phys. Rev. Lett. 43 (1979) 341

1979LE1B M. LeMere and Y.C. Tang, Phys. Rev. C19 (1979) 391

1979LE1T Legrand and Lombard, Conf. Proc. TRIUMF, Vancouver (1979) Paper 4C15

1979LU1A Lu et al, Scientia Sinica 22 (1979) 1248

1979MA1J MacGregor, Phys, Rev. Lett. 42 (1979) 1724

1979MI1K Miller, in NATO Inst. Vol. 45 (Plenum Press, 1979) 513

1979NA06 A. Nadasen, T.A. Carey, P.G. Roos, N.S. Chant, C.W. Wang and H.L. Chen, Phys. Rev. C19 (1979) 2099

1979OH1B Ohlsen et al, Bull. Amer. Phys. Soc. 24 (1979) 822

1979OK03 N.T. Okumusoglu and C.O. Blyth, Nucl. Phys. A325 (1979) 45

1979RU1B C.L. Ruiz, R.W. Huggett and P.N. Kirk, Phys. Rev. Lett. 43 (1979) 334

1979SA09 A.M. Saperstein and J.S. Chalmers, Phys. Rev. C19 (1979) 923

1979SA1W M. Sandel, J.P. Vary and S.I. Garpman, Phys. Rev. C20 (1979) 744

1979SA35 T. Saito, Nucl. Phys. A331 (1979) 477

1979SC07 P. Schwaller, M. Pepin, B. Favier, C. Richard-Serre, D.F. Measday and P.U. Renberg, Nucl. Phys. A316 (1979) 317

1979SE04 F. Seiler and H.W. Roser, Nucl. Phys. A315 (1979) 45

1979SH1V Sherif and Sloboda, Conf. Proc. TRIUMF, Vancouver (1979) Paper 4C22

1979SH21 J.R. Shepard, E. Rost and G.R. Smith, Phys. Lett. B89 (1979) 13

1979TE07 A. Tekou, Nuovo Cim. A54 (1979) 25

1979VA1L Vazeille, Conf. Proc. TRIUMF, Vancouver (1979) Paper 6E17

1979WI1B Wildermuth and Kanellopoulos, Rep. Prog. Phys. 42 (1979) 1719

1979ZO1A Zofka, in Conf. Proc. TRIUMF, Vancouver (1979) Paper 5E7

1980AB1C Ableev et al, Proc. Int. Conf. on Nucl. Phys. (Berkeley) (1980) 73

1980AM1B R.D. Amado and H. Primakoff, Phys. Rev. C22 (1980) 1338

1980AR08 L.G. Arnold, B.C. Clark, R.L. Mercer, Phys. Rev. C21 (1980) 1899

1980AU09 J.P. Auger, R.J. Lombard, Nucl. Phys. A350 (1980) 332

1980BA1X Bando and Shimodaya, Proc. Int. Conf. on Nucl. Phys. (Berkeley) (1980) 140

1980BR1D Brunelli, Nuovo Cim. B55 (1980) 264

1980BR20 M. Bruno, F. Cannata, M. D'Agostino, G. Vannini, F. Bongiovanni, M. Frisoni and M. Lombardi, Lett. Nuovo Cim. 29 (1980) 1

1980BR28 M. Bruno, F. Cannata, M. D'Agostino, G. Vannini, M. Lombardi and Y. Kioke, Nuovo Cim. 29 (1980) 385

1980CA13 R. Caplar, H. Gemmeke, L. Lassen, W. Weiss and D. Fick, Nucl. Phys. A342 (1980) 71

1980CA1A J.M. Cameron, Nucl. Phys. A335 (1980) 453

1980DM1A Dmitriev, Kosmach, Molchanov and Ostroumov, Sov. J. Nucl. Phys. 31 (1980) 62; Yad. Fiz. 31 (1980) 119

1980DR01 L.J. Dries, H.W. Clark, R. Detoma, Jr., J.L. Regner and T.R. Donoghue, Phys. Rev. C21 (1980) 475

1980DR1C Drosg, Bull. Amer. Phys. Soc. 25 (1980) 721

1980DY1A Dymarz and Malecki, Proc. Int. Conf. on Nucl. Phys. (Berkeley) (1980) 922

1980EP01 M.B. Epstein, D.J. Margaziotis, J. Simone, D.K. Hasell, B.K.S. Koene, B.T. Murdoch, W.T.H. van Oers, J.M. Cameron, L.G. Greeniaus, G.A. Moss et al, Phys. Rev. Lett. 44 (1980) 20

1980FA08 F.L. Fabbri, P. Picozza, L. Satta, J. Berger, J. Duflo, L. Goldzahl, J. Oostens, F. Plouin, M. Van Den Bossche, L. Vu Hai et al, Nucl. Phys. A338 (1980) 429

1980FU1G Furutani et al, Suppl. Prog. Theor. Phys. 68 (1980) 193

1980GO1K Goryachy and Peresypkin, Ukr. Fiz. Zh. 25 (1980) 771, 776

1980GR14 W. Gruebler, P.A. Schmelzbach and V. Konig, Phys. Rev. C22 (1980) 2243

1980HA1M Han, Lu, Zhuang and Zheng, Proc. Int. Conf. on Nucl. Phys. (Berkeley) (1980) 777

1980IW1A Iwao, Lett. Nuovo Cim. 29 (1980) 40

1980JE01 B. Jenny, W. Gruebler, P.A. Schmelzbach, V. Konig and H.R. Burgi, Nucl. Phys. A337 (1980) 77

1980KA11 J. Kallne, J. Davis, P.C. Gugelot, J.S. McCarthy, G.R. Smith, R.L. Boudrie, B. Hoistad and C.L. Morris, Phys. Rev. C21 (1980) 2681

1980KO04 Y. Koike, Nucl. Phys. A337 (1980) 23

1980LA20 M. Lassaut, N. Vinh Mau, Nucl. Phys. A349 (1980) 372

1980LE19 Z. Lewandowski, E. Loeffler, R. Wagner, F. Brunner, H.H. Muller, W. Reichart, P. Schober and M. Kozlowski, Phys. Lett. B95 (1980) 207

1980MC1C W.J. McDonald, Nucl. Phys. A335 (1980) 463

1980MO03 W. Moller, F. Besenbacher, Nucl. Instrum. Methods 168 (1980) 111

1980MO09 G.A. Moss, L.G. Greeniaus, J.M. Cameron, D.A. Hutcheon, R.L. Liljestrand, C.A. Miller, G. Roy, B.K.S. Koene, W.T.H. van Oers, A.W. Stetz et al, Phys. Rev. C21 (1980) 1932

1980NA09 A. Nadasen, N.S. Chant, P.G. Roos, T.A. Carey, R. Cowen, C. Samanta and J. Wesick, Phys. Rev. C22 (1980) 1394

1980NE1B Nemets, Pugach, Pavlenko, Kovalenko and Chesnokova, Izv. Akad. Nauk SSSR Ser. Fiz. 44 (1980) 2357

1980OK04 N.T. Okumusoglu, A.K. Basak and C.O. Blyth, Nucl. Phys. A349 (1980) 339

1980PE1J Petrov, Nature 285 (1980) 466

1980PE1K R. Peierls and N. Vinh Mau, Nucl. Phys. A343 (1980) 1

1980RO1L Roy and Sanchez Gomez, Ann. Fis. 76 (1980) 168

1980SC1H T. Schimert, D.J. Stubeda, M. Lemere and Y.C. Tang, Nucl. Phys. A343 (1980) 429

1980ST1A K. Stephenson and W. Haeberli, Nucl. Instrum. Meth. 169 (1980) 483

1980VI01 R.D. Viollier and E. Turtschi, Ann. Phys. 124 (1980) 290

1980WA06 S.J. Wallace, Y. Alexander, Phys. Lett. B90 (1980) 346

1980WE1C Wesick et al, Bull. Amer. Phys. Soc. 25 (1980) 721

1980ZE1D Zeng, Zhao and Huang, Proc. Int. Conf. on Nucl. Phys., Berkeley (1980) p. 857

1980ZH1A Zhang et al, Proc. Int. Conf. on Nucl. Phys., Berkeley (1980) p. 920

1981AL1J Aladashvill et al, Acta Phys. Slovaca 31 (1981) 29; Phys. Abs. 67738 (1981)

1981AU07 J.P. Auger, C. Lazard, R.J. Lombard, J. Phys. (London) G7 (1981) 1627

1981AV02 I.K. Averyanov, A.I. Golubev and A.A. Sadovoy, Yad. Fiz. 33 (1981) 66

1981BA20 O.L. Bartaya and J.V. Mebonia, Yad. Fiz. 33 (1981) 987

1981BA2N Bando, Seki and Shono, Prog. Theor. Phys. 66 (1981) 2118; Prog. Theor. Phys. 68 (1982) 346

1981BA2Q Bando, Prog. Theor. Phys. 66 (1981) 1349

1981BA38 A.K. Basak, O. Karban, S. Roman, G.C. Morrison, C.O. Blyth and J.M. Nelson, Nucl. Phys. A368 (1981) 93

1981BE10 J.J. Bevelacqua, Nucl. Phys. A357 (1981) 126

1981BE1G Berghaus, Bruckmann, Lara and Wick, Santa Fe 1980, AIP Conf. Proc. 69 (1981) 1305

1981BE1P Belyaev and Kartavtsev, Proc. Versailles Conf. (1981) p. 365

1981BE25 J.J. Bevelacqua, Phys. Lett. B102 (1981) 79

1981BO2C Bogdanova, Markushin, Ponomarev and Melezhik, Yad. Fiz. 34 (1981) 1191

1981BR1G L. Bracci and G. Fiorentini, Nucl. Phys. A364 (1981) 383

1981BY1E Bystritsky et al, Zh. Eksp. Teor. Fiz. 80 (1981) 1700

1981CL1B Clark et al, Santa Fe 1980, AIP Conf. Proc. 69 (1981) 1469

1981DA03 N.E. Davison, Gh. Gregoire, Th. Delbar, K. Grotowski and S.K. Datta, Nucl. Phys. A352 (1981) 83

1981DE1G Detomo, Clark, Rinckel, Brown and Donoghue, Santa Fe 1980, AIP Conf. Proc. 69 (1981) 1466

1981DE1X Delbar, IPC-N-8102 (1981)

1981DE2E Detomo et al, Bull. Amer. Phys. Soc. 26 (1981) 1221

1981DR05 M. Drosg, Z. Phys. A300 (1981) 315

1981DU1F Dubovoi and Podlipchuk, Proc. Samarkand Conf. (1981) p. 473

1981ER10 J. Ero, Z. Fodor, P. Koncz, Z. Seres, M. Csatlos, B.A. Khomenko, N.N. Khovanskij, Z.V. Krumstein, Yu.P. Merekov and V.I. Petrukhin, Nucl. Phys. A372 (1981) 317

1981FE02 F. Fernandez, J.C. Nalda-Garcia, J. Phys. Soc. Jpn. 50 (1981) 24

1981FR20 J. Frohlich, Z. Phys. A302 (1981) 275

1981FU11 K. Fukunaga, S. Kakigi, T. Ohsawa, A. Okihana, S. Tanaka, T. Sekioka, H. Nakamura-Yokota and S. Kato, Nucl. Phys. A369 (1981) 289

1981GE1C Gerstein et al, Proc. Versailles Conf. (1981) p. 302

1981GU1F S.A. Gurvitz, Phys. Rev. Lett. 47 (1981) 560

1981HA1N Harms and Haefele, Amer. Sci. 69 (1981) 310

1981HA1P Hardekopf et al, Nucl. Sci. 28 (1981) 1339

1981IG1A Igo, Santa Fe 1980, AIP Conf. Proc. 69 (1981) 1157

1981JA1F Jarmie, Nucl. Sic. Eng. 78 (1981) 404

1981KH07 Z.A. Khan, Z. Phys. A303 (1981) 161

1981KH1C Khanzadeev et al, Proc. Versailles Conf. (1981) p. 131

1981KO1V Kolesnikov, Zhukhovitskii, Kopylov and Tarasov, Sov. J. Nucl. Phys. 34 (1981) 533

1981KR1J Kramer, John and Schenzle, Clustering Phenomena in Nuclei 2 (1981)

1981KU1H Kudryavtsev, Lisin and Popov, JETP Lett. 34 (1981) 279

1981LI1B Liljestrand et al, Proc. Versailles Conf. (1981) p.544

1981LY1B Lyulka, Yad. Fiz. 34 (1981) 950

1981MUZQ S.F. Mughabghab, M. Divadeenam and N.E. Holden, Neutron Cross Sections 1A (1981) Z=1–60

1981NE1B O.F. Nemets and A.M. Vasnogordsky, Fiz. Elem. Chastits At. Yadra 12 (1981) 424

1981NI1E Nikitiu, Fiz. Elem. Chastits At. Yadra 12 (1981) 805

1981OS02 H. Oswald, W. Burgmer, D. Gola, C. Heinrich, H.J. Helten, H.Paetz gen. Schieck and Y. Koike, Phys. Rev. Lett. 46 (1981) 307

1981PA25 M.V. Pasechnik, V.P. Badovsky, O.K. Gorpinich, E.P. Kadkin, S.N. Kondratev, G.P. Palkin, L.S. Saltykov, V.V. Tokarevsky and A.D. Fursa, Izv. Akad. Nauk SSSR Ser. Fiz. 45 (1981) 2160

1981RA18 M. Rayet, Nucl. Phys. A367 (1981) 381

1981RE1B J. Revai and J. Zofka, Phys. Lett. B101 (1981) 228

1981RO13 R. Roy, F. Seiler, H.E. Conzett, F.N. Rad, Phys. Rev. C24 (1981) 2421

1981RO1G Roser and Simonius, Santa Fe 1980, AIP Conf. Proc.69 (1981) 1446

1981RO1J Roy et al, Santa Fe 1980, AIP Conf. Proc.69 (1981) 158

1981SA1N F.D. Santos and P.C. Colby, Nucl. Phys. A367 (1981) 197

1981SE1B Seth, in Helsingon (1981) 655

1981SE1J Seth et al, Proc. Versailles Conf. (1981) 537

1981SH04 H.S. Sherif, R.S. Sloboda, Phys. Lett. B99 (1981) 369

1981TE01 A. Tekou, J. Phys. G7 (1981) 1439

1981TO1G Tonsfeldt, Clegg, Ludwig and Wilkerson, Santa Fe 1980, AIP Conf. Proc. 691 (1981) 961

1981VA1L Vachakidze, Dzhalagania and Khan, Proc. Samarkand Conf. (1981) 507

1981WA1J Wang, Zhang, Li and Ruan, Proc. Versailles Conf. (1981) 374

1981WH1C Wharton et al, BAPS 26 (1981) 581

1981WH1D Wharton et al, Proc. Versialles Conf. (1981) 327

1981WI1F Willis et al, Proc. Versailles Conf. (1981) 189

1981WO1C Woolverton et al, Bull. Amer. Phys. Soc. 26 (1981) 791

1981YA1B Yavin, Proc. Versailles Conf. (1981) 181

1981YA1C Yavin, CEA-N-2211 (1981)

1981ZH03 M.A. Zhusupov, Yu.N. Uzikov, J. Phys. (London) G7 (1981) 1621

1982AV02 Y. Avishai, Phys. Lett. B112 (1982) 311

1982AZ01 A.A. Azzam, M.A. Fawzy, Indian J. Phys. A56 (1982) 1

1982BA1P H. Bando and M. Bando, Phys. Lett. B109 (1982) 164

1982BE1P Belyaev et al, J. Phys. G8 (1982) 903

1982BE1T W. Bell, K. Braune, G. Claesson, D. Drijard, M.A. Faessler, H.G. Fischer, H. Frehse, R.W. Frey, S. Garpman, W. Geist et al, CERN-Heidelberg-Lund Collaboration, Phys. Lett. B112 (1982) 271

1982BE1X W. Bell, K. Braune, G. Claesson, D. Drijard, M.A. Faessler, H.G. Fischer, H. Frehse, R.W. Frey, S. Garpman, W. Geist et al, Phys. Lett. B117 (1982) 131

1982BR1R Bracci and Fiorentini, Phys. Rept. 86 (1982) 169

1982COZO P.C. Colby and W. Haeberli, Bull. Amer. Phys. Soc. 27 (1982) 700, AE7

1982DA1H C. Daskaloyannis, M. Grypeos and H. Nassena, Phys. Rev. C26 (1982) 702

1982DA1K Darden and Sen, Proc. of 5th Oaxtepec Symp. on Nucl. Phys., UNAM 5 (1982) 1

1982DO01 K.G.R. Doss, P.D. Barnes, N. Colella, S.A. Dytman, R.A. Eisenstein, C. Ellegaard, F. Takeutchi, W.R. Wharton, J.F. Amann, R.H. Pehl et al, Phys. Rev. C25 (1982) 962

1982DO1E Dobrikov, Nemets, Gass and Shvedov, in Kiev (1982) 318

1982DO1F Dobrikov, Nemets, Gass and Shvedov, in Kiev (1982) 319

1982EM1A Emelianov, Kukulin, Klimov and Pomerantsev, in Kiev (1982) 448

1982FA1B M.A. Faessler, Nucl. Phys. A374 (1982) 461

1982FA1F Faessler, Phys. Rept. 88 (1982) 401

1982FI13 G.F. Filippov, L.L. Chopovsky and V.S. Vasilevsky, Nucl. Phys. A388 (1982) 47

1982FI1K Filkov, Tsarev and Starkov, Conf. on Hypernucl. Kaon Phys., Heidelberg, June 1982 (1982) 331

1982FR11 J. Frohlich, H. Kriesche, L. Streit, H. Zankel, Nucl. Phys. A384 (1982) 97

1982FR14 J. Frohlich, Z. Phys. A307 (1982) 275

1982FR1D S. Fredriksson and M. Jandel, Phys. Rev. Lett. 48 (1982) 14

1982GO1A L. Goldzahl, F. Plouin and G.A. Moss, Phys. Rev. C26 (1982) 744

1982GO1H Gorpinitch et al, in Kiev (1982) 295

1982GO1R Golubev et al, JETP Lett. 35 (1982) 351

1982HE1C R. Henneck, Ch. Jacquemart, J. Lang, R. Muller, Th. Roser, M. Simonius, F. Tedaldi, W. Haeberli and S. Jaccard, Phys. Rev. Lett. 48 (1982) 725

1982HE1F Heikkinen, Bull. Amer. Phys. Soc. 27 (1982) 778

1982HI06 S.-I. Higuchi, K. Shibata, S. Shirato and H. Yamada, Nucl. Phys. A384 (1982) 51

1982IG2A G. Igo, Nucl. Phys. A374 (1982) 253

1982IS06 M. Ishikawa, S. Seki, K. Furuno, Y. Tagishi, M. Sawada, T. Sugiyama, K. Matsuda, J. Sanada, Y. Koike, J. Phys. Soc. Jpn. 51 (1982) 1327

1982JO1C Johnstone and Thomas, J. Phys. G8 (1982) L105

1982KA21 J. Kallne, J. Phys. G8 (1982) 1371

1982KIZW E.R. Kinney, G.S. Adams, J.L. Matthews and W.W. Sapp, Bull. Amer. Phys. Soc. 27 (1982) 708, BE5

1982KU1C Kudriatsev and Popov, in Kiev (1982) 570

1982LA11 M. Lattuada, F. Riggi, C. Spitaleri, D. Vinciguerra, C.M. Sutera, A. Pantaleo, Nuovo Cim. A69 (1982) 1

1982LA14 J.M. Lambert, P.A. Treado, P.G. Roos, N.S. Chant, A. Nadasen, I. Slaus and Y. Koike, Phys. Rev. C26 (1982) 357

1982LA20 M. Lattuada, F. Riggi, C. Spitaleri, D. Vinciguerra, C.M. Sutera, A. Pantaleo, Nuovo Cim. A71 (1982) 429

1982LA21 M. Lattuada, F. Riggi, C. Spitaleri, D. Vinciguerra and P.G. Fallica, Nuovo Cim. A72 (1982) 51

1982LE1G C.-L. Lee and D. Robson, Nucl. Phys. A379 (1982) 11

1982LE1L Le Bornec and Willis, in “Pion Prod. & Absorp. in Nucl.-Indiana 1981”, AIP Conf. Proc. 79 (1982) 155

1982LE28 E.B. Levshin, K.G. Sailer and A.D. Fursa, Ukr. Fiz. Zh. 27 (1982) 1126; Phys. Abs. 113434 (1982)

1982MA19 D.J. Margaziotis, M.B. Epstein, W.T.H. van Oers, D.K. Hasell, R. Abegg, G.A. Moss, L.G. Greeniaus, J.M. Cameron and A.W. Stetz, Phys. Rev. C25 (1982) 2873

1982MI1E Miller, Bull. Amer. Phys. Soc. 27 (1982) 784

1982NE09 O.F. Nemets, A.M. Yasnogorodsky, V.V. Ostashko, O.M. Povoroznik and V.N. Unn, Pisma Zh. Eksp. Teor. Fiz. 35 (1982) 537; JETP Lett. 35 (1982) 666

1982NG01 Nguyen Tien Nguyen and I. Ulehla, Czech. J. Phys. B32 (1982) 1040

1982OR03 M.C.L. Orlowski, Bao Cheng-Guang and Liu Yuen, Z. Phys. A305 (1982) 249

1982PA1B Parmentola and Feshbach, Ann. Phys. 139 (1982) 314

1982PR1E J. Proriol, S. Maury and B. Jargeaix, Phys. Lett. B110 (1982) 95

1982PR1F Proriol and Jargeaix, Nuovo Cim. A72 (1982) 278

1982PR1G Proriol, Jargeaix, Maury and Vazeille, Nuovo Cim. A71 (1982) 149

1982RA1A J. Rapaport, Phys. Rept. 87 (1982) 25

1982RA1F Ramey, Bull. Amer. Phys. Soc. 27 (1982) 779

1982SA05 A.L. Sagle, F.P. Brady, J.L. Romero, B.E. Bonner, N.S.P. King, M.W. McNaughton, H.E. Conzett, Phys. Rev. C25 (1982) 1685

1982VA01 W.T.H. van Oers, B.T. Murdoch, B.K.S. Koene, D.K. Hasell, R. Abegg, D.J. Margaziotis, M.B. Epstein, G.A. Moss, L.G. Greeniaus, J.M. Greben et al, Phys. Rev. C25 (1982) 390

1982VE03 G.N. Velichko, A.A. Vorobyev, Yu.K. Zalite, G.A. Korolev, E.M. Maev, N.K. Terentev, Y. Terrien, A.V. Khanzadeev, Yad. Fiz. 35 (1982) 270; Sov. J. Nucl. Phys. 35 (1982) 154

1982WA1H S.J. Wallace, Nucl. Phys. A374 (1982) 203

1982WH1A Wharton, in "Pion Production and Absorption in Nucl. - Indiana 1981", AIP Conf. Proc. 79 (1982) 371

1983AS02 E. Aslanides, P. Baumann, G. Bergdolt, P. Engelstein, P. Fassnacht, F. Hibou, E. Chiavassa, G. Dellacasa, M. Gallio, A. Musso et al, Nucl. Phys. A393 (1983) 314

1983BL1C Blue et al, J. Appl. Phys. 54 (1983) 615

1983BR1E Bromley, Proc. Int. Conf. on Nucl. Phys., Florence, Aug.-Sept. 1983, Vol. 2, Editors: P. Blasi and R.A. Ricci; Tipografia Compositori Bologna (1983) 3

1983BR1G Brown, Jarmie and Hardekopf, IEEE Trans. Nucl. Sci. 30 (1983) 1164

1983DE14 Th. Delbar, Gh. Gregoire, P. Belery and G. Paic, Phys. Rev. C27 (1983) 1876

1983DU1C Dubovoi and Kertkoev, in Moscow (1983) p. 450

1983GI1C Gibson, Dover, Bhamathi and Lehman, Phys. Rev. C27 (1983) 2085

1983HUZZ J. Hurd, J. Boswell, R.C. Minehart, Y. Tzeng, H.J. Ziock and K.O.H. Ziock, Bull. Amer. Phys. Soc. 28 (1983) 671

1983JO1E J.A. Johnstone and A.W. Thomas, Nucl. Phys. A392 (1983) 409

1983JO1F Jones et al, Bull. Amer. Phys. Soc. 28 (1983) 735

1983MO01 G.A. Moss, C.A. Davis, J.M. Greben, L.G. Greeniaus, G. Roy, J. Uegaki, R. Abegg, D.A. Hutcheon, C.A. Miller and W.T.H. Van Oers, Nucl. Phys. A392 (1983) 361

1983RI01 C. Rioux, R. Roy, R.J. Slobodrian, H.E. Conzett, Nucl. Phys. A394 (1983) 428

1983SA1H Safronov, in Moscow (1983) 453

1983SC10 P. Schmalbrock, H.W. Becker, L. Buchmann, J. Gorres, C. Rolfs, H.P. Trautvetter and W.S. Rodney, Z. Phys. A310 (1983) 243

1983SH12 H.S. Sherif, M.S. Abdelmonem, R.S. Sloboda, Phys. Rev. C27 (1983) 2759

1983SL01 I. Slaus, J.M. Lambert, P.A. Treado, F.D. Correll, R.E. Brown, R.A. Hardekopf, N. Jarmie, Y. Koike and W. Gruebler, Nucl. Phys. A397 (1983) 205

1983VI1D Vidrug-Vlasenko, Zavarzin, Kun and Aleshin, in Moscow (1983) 407

1983YO01 R.L. York, J.C. Hiebert, H.L. Woolverton, L.C. Northcliffe, Phys. Rev. C27 (1983) 46