

Energy Levels of Light Nuclei $A = 5$

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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)

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${}^5\mathbf{n}$

(Not illustrated)

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

 ${}^5\mathbf{H}$

(Not illustrated)

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

 ${}^5\mathbf{He}$

(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 ${}^5\text{He}$ is predicted to lie at $E_x \approx 40$ MeV (1981BE25; theor.): (1979JA31, 1981BE10, 1981KU1H, 1982EM1A, 1982FI13, 1982FR1D).

Complex reactions involving ${}^5\text{He}$: (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 ${}^5\text{He}$: (1979BR02, 1981AV02, 1981BE10, 1982EM1A, 1982FI13, 1982KU1C, 1982NG01).

1. ${}^3\text{H}(d, \gamma){}^5\text{He}$

$$Q_m = 16.70$$

Table 5.1: Energy levels of ${}^5\text{He}$ ^a

| E_x (MeV) | $J^\pi; T$ | $\Gamma_{\text{c.m.}}$ (MeV) | Decay | Reactions |
|-----------------------------|---|------------------------------|------------------------------|---|
| g.s. | $\frac{3}{2}^-; \frac{1}{2}$ | 0.60 ± 0.02 ^a | n, α | 1, 4, 6, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 |
| 4 ± 1 | $\frac{1}{2}^-; \frac{1}{2}$ | 4 ± 1 | n, α | 4, 6, 11, 17, 18, 21 |
| 16.76 ± 0.13 | $\frac{3}{2}^+; \frac{1}{2}$ | 0.10 ± 0.05 | γ , n, d, t, α | 1, 2, 5, 6, 8, 9, 12, 13, 14, 20, 21 |
| 19.8 ± 0.4 ^b | $(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$ | 2.5 ± 0.5 | n, d, t, α | 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 γ -rays for $E_d = 25$ to 100 keV has been measured: the ratio $\sigma(\text{d}, \gamma)/\sigma(\text{d}, \text{n})$ is approximately constant at $(2.1 \pm 0.6) \times 10^{-4}$, leading to $\Gamma_\gamma = 14 \pm 4$ eV, where Γ_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 ± 0.12 $\mu\text{b}/\text{sr}$ (90°) and the γ to n branching ratio is an order of magnitude smaller: 2.3×10^{-5} . The angular distribution of the γ -rays is forward peaked and the total cross section is estimated to be 4.8 μb : see (1979AJ01).

- | | | |
|--|-----------------|---------------|
| 2. (a) ${}^3\text{H}(\text{d}, \text{n}){}^4\text{He}$ | $Q_m = 17.5894$ | $E_b = 16.70$ |
| (b) ${}^3\text{H}(\text{d}, 2\text{n}){}^3\text{He}$ | $Q_m = -2.9883$ | |
| (c) ${}^3\text{H}(\text{d}, \text{pn}){}^3\text{H}$ | $Q_m = -2.2246$ | |

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, $\sigma(\text{peak}) = 5.0$ 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) for the earlier references] and at $E_t = 12.5$ to 117 keV (1983BR1G; σ_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 ${}^3\text{H}(\text{d}, \text{n}){}^4\text{He}$ and ${}^3\text{He}(\text{d}, \text{p}){}^4\text{He}$ ^a

| E_r (keV) | Γ_{lab} (keV) | l_d | J^π | $l_{\text{n,p}}$ | R (fm) | E_λ (keV) | γ_d^2 (keV) | $\gamma_{\text{n,p}}^2$ (keV) | θ_d^2 ^b | $\theta_{\text{n,p}}^2$ ^b | E_x (MeV) |
|------------------|--------------------------------|-------|-----------------|------------------|-------------|----------------------|-----------------------|----------------------------------|---------------------------|--------------------------------------|----------------|
| 107 ^c | 135 | 0 | $\frac{3}{2}^+$ | 2 | 5.0 | -464 | 2000 ± 500 | 50 ± 10 | 1.0 | 0.018 | 16.76 |
| 450 ^d | ≈ 450 | 0 | $\frac{3}{2}^+$ | 2 | 7.0 | -126 | 715 | 17 | 0.7 | 0.011 | 16.66 |
| | | | | | 5.0 | -391 | 2930 | 42 | 1.4 | 0.013 | |
| | | | | | 7.0 | 129 | 780 | 12 | 0.7 | 0.008 | |

^a See references in (1979AJ01).

^b Units of $3\hbar^2/2MR^2$.

^c ${}^3\text{H}(\text{d}, \text{n}){}^4\text{He}$.

^d ${}^3\text{He}(\text{d}, \text{p}){}^4\text{He}$.

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 $\theta_1 = 30^\circ$ 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 $P_1(30^\circ)$ 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 ≈ 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 ${}^5\text{He}$ near 20 MeV. Comparison with the ${}^3\text{He}(\text{d}, \text{p}){}^4\text{He}$ 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 $A_{zz}(0^\circ)$ has been measured for $E_d = 0.24$ to 6.75 MeV: large differences in $A_{zz}(0^\circ)$ for this reaction and for ${}^3\text{He}(\text{d}, \text{p})$ are reported for $E_d < 1.65$ 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 $E_{\text{c.m.}} = 2.9 \pm 0.3$ MeV [$E_x = 19.6$ MeV], $\Gamma_{\text{c.m.}} = 1.9 \pm 0.2$ 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. ${}^3\text{H}(d, d){}^3\text{H}$

$$E_b = 16.70$$

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 ${}^3\text{He}(d, d)$ [see ${}^5\text{Li}$]. Together with data from ${}^3\text{H}(d, n){}^4\text{He}$, 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 ${}^7\text{Li}(p, {}^3\text{He}){}^5\text{He}$]. 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 ${}^5\text{He}$ 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 ${}^5\text{He}^*(20.0)$. For other polarization measurements (and for references) see (1979AJ01). See also (1978TA1A, 1981BO2C; theor.).

4. (a) ${}^3\text{H}(t, n){}^5\text{He}$

$$Q_m = 10.44$$

(b) ${}^3\text{H}(t, 2n){}^4\text{He}$

$$Q_m = 11.3322$$

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

5. (a) ${}^3\text{He}(t, p){}^5\text{He}$

$$Q_m = 11.21$$

(b) ${}^3\text{He}(t, pn){}^4\text{He}$

$$Q_m = 12.0959$$

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

6. ${}^4\text{He}(n, n){}^4\text{He}$

$$E_b = -0.89$$

The coherent scattering length (thermal, bound) is 3.07 ± 0.02 fm, $\bar{\sigma}_s = 0.76 \pm 0.01$ 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 detect 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- α phase shifts. At the $\frac{3}{2}^+$ state the best fit to all data is given by $E_{res} = 17.669$ MeV ± 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 discrepancies with the results of (1966HO07) [below $E_n = 22$ MeV].

An R -function analysis of the ${}^4\text{He} + n$ 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 ${}^4\text{He} + n$ data alone (rather than also including the ${}^4\text{He} + p$ 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. ${}^4\text{He}(n, d){}^3\text{H}$

$$Q_m = -17.5894$$

$$E_b = -0.89$$

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

8. ${}^4\text{He}(p, \pi^+){}^5\text{He}$

$$Q_m = -141.24$$

See (1981WI1F, 1982LE1L).

9. (a) ${}^4\text{He}(d, p){}^5\text{He}$

$$Q_m = -3.11$$

(b) ${}^4\text{He}(d, pn){}^4\text{He}$

$$Q_m = -2.2246$$

A typical proton spectrum consists of a peak corresponding to formation of the ground state of ${}^5\text{He}$, 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 ${}^6\text{Li}$.

At $E_\alpha = 70$ MeV, a kinematically complete experiment (reaction (b)) shows evidence for sequential decay, proceeding through excited states of ${}^5\text{He}$. Peaks in the coincident yield of protons and deuterons are ascribed to narrow states at $E_x = 16.7 \pm 0.1$ MeV, $\Gamma = 80 \pm 30$ keV, at $E_x = 18.6 \pm 0.1$, 18.8 ± 0.1 and 19.2 ± 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 $E_{\bar{d}} = 12$ and 17 MeV (1983SL01), 12.0 and 21 MeV (1982IS06) and at 18 MeV (1981OS02). See also reaction 5 in ${}^6\text{Li}$, (1980BR20, 1980BR28, 1982LA14) and (1978NA12, 1980KO04; theor.).

$$10. {}^4\text{He}(t, nd){}^4\text{He} \quad Q_m = -6.2573$$

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

$$11. {}^6\text{Li}(\gamma, p){}^5\text{He} \quad Q_m = -4.59$$

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

$$12. {}^6\text{Li}(e, ep){}^5\text{He} \quad Q_m = -4.59$$

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

$$13. (a) {}^6\text{Li}(n, d){}^5\text{He} \quad Q_m = -2.37$$

$$(b) {}^6\text{Li}(n, nd){}^4\text{He} \quad Q_{|rmm} = -1.4753$$

Angular distributions of ground-state deuterons have been studied at $E_n = 6.57, 6.77, 14.4$ and 56.3 MeV and recently at 14.1 MeV (1982HI06). At $E_n = 56.3$ MeV angular distributions have also been obtained to ${}^5\text{He}^*(16.7, 18.5 \pm 0.5, 20.5 \pm 0.5)$. 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. ${}^6\text{Li}(p, 2p){}^5\text{He}$ $Q_m = -4.59$

At $E_p = 100$ MeV the population of ${}^5\text{He}^*(0, 16.7)$ and possibly of a broad structure at $E_x \approx 19$ MeV is observed: momentum distributions for ${}^5\text{He}^*(0, 16.7)$ 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) ${}^6\text{Li}(d, {}^3\text{He}){}^5\text{He}$ $Q_m = 0.90$

(b) ${}^6\text{Li}(d, n{}^3\text{He}){}^4\text{He}$ $Q_m = 1.794$

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

16. ${}^6\text{Li}(\alpha, \alpha p){}^5\text{He}$ $Q_m = -4.59$

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

17. ${}^7\text{Li}(\gamma, d){}^5\text{He}$ $Q_m = -9.62$

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

18. (a) ${}^7\text{Li}(\pi^+, 2p){}^5\text{He}$ $Q_m = 128.51$

(b) ${}^7\text{Li}(\pi^-, 2n){}^5\text{He}$ $Q_m = 126.95$

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

19. (a) ${}^7\text{Li}(n, t){}^5\text{He}$ $Q_m = -3.36$

(b) ${}^7\text{Li}(n, tn){}^4\text{He}$ $Q_m = -2.468$

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

20. (a) ${}^7\text{Li}(p, {}^3\text{He}){}^5\text{He}$ $Q_m = -4.12$
 (b) ${}^7\text{Li}(p, \text{pd}){}^5\text{He}$ $Q_m = -9.62$

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

21. (a) ${}^7\text{Li}(d, \alpha){}^5\text{He}$ $Q_m = 14.23$
 (b) ${}^7\text{Li}(d, n){}^4\text{He}{}^4\text{He}$ $Q_m = 15.121$

At $E_d = 24$ MeV, the α -particle spectrum from reaction (a) shows structures corresponding to the ground and 16.7 MeV states and to states at $E_x \approx 20.2$ and 23.8 MeV with $\Gamma \approx 2$ MeV and ≈ 1 MeV respectively: see (1979AJ01). See also (1977RO1C).

Reaction (b) proceeds mainly via excited states of ${}^8\text{Be}$ and ${}^5\text{He}_{\text{g.s.}}$. 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 ${}^5\text{He}_{\text{g.s.}} = 0.6$ MeV and $E_x = 4.1 \pm 0.2$, $\Gamma_{\text{c.m.}} = 4.4 \pm 0.2$ MeV for the $P_{1/2}$ state. See also (1980NE1B, 1982LA21), and ${}^7\text{Li}$, ${}^8\text{Be}$ and ${}^9\text{Be}$.

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

Reaction (a) has been studied for $E_p = 26.0$ 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 $E_p = 30, 50$ and 75 MeV. See also ${}^9\text{Be}$.

$$23. \text{}^9\text{Be}(\text{}^3\text{He}, \text{}^7\text{Be})\text{}^5\text{He} \quad Q_m = -0.88$$

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

$$24. \text{(a) } \text{}^9\text{Be}(\alpha, 2\alpha)\text{}^5\text{He} \quad Q_m = -2.46$$

$$\text{(b) } \text{}^9\text{Be}(\alpha, \text{}^8\text{Be})\text{}^5\text{He} \quad Q_m = -2.56$$

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 ${}^5\text{He}_{\text{g.s.}}$ is observed for $E_x \leq 25$ MeV (1976WO11). See also (1981BA20; theor.).

$$25. \text{}^{10}\text{B}(\text{d}, \text{}^7\text{Be})\text{}^5\text{He} \quad Q_m = -1.97$$

See (1982DO1E).

$$26. \text{}^{11}\text{B}(\text{d}, \text{n})\text{}^4\text{He}\text{}^4\text{He}\text{}^4\text{He} \quad Q_m = 6.4568$$

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

⁵Li
(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 ⁵Li: (1979BR02, 1979RU1B).

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

Reactions involving antiprotons: (1981YA1B).

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

Other topics: (1978BE2J, 1982NG01).

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

1. ³He(d, γ)⁵Li $Q_m = 16.39$

Excitation curves and angular distributions have been measured for $E_d = 0.2$ to 5 MeV and $E(^3\text{He}) = 2$ to 26 MeV. A broad maximum in the cross section is observed at $E_d = 0.45 \pm 0.04$ MeV [⁵Li*(16.66)]. $\sigma_{\gamma_0} = 21 \pm 4 \mu\text{b}$, $\Gamma_{\gamma_0} = 5 \pm 1$ eV. The radiation at resonance is isotropic, consistent with s-wave capture. Study of γ_0 and γ_1 yield $\Gamma = 2.6 \pm 0.4$ MeV for the ground-state width, and $E_x = 7.5 \pm 1.0$ 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 $E_x \approx 18$ MeV: even parity is deduced from the relative intensity of γ_0 and γ_1 . It is presumed to be the $\frac{1}{2}^+$ state reported in reactions 2 and 6. A broad peak is also observed at $E_x \approx 20.7$ MeV in the γ_0 cross section. The cross section for γ_1 is ≈ 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 | $Q_m = 18.3532$ | $E_b = 16.39$ |
| (b) ³ He(d, np) ³ He | $Q_m = -2.2246$ | |
| (c) ³ He(d, 2p) ³ H | $Q_m = -1.4608$ | |
| (d) ³ He(d, 2d) ¹ H | $Q_m = -5.4936$ | |

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 · b. [However

Table 5.3: Energy levels of ${}^5\text{Li}$ ^a

| E_x (MeV) | $J^\pi; T$ | $\Gamma_{\text{c.m.}}$ (MeV) | Decay | Reactions |
|------------------|---|------------------------------|---|--|
| g.s. | $\frac{3}{2}^-; \frac{1}{2}$ | ≈ 1.5 | p, α | 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 ± 2 | p, α | 1, 6, 9, 11, 13, 15, 17 |
| 16.66 ± 0.07 | $\frac{3}{2}^+; \frac{1}{2}$ | ≈ 0.3 | γ , p, d, ${}^3\text{He}$, α | 1, 2, 3, 6, 11, 13, 14 |
| (18 ± 1) | $(\frac{1}{2}^+); \frac{1}{2}$ | broad | γ , p, d, ${}^3\text{He}$, α | 1, 2 |
| (20.0 ± 0.5) | $(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$ | ≈ 5 | γ , p, d, ${}^3\text{He}$, α | 1, 2, 3, 4, 11, 13 |
| ^a | | | | |

^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 ± 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 $E_d = 0.48$ 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 $E_d = 0$ to 40 MeV]. (1981RO13) report measurements of angular distributions, of σ_t and of the VAP for $E_d = 14.6$ 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 $E_d = 15$ 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 ${}^4\text{He}^*(20.1)$ [$J^\pi = 0^+$] and suggest that the reaction goes primarily via a $J^\pi = \frac{3}{2}^-$, $T = \frac{1}{2}$ state of ${}^5\text{Li}$ located 0.8 ± 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 ${}^4\text{He}^*(0^+)$ is stronger than is the attraction of such a nucleon to ${}^4\text{He}_{\text{g.s.}}$. (1976SC26). (1981FU11) have studied the deuteron breakup (reactions (b), (c), (d)) at $E({}^3\text{He}) = 89.4$ and 118.9 MeV.

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

3. ${}^3\text{He}(d, d){}^3\text{He}$

$$E_b = 16.39$$

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: $E_{\bar{d}} = 1.5$ to 11.5 MeV; $\sigma(\theta)$ and VAP, $T_{20}(\theta)$, $T_{21}(\theta)$, $T_{22}(\theta)$) and (1981RO13: $E_{\bar{d}} = 14.6$ to 40 MeV; $\sigma(\theta)$, σ_t and VAP). See also (1983BR1E) and (1978TA1A, 1979SE04, 1980ZE1D, 1981SA1N; theor.).

4. (a) ${}^3\text{He}(t, n){}^5\text{Li}$

$$Q_m = 10.13$$

(b) ${}^3\text{He}(t, np){}^4\text{He}$

$$Q_m = 12.0959$$

At $E({}^3\text{He}) = 14$ 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 ${}^6\text{Li}$.

5. (a) ${}^3\text{He}({}^3\text{He}, p){}^5\text{Li}$

$$Q_m = 10.90$$

(b) ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$

$$Q_m = 12.8596$$

(c) ${}^3\text{He}({}^3\text{He}, 3p){}^3\text{H}$

$$Q_m = -6.9544$$

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

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; $E_{\bar{p}} = 28.8, 29.77$ and 30.40 MeV), (1979IM01; $E_{\bar{p}} = 45.0, 52.3, 59.6$ and 64.9 MeV), (1980MO09; $E_{\bar{p}} = 200, 350$ and 500 MeV), (1979GR08; $E_{\bar{p}} = 222, 325$ and 518 MeV; analyzing powers at $\theta_{\text{lab}} = 15^\circ$), (1982VE03; $E_p = 992$ MeV) and (1979CO01; $E_{\bar{p}} = 0.56, 0.80, 1.03, 1.24, 1.73$ 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 ${}^5\text{Li}_{g.s.}$ 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 σ^+ and σ^- (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 γ -ray transitions within the broad ground state of ${}^5\text{Li}$ 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) ${}^4\text{He}(p, d){}^3\text{He}$ | $Q_m = -18.3532$ | $E_b = -1.96$ |
| (b) ${}^4\text{He}(p, pn){}^3\text{He}$ | $Q_m = -20.5778$ | |
| (c) ${}^4\text{He}(p, 2p){}^3\text{H}$ | $Q_m = -19.8140$ | |
| (d) ${}^4\text{He}(p, pd){}^2\text{H}$ | $Q_m = -23.8467$ | |

Angular distributions of ${}^3\text{He}$ 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 ${}^4\text{He}(\vec{n}, d)$ 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 for $q \lesssim 150$ 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) ${}^4\text{He}(d, n){}^5\text{Li}$ | $Q_m = -4.19$ |
| (b) ${}^4\text{He}(d, np){}^4\text{He}$ | $Q_m = -2.2246$ |

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

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

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

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

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

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

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

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

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

Angular distributions of the t_0 group have been measured at $E_{\text{d}} = 15$ and 20 MeV: see (1974AJ01). reaction (b) has been studied at $E_{\text{d}} = 0.47$ MeV and 7.5 to 10.5 MeV [see (1979AJ01)] and at $E_{\text{d}} = 117$ to 772 keV (1979HO04; differential cross sections and energy spectra). See also ${}^8\text{Be}$.

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

At $E(^3\text{He}) = 25.5$ MeV, the spectra show $^5\text{Li}^*(0, 16.7)$ 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 $^5\text{Li}^*(0, 16.7)$ [$\Gamma \approx 1.6$ and ≈ 0.4 MeV] (1981BA38). In reaction (b) the E_x and Γ of the first excited state are reported to be 7.5 MeV and 5 ± 1 MeV, respectively (1982LA20). See also (1979AJ01), (1981DU1F; theor.) and ^8Be .

$$14. \ ^7\text{Li}(\pi^+, \text{d})^5\text{Li} \quad Q_{\text{m}} = 129.66$$

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

$$15. \text{ (a) } ^7\text{Li}(\text{p}, \text{t})^5\text{Li} \quad Q_{\text{m}} = -4.43$$

$$\text{ (b) } ^7\text{Li}(\text{p}, \text{nd})^5\text{Li} \quad Q_{\text{m}} = -10.69$$

At $E_{\text{p}} = 43.7$ MeV, a triton group is observed to $^5\text{Li}(0)$ ($\Gamma = 1.55 \pm 0.15$ 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. $^5\text{Li}^*(16.7, 20.0)$ were not observed. The formation of $^5\text{Li}^*(16.7)$ ($^4S_{3/2}$) would be S -forbidden: the absence of $^5\text{Li}^*(20.0)$ would indicate that this state(s) is also of quartet character [see reaction 19 in ^5He]. Weak, broad states at $E_x = 22.0 \pm 0.5$ MeV and 25.0 ± 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 $E_{\text{p}} = 670$ MeV see (1979AL11). See also (1980CA13).

$$16. \ ^9\text{Be}(^3\text{He}, ^7\text{Li})^5\text{Li} \quad Q_{\text{m}} = -0.31$$

See (1983DE14).

$$17. \ ^9\text{Be}(\alpha, ^8\text{Li})^5\text{Li} \quad Q_{\text{m}} = -18.85$$

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

$$18. \ ^{10}\text{B}(\text{d}, ^7\text{Li})^5\text{Li} \quad Q_{\text{m}} = -1.40$$

See (1982DO1E; $E_{\text{d}} = 13.6$ MeV).

19. $^{10}\text{B}(^3\text{He}, p\alpha)^4\text{He}^4\text{He}$ $Q_m = 12.4175$

See (1979AJ01).

20. $^{10}\text{B}(\alpha, ^9\text{Be})^5\text{Li}$ $Q_m = -8.55$

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

^5Be
(Fig. 3)

The absence of any group structure in the neutron spectrum in the reaction $^3\text{He}(^3\text{He}, n)^5\text{Be}$ at $E(^3\text{He}) = 18.0$ to 26.0 MeV indicates that $^5\text{Be}(0)$ is at least 4.2 MeV unstable with respect to $^3\text{He} + 2p[(M - A) > 33.7$ MeV]. With Coulomb corrections adjusted to match the 16.7 MeV states of ^5He – ^5Li , this observation places the first $T = \frac{3}{2}$ level in these nuclei above $E_x = 21.4$ 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. Drosge, 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 (1979) 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 Drog, 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. Dufflo, 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 Peresyphkin, 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. Liljestrang, 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 Aladashvili 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. Droszg, 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 Liljestrang 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, Dzhlagania 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. Versailles 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. Takeuchi, 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, Kukulín, 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. Haerberli 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. Sutura, 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. Sutura, 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. Orłowski, Bao Cheng-Guang and Liu Yuen, Z. Phys. A305 (1982) 249
- 1982PA1B Parmentola and Feshbach, Ann. Phys. 139 (1982) 314
- 1982PR1E J. Proriot, S. Maury and B. Jargeaix, Phys. Lett. B110 (1982) 95
- 1982PR1F Proriot and Jargeaix, Nuovo Cim. A72 (1982) 278
- 1982PR1G Proriot, 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. Chivavassa, 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