Energy Levels of Light Nuclei
$A = 5$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*490 (1988), 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. The introduction and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the NNDC/TUNL format.

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Table of Contents for $A = 5$

Below is a list of links for items found within the PDF document. The introductory Table 2 *is available on this website via the link.*

^{5}n

(Not illustrated)

^{5}n has not been observed. It is suggested that it is unbound by 10 MeV: see (1984AJ01). See also (1984DE52).

^{5}H

(Not illustrated)

The ^{9}Be(^{11}B, ^{15}O) reaction at $E(^{11}\text{B}) = 52$–76 MeV shows no evidence for the formation of ^{5}H (1986BE35, 1987BO40). For the earlier work see (1984AJ01). See also (1987KO47, 1988SEZJ). There is some evidence for the formation of a very broad (8 ± 3 MeV) state of ^{5}H at $E_x = 7.4 \pm 0.7$ MeV in the ^{9}Be(π^-, pt) reaction (1987GO25). ^{5}H is calculated to have $J^\pi = \frac{1}{2}^+$, to be unstable with respect to two neutron emission and to have excited states at $E_x = 2.44$, 4.29 and 7.39 MeV with $J^\pi = \frac{5}{2}^+$, $\frac{3}{2}^+$, and $\frac{3}{2}^+$ $[(0+1)\hbar\omega$ model space], and at $E_x = 2.85$, 3.46 and 6.02 MeV with $J^\pi = \frac{3}{2}^+$, $\frac{5}{2}^+$ and $\frac{3}{2}^+$ $[(0+2)\hbar\omega$ model space] (1985PO10). See also (1982SM09, 1986BE44, 1987PE1C) and (1983ANZQ; theor.).

^{5}He

(Figs. 1 and 3)

GENERAL: See also (1984AJ01).

Model discussions: (1983JA09, 1984VA06, 1984ZW1A, 1985FI1E, 1985GE06, 1985KW02, 1986KR12, 1988WO04).

Special states: (1982PO12, 1983VO02, 1984BE1B, 1984FI20, 1984GL1C, 1984VA06, 1984VAZS, 1984ZW1A, 1985BA68, 1985FI1E, 1987SV1A, 1988BA75, 1988KW02, 1988US1B).

Electromagnetic transitions: (1985FI1E).

Astrophysical questions: (1984SU1A, 1985BO1E).

Complex reactions involving ^{5}He: (1985BO1J, 1985DE17, 1985PO11, 1986CS1A, 1986PO06, 1987BL1K, 1987BO40, 1987KI16, 1987PE1C).

Reactions involving pions: (1984DE52, 1985BE1C, 1985GE06, 1986CE04).

Hypernuclei: (1982KA1D, 1983BA1D, 1983BE1G, 1983MO1C, 1983SH1E, 1983SH38, 1984AS1D, 1984BO1A, 1984BO1H, 1984CH1G, 1984HU1B, 1984KO1F, 1984MI1E, 1984SH07, 1984SH1J, 1984ZH1B, 1985AH1A, 1985BA1F, 1985GI1E, 1985IK1A, 1985KO1G, 1985KU1A, 1985MO1F, 1985OS1C, 1985TA1E, 1985YA05, 1985YA1B, 1986AN1R, 1986BA1H, 1986BA1W, 1986BO1E, 1986CH1I, 1986DA1B, 1986DO1B, 1986LI1L, 1986MA1C, 1986SH1I, 1986SH1K, 1986SH1V,

1986SZ1A, 1986WA1J, 1986YA1F, 1987BO1L, 1987BO1O, 1987KA1Q, 1987MI38, 1987PO1H, 1987SH1H, 1987YA1C, 1987YA1M, 1988BA1G, 1988BO1E, 1988LA1B, 1988LI1C, 1988NO1A, 1988PO1H, 1988TA29).

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

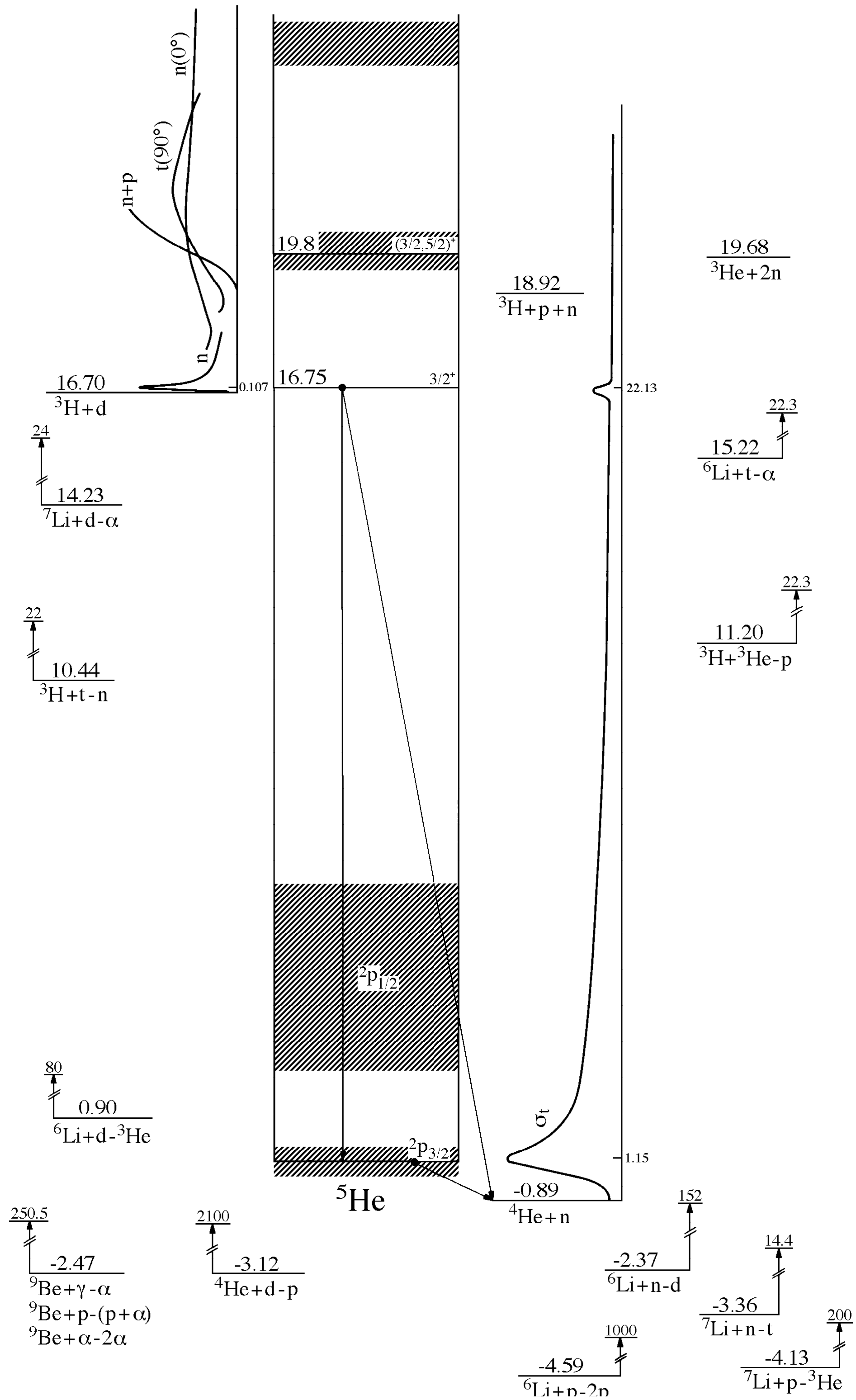
E_x (MeV) [b]	$J^\pi; T$	$\Gamma_{c.m.}$ (MeV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$	0.60 ± 0.02 [a]	n, α	1, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29
4 ± 1	$\frac{1}{2}^-; \frac{1}{2}$	4 ± 1	n, α	4, 6, 9, 10, 16, 20, 21, 29
16.75 ± 0.05	$\frac{3}{2}^+; \frac{1}{2}$	0.076 ± 0.012	γ, n, d, t, α	1, 2, 5, 6, 8, 10, 11, 12, 20, 21, 22
19.8 ± 0.4 [c]	$(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$	2.5 ± 0.5	n, d, t, α	2, 3, 5, 8, 10, 12, 14, 18, 20, 21, 22
$24 - 25$ [c]		broad		20, 21
(35.7 ± 0.4)		≈ 2		18, 22

[a] See Table 5.2 in (1966LA04) and Table 5.2 here. A study by G.M. Hale, D. Dodder and K. Witte on the S-matrix pole parameters for ^{5}He is underway. I thank Dr. Hale for his comments concerning questions regarding R- and S-matrix calculations.

[b] Positive-parity states are predicted to lie at $E_x \approx 5$ MeV $(\frac{1}{2}^+)$ and 12 MeV $(\frac{3}{2}^+, \frac{5}{2}^+)$: see (1988WO10).

[c] See the "States of ^{5}He" section in ^{5}He in (1974AJ01).

Fig. 1: Energy levels of ^{5}He. In these diagrams, energy values are plotted vertically in MeV, based on the ground state as zero. Uncertain levels or transitions are indicated by dashed lines; levels which are known to be particularly broad are cross-hatched. Values of total angular momentum J, parity, and isobaric spin T which appear to be reasonably well established are indicated on the levels; less certain assignments are enclosed in parentheses. For reactions in which ^{5}He is the compound nucleus, some typical thin-target excitation functions are shown schematically, with the yield plotted horizontally and the bombarding energy vertically. Bombarding energies are indicated in laboratory coordinates and plotted to scale in cm coordinates. Excited states of the residual nuclei involved in these reactions have generally not been shown; where transitions to such excited states are known to occur, a brace is sometimes used to suggest reference to another diagram. For reactions in which the present nucleus occurs as a residual product, excitation functions have not been shown; a vertical arrow with a number indicating some bombarding energy, usually the highest, at which the reaction has been studied, is used instead. Further information on the levels illustrated, including a listing of the reactions in which each has been observed, is contained in the master table, entitled "Energy levels of ^{5}He".


n(0°)
t(90°)
n+p
n
19.8
(3/2,5/2)+
16.75
3/2+
0.107
16.70
3H+d
24
14.23
7Li+d-α
22
10.44
3H+t-n
2p1/2
80
0.90
6Li+d-3He
2p3/2
5He
250.5
-2.47
9Be+γ-α
9Be+p-(p+α)
9Be+α-2α
2100
-3.12
4He+d-p
19.68
3He+2n
18.92
3H+p+n
22.13
22.3
15.22
6Li+t-α
22.3
11.20
3H+3He-p
σt
1.15
-0.89
4He+n
152
-2.37
6Li+n-d
14.4
-3.36
7Li+n-t
1000
-4.59
200
-4.13
7Li+p-3He

Other topics: (1983BE55, 1984BE1B, 1984PO11, 1985AN28, 1985GI1E, 1986BL1D, 1987SV1A, 1988KW02, 1988US1B).

Ground state of ^{5}*He*: (1983ANZQ, 1984FR13, 1985AN28, 1985FI1E, 1985TA1F, 1985FA01, 1987SV1A, 1988WA08, 1988WO04).

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

At low energies the reaction is dominated by a resonance at $E_{\rm d} = 107$ keV; the mirror reaction shows resonance at $E_{\rm d} = 430$ keV. The branching ratio $\Gamma_{\gamma_0}/\Gamma_{\rm n}$ integrated over the resonance from 0 to 275 keV is $(5.6 \pm 0.6) \times 10^{-5}$ (1986MO05), in very good agreement with the earlier value of $(5.4 \pm 1.3) \times 10^{-5}$ for $E_{\rm d} = 45$ to 146 keV (1984CE08). Assuming $\Gamma_{\rm n}$ of ^{5}He*(16.7) is 37 ± 5 keV (see reaction 6), then $\Gamma_{\gamma_0} = 2.1 \pm 0.4$ eV. (1986MO05) also report branching ratios up to $E_{\rm d} = 0.72$ MeV and summarize the earlier work to 5 MeV. For measurements of TAP and VAP at $E_{\vec{\rm d}} = 0.4$ and 8.6 MeV, see (1987RIZZ; prelim.). See also (1985RIZZ), (1979AJ01) and (1984NE1B, 1986LA1F, 1988KI1C; applications).

2. (a) ^{3}H(d, n)^{4}He $\quad Q_{\rm m} = 17.5894 \quad E_{\rm b} = 16.70$
(b) ^{3}H(d, 2n)^{3}He $\quad Q_{\rm m} = -2.9883$
(c) ^{3}H(d, pn)^{3}H $\quad Q_{\rm m} = -2.2259$

The cross section has been measured in the range $E_{\rm t} = 12.5$ to 117 keV (1984JA08) [$0.525(\pm 4.8\%)$ mb to $3.739(\pm 1.4\%)$ b] and in the range $E_{\rm d} = 79.913$ to 115.901 keV ($\pm\, 0.015$ keV) (1987BR10) [3.849 to 4.734 b ($\pm\, 1.6\%$)]. See also (1985FI1G; $E_{\rm d} = 13.8$ to 114.3 keV). A strong resonance, σ (peak) $= 4.88$ b, appears at $E_{\rm d} = 105$ keV: see Table 5.2 in (1979AJ01) and (1987BR10). For a discussion of R-matrix analysis and evidence for a "shadow" pole, see (1987BR10, 1987HA20). See also (1987HA44, 1987MO1K). From $E_{\rm d} = 10$ to 500 keV, the cross section is well fitted with the assumption of s-wave formation of a $J^{\pi} = \frac{3}{2}^{+}$ state. Measurements of cross sections and angular distributions for reaction (a) have been reported to $E_{\rm d} = 21$ MeV and $E_{\rm t} = 20.0$ MeV [see (1974AJ01, 1979AJ01, 1984AJ01)] as well as at 1.0, 1.5 and 2.0 MeV (1987LI07).

A study of reaction (a) with polarized deuterons at $E_{\rm d} = 0.2$ to 1.0 MeV indicates intervention of the s-wave, $J^{\pi} = \frac{1}{2}^{+}$ channel, as well as possible p-waves above $E_{\rm d} = 0.3$ MeV. The polarization increases monotonically from 0.03 at $E_{\rm d} = 3$ MeV to $\approx$ 0.5 at $E_{\rm d} = 6.5$ MeV and then with a lower slope to 0.69 at $E_{\rm d} = 13$ 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 $E_{\rm d} = 6$ MeV, but then the proton polarization becomes $\approx$ 15% higher, converging back to the neutron values at $E_{\rm d} \approx$ 12–13 MeV. This may be due to experimental factors. Vector polarization transfer coefficients, $K_{\rm y}^{\rm y'}$ $(0°)$ have been measured for $E_{\vec{\rm d}} = 5$ to 11 MeV (1985HOZU, 1986HO1E; prelim.). For other polarization work see (1984AJ01).

(1987BR10) have derived astrophysical S-factors in the range $E_\mathrm{d} = 79.9$ to 115.9 keV [$S(0) = 11.71 \pm 0.08$ MeV · b; multilevel fit], as well as reactivities. See (1984JA08) for the earlier work, and (1985CA41, 1987VA36).

Reaction (b) has been studied for $E_\mathrm{d} = 10.9$ to 83 MeV. A study of reaction (c) leads to the suggestion of a resonance at $E_\mathrm{c.m.} = 2.9 \pm 0.3$ MeV [$E_\mathrm{x} = 19.6$ MeV], $\Gamma_\mathrm{c.m.} = 1.9 \pm 0.2$ MeV, consistent with $J^\pi = \frac{3}{2}^-$ [see, however, Table 5.1]: see (1974AJ01, 1979AJ01). See also (1983BAZP, 1984SLZZ, 1987GOZF), (1986BR20, 1986RA21) and (1984SHZK, 1985FIZW, 1986CO1J, 1986ILZZ, 1986KO21, 1986VAZU; theor.). For applications see (1983GO1C, 1983HU1A, 1984BA1D, 1984HU04, 1984MA71, 1984VL1A, 1986AL1H, 1986CA1E, 1986EN1A, 1986GR1H, 1986HA1N, 1986HA1V, 1986KE1H, 1986KN1A, 1986KU1G, 1986LE1F, 1986LO1B, 1986OK1B, 1986PA1G, 1986PE1H, 1986SA1M, 1986TA1K, 1986WI1B, 1987BA2I, 1987BO1Q, 1987KA1O, 1987LE1G, 1987SO1A, 1987WU1C, 1987ZW1A, 1988KU1E).

For recent developments in muon-catalyzed fusion see (1986JO1B, 1987BA2P, 1987BR1G) and (1983JO1B, 1983TA1C, 1984AN1A, 1984BA1V, 1984BR1G, 1984CA1B, 1987AC1A, 1987BA2L, 1987BE1Y, 1987BR1T, 1987CA1O, 1987NA1K, 1987PE1D), (1983PO1E, 1984AJ01, 1984AN1C, 1984CH1F, 1984HA1J, 1984KR1B, 1984MO1G, 1984OT1A, 1986BR1H, 1986JO1C, 1986KA1K, 1987BR1W, 1987JO1A, 1987PO1M) and (1983SG1A, 1984BU1E, 1984BY1B, 1984FI1F, 1984ME1B, 1985BA1G, 1985CO1C, 1985FR1D, 1985GO1E, 1985GU1G, 1985HI1A, 1985KA1C, 1985KA1N, 1985ME1C, 1985ME1D, 1985RA1B, 1985VA1B, 1986BL15, 1986BO1F, 1986CO1K, 1986DA1D, 1986HU1C, 1986JO1C, 1986KH1B, 1986ME1D, 1986TA1J, 1986TA1L, 1987AK1B, 1987BE1W, 1987CO1N, 1987CO1P, 1987CO1W, 1987KA1Z, 1987KO1R, 1987ME1E, 1987RA1L, 1987TA1I, 1987WY1A, 1988JA1C, 1988RO1G; theor.).

3. ^{3}H(d, d)^{3}H $\qquad E_\mathrm{b} = 16.70$

The elastic scattering has been studied for $E_\mathrm{d} = 2.6$ to 11.0 MeV: see (1984AJ01). The excitation curves show an interference at $E_\mathrm{x} \approx 19$ MeV and a broad ($\Gamma > 1$ MeV) resonance corresponding to $E_\mathrm{x} = 20.0 \pm 0.5$ 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 $\mathrm{D}_{3/2}$ or $\mathrm{D}_{5/2}$ 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 $E_\mathrm{d} = 3.2$ to 12.3 MeV show resonance-like behavior in the vector analyzing power near $E_\mathrm{d} = 5$ 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 $E_\mathrm{x} \approx 19.6$ 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). For d-t correlations see (1987PO03). See also "Complex reactions" in the ^{5}He "GENERAL section" and (1981PL1A, 1983HAYX, 1986BO01; theor.).

4. ^{3}H(t, n)^{5}He $Q_{\rm m} = 10.44$

At $E_{\rm t} = 0.5$ MeV, the reaction appears to proceed via three channels: (i) direct breakup into $^{4}{\rm He} + 2{\rm n}$, 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 ± 0.18 MeV. Some evidence is also shown for ^{5}He* at $E_{\rm x} \approx 2$ MeV, $\Gamma \approx 2.4$ MeV: see (1979AJ01). See also ^{6}He and (1986BA73; theor.).

5. ^{3}He(t, p)^{5}He $Q_{\rm m} = 11.20$

Some evidence is reported at $E_{\rm t} = 22.25$ MeV for a broad state of ^{5}He at $E_{\rm x} \approx 20$ MeV, in addition to a sharp peak corresponding to ^{5}He*(16.7): see (1979AJ01). See also ^{6}Li.

6. ^{4}He(n, n)^{4}He $E_{\rm b} = -0.89$

The coherent scattering length (thermal, bound) is 3.07 ± 0.02 fm, $\bar{\sigma}_{\rm s} = 0.76 \pm 0.01$ b. Total cross sections have been measured for $E_{\rm n} = 4 \times 10^{-4}$ eV to 150.9 MeV and at 10 GeV/c [see (1984AJ01)] and at $E_{\rm n} = 1.5$ to 40 MeV (1983HA20).

The total cross section has a peak of 7.6 b at $E_{\rm n} = 1.15 \pm 0.05$ MeV, $E_{\rm c.m.} = 0.92 \pm 0.04$ MeV, with a width of about 1.2 MeV: see (1966LA04). A second resonance is observed at $E_{\rm n} = 22.133 \pm 0.010$ MeV [$\sigma_{\rm peak} = 0.9$ b] with a total width of 76 ± 12 keV and $\Gamma_{\rm n} = 37 \pm 15$ keV (1983HA20). Attempts to detect additional resonances in the total cross section have been unsuccessful: see (1966LA04).

The ${\rm P}_{3/2}$ phase shift shows strong resonance behavior near 1 MeV, while the ${\rm P}_{1/2}$ phase shift changes more slowly, indicating a broad ${\rm P}_{1/2}$ level at several MeV excitation. (1966HO07) have constructed a set of phase shifts for $E_{\rm n} = 0$ 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 $E_{\rm res} = 17.669$ MeV± 10 keV, $\gamma_{\rm d}^{2} = 2.0$ MeV$\pm$25%, $\gamma_{\rm n}^{2} = 50$ keV$\pm$20% (see Table 5.2 in (1979AJ01)).

An R-function analysis of the $^{4}{\rm He} + {\rm n}$ data below 21 MeV (including absolute neutron analyzing power measurement and accurate cross section measurements) has led to a set of phase shifts and analyzing powers which are based on the $^{4}{\rm He} + {\rm n}$ data alone (rather than also including the $^{4}{\rm He} + {\rm p}$ data). At $r = 3.3$ fm the values obtained for the ${\rm P}_{1/2}$ and ${\rm P}_{3/2}$ resonances are, respectively, $E_{\rm c.m.} = 1.97$ and 0.77 MeV, $\Gamma_{\rm c.m.} = 5.22$ and 0.64 MeV: see (1984AJ01). Angular distributions of A_{y} have been studied by (1984KL05, 1984KR23, 1986KL04) for $E_{\vec{\rm n}} = 15$ to 50 MeV: see also for phase-shift analysis and comparison with ^{4}He(p, p).

The excitation energies and the spectroscopic factors for ^{5}He states are obtained by (1985BA68) from 2-level R-matrix fits to the phase shifts, as functions of the channel radius. For $a \approx 5.1$ fm a very broad state with $J^{\pi} = \frac{1}{2}^{+}$ is found to lie at $E_{\rm x} \approx 7$ MeV in both ^{5}He and ^{5}Li, in agreement with the shell-model calculation by (1984VA06). Broad $\frac{3}{2}^{+}$ and $\frac{5}{2}^{+}$ states then lie at ≈ 14 MeV and the $\frac{1}{2}^-$ state is at about 2.6 MeV. (1985BA68) suggest that the phase-shift analysis should be redone with values of a larger than those previously used ($a \approx 3$ fm). See also (1984AJ01, 1984SI1A, 1985AL1D, 1985SI1B, 1985WI1B, 1986BA1Y), (1986BU1D, 1986DO1H; applications) and (1981PL1A, 1982AZ02, 1983DM01, 1983KU06, 1984BL21, 1984FI20, 1984SC1A, 1984SHZK, 1985HA04, 1985HO1B, 1985KI11, 1985MI1F, 1985NEZW, 1985SO06, 1985SO08, 1985SP05, 1985TI07, 1985TI08, 1986CA1K, 1986KO1J, 1986OK06, 1986WI04, 1987CA13, 1987DU1B, 1987HA44, 1987KR16, 1987MO1K, 1987PO1G, 1987QI01, 1987SH09, 1987SO04, 1987US1A, 1987VA36; theor.). For the breakup reaction see (1987MI1N, theor.).

7. ^{4}He(p, π^+)^{5}He $\qquad Q_{\rm m} = -141.24$

Differential cross sections have recently been reported at $E_{\rm p} = 201$ MeV (1985LE19) and at $E_{\vec{\rm p}} = 800$ MeV (1984HO01; also A_y). See also (1987SO1C) and (1985GE06; theor.).

8. (a) ^{4}He(d, p)^{5}He $\qquad Q_{\rm m} = -3.12$
(b) ^{4}He(d, pn)^{4}He $\qquad Q_{\rm m} = -2.22459$

A typical proton spectrum (reaction (a)) consists of a peak corresponding to the formation of the ground state of ^{5}He, plus a continuum of protons ascribed to reaction (b). A study of the latter reaction shows evidence for sequential decay via ^{5}He*(0, 16.7 ± 0.1 [$\Gamma = 80 \pm 30$ keV]) and suggests some fine structure near $E_{\rm x} = 19$ MeV [see also reactions 12 and 20]: see (1979AJ01). Differential cross sections and VAP have been measured for the ground state group at $E_{\vec{\rm d}} = 5.4$, 6.0, and 6.8 MeV (1985LU08; also TAP) and at 6 to 11 MeV (1985OS02). At $E_\alpha = 28.3$ MeV tensor polarization measurements involving the ground state transitions to ^{5}He (and ^{5}Li) deviate from theoretical predictions which assume charge symmetry (1985WI15). See also ^{6}Li (1988PUZZ; $E_{\vec{\rm d}} = 2.1$ GeV) and (1985DO03, 1985NEZW, 1986KO1J, 1987FU10, 1987KA1M, 1987KUZI; theor.).

9. ^{4}He(^{7}Li, ^{6}Li)^{5}He $\qquad Q_{\rm m} = -8.14$

(1988WO10) report a study of this reaction and of the ^{4}He(^{7}Li, ^{6}He)^{5}Li reaction at $E(^7{\rm Li}) = 50$ MeV, and of the ^{6}Li(^{12}C, ^{13}N)^{5}He and ^{6}Li(^{13}C, ^{14}C)^{5}Li reactions at E(C) $= 90$ MeV. Properties of the two lowest states of $A = 5$, from R-matrix parameters ($a = 5.5$ fm), are displayed in Table 5.2. Positive-parity states are then predicted to lie at $E_{\rm x} \approx 5$ MeV ($\frac{1}{2}^+$) and 12 MeV ($\frac{3}{2}^+$, $\frac{5}{2}^+$) in ^{5}He–^{5}Li (1988WO10).

Table 5.2: R-matrix values of the peak energy and FWHM of the $\frac{3}{2}^-$ and $\frac{1}{2}^-$ states of ^{5}He and ^{5}Li [a]

	$E_{\rm max}$ $(\frac{3}{2}^-)$		Γ $(\frac{3}{2}^-)$		$E_{\rm x}$ $(\frac{1}{2}^-)$		Γ $(\frac{1}{2}^-)$	
	^{5}He	^{5}Li	^{5}He	^{5}Li	^{5}He	^{5}Li	^{5}He	^{5}Li
[b]	0.838 ± 0.018	1.76 ± 0.06	0.645 ± 0.046	1.18 ± 0.13	1.94 ± 0.46	1.87 ± 0.56	3.6 ± 1.2	4.1 ± 2.5
[c]	0.869 ± 0.003	1.86 ± 0.01	0.723 ± 0.019	1.44 ± 0.08	2.58 ± 0.40	2.68 ± 0.50	5.3 ± 2.3	6.1 ± 2.8

[a] (1988WO10): a $= 5.5$ fm. Energies are in MeV. See also footnote [a] to Table 5.1.
[b] Strippingreactions: ^{4}He(^{7}Li, ^{6}Li)^{5}He and ^{4}He(^{7}Li, ^{6}He)^{5}Li.
[c] Pickup reactions: ^{6}Li(^{12}C, ^{13}N)^{5}He and ^{6}Li(^{13}C, ^{14}C)^{5}Li.

10. (a) ^{6}Li(γ, p)^{5}He $\qquad Q_{\rm m} = -4.59$
(b) ^{6}Li(e, ep)^{5}He $\qquad Q_{\rm m} = -4.59$
(c) ^{6}Li(π^+, π^+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 ± 2): see (1979AJ01). The (γ, $\rm p_{0+1}$) cross section has been reported for $E_\gamma = 34.5$ to 98.8 MeV. A broad secondary structure is also observed (1988CA11). In reaction (b) the missing energy spectrum show strong peaks due to ^{5}He*(0, 16.7) and possibly some strength in the region $E_{\rm x} = 5$–15 MeV (1986LAZH; prelim.). See also ^{6}Li. At $E_{\pi^+} = 130$ and 150 MeV, ^{5}He*(0, 16.7) are populated (1987HU02).

11. ^{6}Li(n, d)^{5}He $\qquad Q_{\rm m} = -2.37$

Angular distributions of $\rm d_0$ have been studied at $E_{\rm n} = 6.6$ to 56.3 MeV. At $E_{\rm n} = 56.3$ MeV angular distributions have also been obtained to ^{5}He*(16.7) and, possibly, to two higher states: see (1979AJ01, 1984AJ01). See also (1986BOZG).

12. ^{6}Li(p, 2p)^{5}He $\qquad Q_{\rm m} = -4.59$

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. Recent work is reported at $E_{\rm p} = 47$ and 70 MeV (1983VD03), 70 MeV (1983GO06) and 1 GeV (1985BE30, 1985DO16). See also (1984AJ01).

13. ^{6}Li(d, ^{3}He)^{5}He $\qquad Q_{\rm m} = 0.90$

$^5He_{g.s.}$ has been observed at $E_d = 14.5$ MeV: see (1979AJ01).

14. $^6Li(\alpha, \alpha p)^5He$ $\quad Q_m = -4.59$

At $E_\alpha = 140$ MeV ^{5}He*(0, 20.0) are populated: see (1984AJ01).

15. $^6Li(^6Li, ^7Be)^5He$ $\quad Q_m = 1.01$

Angular distributions have been obtained at $E(^6\text{Li})' = 156$ MeV to $^5He_{g.s.}$. Unresolved states at $E_x = 16$–20 MeV are also populated (1987MI34).

16. $^6Li(^{12}C, ^{13}N)^5He$ $\quad Q_m = -2.65$

See reaction 9 (1988WO10).

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

See ^{7}Li.

18. (a) $^7Li(\pi^+, 2p)^5He$ $\quad Q_m = 128.51$
(b) $^7Li(\pi^-, 2n)^5He$ $\quad Q_m = 126.94$

Reaction (a) at $E_{\pi^+} = 59.4$ MeV involves ^{5}He*(0, 4.) and a broad peak centered at $E_x \approx 21$ MeV with $\Gamma \approx 4$ MeV. It is not clear whether ^{5}He*(16.7) is populated (1986RI01). See also (1979AJ01, 1984AJ01).

19. $^7Li(n, t)^5He$ $\quad Q_m = -3.36$

The angular distribution of t_0 has been measured at $E_n = 14.4$ MeV: see (1979AJ01) and ^{8}Li. See also (1986BOZG).

20. (a) ^{7}Li(p, ^{3}He)^{5}He $\quad Q_{\rm m} = -4.13$

(b) ^{7}Li(p, pd)^{5}He $\quad Q_{\rm m} = -9.62$

At $E_{\rm p} = 43.7$ MeV, angular 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 ± 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 analog 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 $^{4}D_{3/2}$ or $^{4}D_{5/2}$ [compare ^{3}H(d, d)]. Particle-particle coincidence data have been obtained at $E_{\rm p} = 43.7$ MeV. They suggest the existence of ^{5}He*(20.0) with $\Gamma = 3.0 \pm 0.6$ MeV and of a broad state at ≈ 25 MeV. No $T = \frac{3}{2}$ states decaying via $T = 1$ states in ^{4}He were observed: see (1979AJ01). In reaction (b) ^{5}He*($0 + 4$, 16.7, 25) appear to be involved at $E_{\rm p} = 670$ MeV (1981ER10) while at 200 MeV some structure at $E_{\rm x} \approx 20$ MeV is reported in addition to the ground state (1986WA11).

21. (a) ^{7}Li(d, α)^{5}He $\quad Q_{\rm m} = 14.23$

(b) ^{7}Li(d, n)2 ^{4}He $\quad Q_{\rm m} = 15.1216$

At $E_{\rm d} = 24$ MeV, the α-particle spectrum from reaction (a) shows structures corresponding to the ground and 16.7 MeV states and to states at $E_{\rm x} \approx 20.2$ and 23.8 MeV with $\Gamma \approx 2$ MeV and ≈ 1 MeV, respectively. Reaction (b) proceeds mainly via excited states of ^{8}Be and ^{5}He$_{\rm g.s.}$ and possibly as well ^{5}He*(4.): see (1979AJ01). See also (1987WA21) and ^{8}Be.

22. (a) ^{7}Li(^{3}He, pα)^{5}He $\quad Q_{\rm m} = 8.73$

(b) ^{7}Li(^{3}He, ^{3}He d)^{5}He $\quad Q_{\rm m} = -9.62$

A kinematically complete experiment is reported at $E(^{3}\text{He}) = 120$ MeV. The cross section for reaction (b) is an order of magnitude greater than that for reaction (a). The missing mass spectrum for the composite of both reactions suggests the population of several states of ^{5}He, in addition to ^{5}He*(0, 16.7, 20.0), including a state at 35.7 ± 0.4 MeV with a width of ≈ 2 MeV (1985FR01).

23. (a) ^{9}Be(p, pα)^{5}He $\quad Q_{\rm m} = -2.47$

(b) ^{9}Be(p, d^{3}He)^{5}He $\quad Q_{\rm m} = -20.82$

Both reactions have been studied at $E_{\rm p} = 26.0$ to 101.5 MeV [see (1984AJ01)] and at $E_{\rm p} = 150.5$ MeV (1985WA13) [reaction (a)]. See also (1985VD03; theor.).

24. ^{9}Be(d, ^{6}Li)^{5}He $\qquad Q_{\rm m} = -9.92$

The angular distribution to ^{5}He$_{\rm g.s.}$ has been measured at $E_{\rm d} = 13.6$ MeV (1984SH1F; prelim.).

25. (a) ^{9}Be(^{3}He, ^{7}Be)^{5}He $\qquad Q_{\rm m} = -0.88$
(b) ^{9}Be(^{3}He, α)2 ^{4}He $\qquad Q_{\rm m} = 19.0043$

See (1984AJ01). For reaction (b) see ^{8}Be and (1987WA25).

26. ^{9}Be(α, 2α)^{5}He $\qquad Q_{\rm m} = -2.47$

See (1984AJ01).

27. ^{10}B(n, ^{5}He)^{6}Li $\qquad Q_{\rm m} = -5.35$

See ^{6}Li.

28. ^{10}B(d, ^{7}Be)^{5}He $\qquad Q_{\rm m} = -1.97$

An angular distribution has been measured at $E_{\rm d} = 13.6$ MeV involving ^{5}He$_{\rm g.s.}$ and ^{7}Be*(0.43) (1983DO10).

29. ^{11}B(^{7}Li, ^{13}C)^{5}He $\qquad Q_{\rm m} = 9.06$

At E(^{11}B) $= 88$ MeV a broad structure is observed at $E_{\rm x} = 5.2 \pm 0.3$ MeV, $\Gamma = 2.0 \pm 0.5$ MeV (1987BEYI). See also (1988BEYJ).

^{5}Li

(Figs. 2 and 3)

GENERAL: See also (1984AJ01).

Model discussions: (1984ZW1A, 1985BA68, 1985FI1E, 1985KW02).

Special states: (1982PO12, 1983FE07, 1984BE1B, 1984FI20, 1984GL1C, 1984VAZS, 1984ZW1A, 1985BA68, 1985FI1E, 1985PO18, 1985PO19, 1985WI1A, 1987SV1A, 1988BA86, 1988KW02).

Electromagnetic transitions: (1985FI1E, 1987KR16).

Astrophysical questions: (1984BA74, 1984SU1A, 1985BO1E, 1986HU1D).

Complex reactions involving ^{5}Li: (1985PO18, 1985PO19, 1985WI1A, 1986BA2D, 1986CH10, 1986CS1A, 1986MA1V, 1986XU1B, 1987BL1K, 1987CH33, 1987CH32, 1987DE1O, 1987DU07, 1987FO08, 1987GA20, 1987GE1B, 1987HA45, 1987KI16, 1987LY04, 1987PE1B, 1988CEZZ, 1988SA09).

Reactions involving pions: (1981MC09, 1983SP06, 1985BA1H, 1985BE1C).

Hypernuclei: (1982KA1D).

Other topics: (1983BE55, 1984BE1B, 1985AN28, 1987DU09, 1987SV1A, 1988KW02).

Ground state of ^{5}Li: (1983ANZQ, 1985AN28, 1985FI1E, 1985TA1F, 1985FA01, 1985WI1A, 1987KR16, 1987SV1A, 1988WA08).

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

The ratio $\Gamma_\gamma/\Gamma_{\rm p\alpha}$ has been determined for $E(^3{\rm He}) = 63$ to 150 keV [$E_{\rm c.m.} = 25$ to 60 keV] by (1985CE13) by measuring simultaneously the γ-rays and the charged particles. Because of the large widths of the final states, γ_0 and γ_1 could not be resolved but the results are consistent with $E_{\rm x} = 3.0 \pm 1.0$ MeV for the excited state. $\Gamma_{\gamma_0}/\Gamma_{\rm p\alpha}$ is roughly constant for $E_{\rm c.m.} = 25$ to 60 keV at $(4.5 \pm 1.2) \times 10^{-5}$ and $\Gamma_{\gamma_1}/\Gamma_{\rm p\alpha} = (8 \pm 3) \times 10^{-5}$ at $E(^3{\rm He}) = 150$ keV (1985CE13). For applications see (1985CE13, 1985CE16).

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)]. $\sigma_{\gamma_0} = 21 \pm 4$ μb, $\Gamma_{\gamma_0} = 5 \pm 1$ eV. The radiation at resonance is isotropic, consistent with s-wave capture. Study of γ_0 and γ_1 yields $\Gamma = 2.6 \pm 0.4$ 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 γ_0 and γ_1. A broad peak is also observed at $E_{\rm x} \approx 20.7$ MeV in the γ_0 cross section. The cross section for γ_1 is ≈ 0.

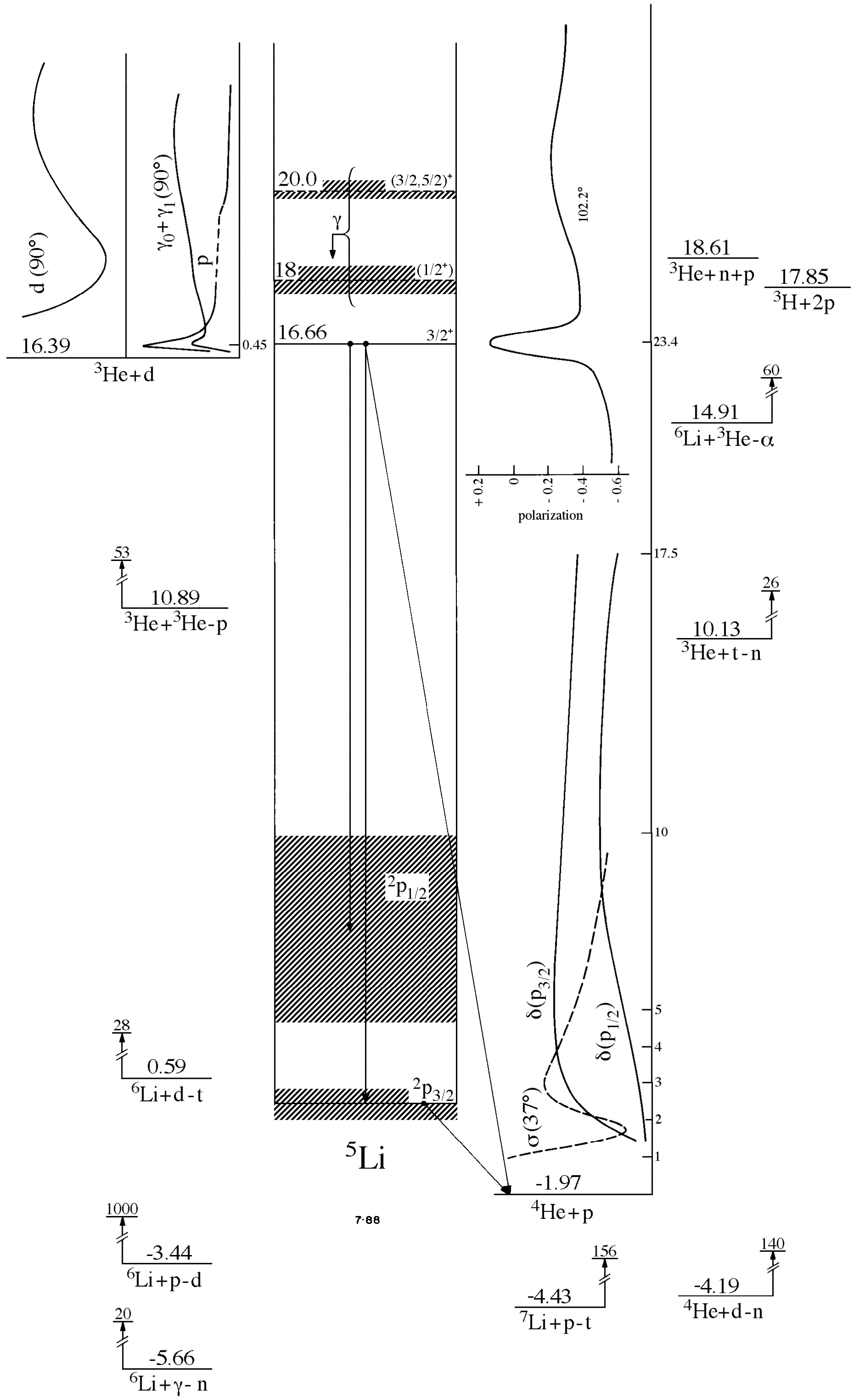


Fig. 2: Energy levels of ^{5}Li. For notation see Fig. 1.

Table 5.3: Energy levels of ^{5}Li

E_x (MeV) [a]	$J^\pi; T$	$\Gamma_{c.m.}$ (MeV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$	≈ 1.5	p, α	1, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23
$5 - 10$	$\frac{1}{2}^-; \frac{1}{2}$	5 ± 2	p, α	1, 6, 10, 11, 13, 14, 15, 17, 18
16.66 ± 0.07	$\frac{3}{2}^+; \frac{1}{2}$	≈ 0.3	γ, p, d, ^{3}He, α	1, 2, 3, 6, 13, 15, 18
(18 ± 1) [a]	$(\frac{1}{2}^+); \frac{1}{2}$	broad	γ, p, d, ^{3}He, α	1, 2, 13
(20.0 ± 0.5) [b]	$(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$	≈ 5	γ, p, d, ^{3}He, α	1, 2, 3, 4, 6, 13, 15
(34)		≈ 4		18, 19

[a] See also Table 5.2. Positive-parity states are predicted to lie at $E_x \approx 5$ MeV ($\frac{1}{2}^+$) and 12 MeV ($\frac{3}{2}^+$, $\frac{5}{2}^+$): see (1988WO10).

[b] For possible additional states see reactions 2 and 18.

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). For cross section and analyzing power measurements for $E_{\vec{d}} = 4$ to 9 MeV see (1985RIZZ; prelim.).

2. (a) ^{3}He(d, p)^{4}He $\quad Q_m = 18.35319 \quad E_b = 16.39$

(b) ^{3}He(d, np)^{3}He $\quad Q_m = -2.22458$

(c) ^{3}He(d, 2p)^{3}H $\quad Q_m = -1.46083$

(d) ^{3}He(d, 2d)^{1}H $\quad Q_m = -5.49353$

Excitation functions and angular distributions have recently been measured for $E_{c.m.} = 6.95$ to 171.3 keV, and $S(E)$ have been deduced: $S(0) = 6.3 \pm 0.6$ MeV · b (1987KR18). See also (1984AJ01). Recently, S-factors have been obtained down to $E_{c.m.} = 5.88$ keV. The effect on S of electron screening at low energies has been studied by (1988EN03).

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 in (1979AJ01). Excitation functions for ground-state protons have also been reported for $E(^3\text{He}) = 0.39$ to 2.15 MeV and 18.7 to 44.1 MeV and for $E_d = 2.8$ to 17.8 MeV [see (1974AJ01)]. Angular distributions have been measured for $E_d = 0.25$ to 27 MeV and $E(^3\mathrm{He}) = 18.7$ to 44.1 MeV [see Table 5.6 in (1974AJ01) and (1979AJ01)]. Resonance-like behavior has been 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 $T_{20}(0°)$ for $E_{\vec{d}} = 0$ to 40 MeV.] Measurements of angular distributions and analyzing powers at $E(^3\mathrm{He}) = 27$ and 33 MeV have suggested the presence of a broad resonance(s) at $E_x \approx 28$ MeV. Vector and tensor analyzing powers have been studied at $E_{\vec{d}} = 1.0$ to 13.0 MeV (1986BI1C, 1986BIZP; prelim.) and 18, 20 and 22 MeV (1986SA1L; prelim.). See also (1986RO1J) and Tables 5.6 in (1974AJ01) and 5.4 in (1979AJ01).

It is suggested that at low energies [$E_d = 2.2$ to 6 MeV] reaction (c) goes primarily via a $J^\pi = \frac{3}{2}^-$, $T = \frac{1}{2}$ state of ^{5}Li located 0.8 ± 0.2 MeV above threshold [i.e., $E_x = 18.9 \pm 0.2$ MeV]: see (1979AJ01). Recent studies of the breakup have been reported at $E_d = 23.08$ MeV (1986BR1J; reaction (c)) and 60 MeV (1985OK03; reaction (d)). For the earlier work see (1984AJ01).

See also (1983MA1E, 1984ALZU, 1984GA1C, 1984HA1J, 1984MU1C, 1984VL1A, 1984WI1C, 1985GU1F, 1985KU1B, 1986BI1E, 1986JA1E, 1986KA1L, 1986LO1B, 1986PO1F, 1986WI1B, 1986WI1E, 1987JO1A, 1987KA1O, 1987TE1D, 1988GU1G, 1988KU1E; applications), (1984YA1A, 1985CA41, 1986DE1K, 1987DO1H, 1987RO25; astrophysics), (1986VA1D, 1987GR08) and (1984DU10, 1984KR1B, 1986AB1C, 1986BL15, 1986ILZZ, 1987AS05; theor.).

3. ^{3}He(d, d)^{3}He $\quad E_b = 16.39$

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 $^2\mathrm{D}_{3/2}$ or (^{2}D, $^4\mathrm{D}_{5/2}$ is favored, if only one state is involved: see (1979AJ01). A phase-shift analysis of the angular distribution and VAP data below 5 MeV suggests several MeV broad states [$^2\mathrm{P}_{3/2}$, $^4\mathrm{D}_{7/2}$, $^4\mathrm{D}_{5/2}$, $^4\mathrm{D}_{3/2}$ and, possibly, $^4\mathrm{D}_{1/2}$]: see (1984AJ01). See also (1987KR18).

Angular distributions and analyzing powers have been measured at many energies to $E = 44$ MeV: see (1979AJ01, 1984AJ01) for the earlier work, (1982COZO, 1983COZR; $E_{\vec{d}} = 10$ MeV; TAP; prelim.) and (1987YAZJ; $E_d = 29.5$ MeV on polarized ^{3}He; prelim.). For d-^{3}He correlations see (1987PO03). See also “Complex reactions” in the ^{5}Li “GENERAL section”. See also (1987GR08) and (1981PL1A, 1983ZE06, 1983ZE1B, 1985SH08, 1986BO01, 1986KA28, 1986YA1E, 1987ZE1D; theor.).

4. ^{3}He(t, n)^{5}Li $\quad Q_m = 10.13$

At $E(^3\mathrm{He}) = 14$ to 26 MeV ^{5}Li*(0, 20.5 ± 0.8) are populated: see (1979AJ01). See also ^{6}Li.

5. ^{3}He(^{3}He, p)^{5}Li $\qquad Q_{\rm m} = 10.89$

The spectrum of protons at $E(^{3}{\rm He}) = 3$ to 18 MeV shows a pronounced peak corresponding to $^{5}{\rm Li}_{\rm g.s.}$ superposed on a continuum: see (1974AJ01). The angular distribution of $\rm p_0$ has been measured at $E(^{3}{\rm He}) = 26$ MeV (1983KI10; polarized target). See also ^{6}Be and (1986OS1D; theor.).

6. ^{4}He(p, p)^{4}He $\qquad E_{\rm b} = -1.97$

Differential cross sections and polarization measurements have been carried out at many energies: see (1966LA04, 1974AJ01, 1979AJ01, 1984AJ01) for the earlier work. Recent measurements are reported at $E_{\vec{\rm p}} = 65$ MeV (1986FU05; A_y), 100 MeV (1983NAZV, 1985GUZX; $\sigma(\theta)$, A_y; prelim.) and 495 MeV (1988STZZ; prelim.) and at $E_{\rm p} = 695, 793, 890, 991$ MeV (1985VE13; $\sigma(\theta)$) and 1 GeV (1985AL09; $\sigma(\theta)$). Cross sections and A_y at $E_{\vec{\rm p}} = 98.7$ and 149.3 MeV for the continuum are reported by (1985WE12).

Phase shifts below $E_{\rm p} = 18$ MeV have been determined by (1977DO01) based on all the available cross-section and polarization measurements, using an R-matrix analysis program. The $\rm P_{3/2}$ phase shift shows a pronounced resonance corresponding to $^{5}{\rm Li}_{\rm g.s.}$ while the $\rm P_{1/2}$ 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 $\rm D_{5/2}$, $\rm D_{3/2}$, $\rm F_{7/2}$ and $\rm F_{5/2}$ phase shifts become greater than 1° at $E_{\rm p} \approx 11$, 13, 14 and 16 MeV, respectively 1977DO01). (1986TH1C; prelim.) have measured A_y for $1.1 \le E_{\vec{\rm p}} \le 2.15$ MeV: $A_y = 1$ for $E_{\rm p} = 1.89$ MeV, $\theta_{\rm c.m.} = 87.0^\circ$.

A phase-shift analysis for $E_{\rm p} = 21.8$ to 55 MeV is presented by (1978HO17) [see also analyzing-power contour diagram for $E_{\rm p} = 20$ to 65 MeV]. A striking anomaly is seen in the analyzing power at $E_{\rm p} = 23$ MeV and the $^{2}{\rm D}_{3/2}$ phase shift clearly shows the $\frac{3}{2}^{+}$ state at $E_{\rm x} = 16.7$ MeV [see also (1979AJ01)]. The other phase shifts $^{2}{\rm S}_{1/2}$, $^{2}{\rm P}_{3/2}$, $^{2}{\rm P}_{1/2}$, $^{2}{\rm D}_{5/2}$, $^{2}{\rm F}_{7/2}$, $^{2}{\rm F}_{5/2}$, $^{2}{\rm G}_{9/2}$ and $^{2}{\rm G}_{7/2}$ are smooth functions of energy. Both the $^{2}{\rm P}_{3/2}$ and $^{2}{\rm P}_{1/2}$ inelastic parameters show a somewhat anomalous behavior at $E_{\rm p} \approx 30$ MeV; the absorption first increases then decreases to stay rather constant at $E_{\rm p} > 40$ MeV. These results are consistent with broad and overlapping states with $J^\pi = \frac{1}{2}^{-}$ and $\frac{3}{2}^{-}$ at $E_{\rm x} \approx 22$ 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 $^{2}{\rm G}_{7/2}$ phase shifts) of a $\frac{7}{2}^{+}$ level around $E_{\rm p} = 29$ MeV [$E_{\rm x} \approx 21$ MeV]. The G-waves are necessary to fit the detailed shape of the angular distributions for $E_{\rm p} = 20$ to 55 MeV (1978HO17). For a contour diagram of the analyzing power for $E_{\rm p} = 130$ to 1800 MeV see (1980MO09). For a measurement of the spin rotation parameter, R, at $E_{\vec{\rm p}} = 500$ MeV see (1983MO01). See also (1986SA1J; prelim.; $E_{\vec{\rm p}} = 65$ Mev).

PNC effects have been studied via the elastic scattering of 46 MeV longitudinally polarized protons on ^{4}He: the longitudinal power $A_z = -(3.3 \pm 0.9) \times 10^{-7}$. This was obtained by measuring σ^{+} and σ^{-} for the positive and negative helicity of the incident protons (1985LA01, 1986LA29):

the conclusion reached by the authors from this, and all other experiments, is that there does not exist any evidence for a non-zero value of f_π, the weak isovector coupling constant. See also (1984AJ01), (1986ADZT) and (1986HA1Q, 1988NA18; theor.).

Work at very high energies ($\gg 1$ GeV) is reported by (1982AB1B, 1984GL04, 1984SA39, 1985AB1A, 1985BA1H, 1985GL1B, 1986BE1S, 1987OT1D): see also reaction 7 and (1984AJ01). See also (1987MU1B). For $\alpha + \mathrm{p}$ correlations see (1987PO03) and the "General section" here.

See also (1986GOZY), (1982NA1B, 1983FA1A, 1984FA1B, 1984FR1C, 1984HA1L, 1984HO1H, 1984SI1A, 1985AD1A, 1985AL1D, 1985FA1A, 1985MI10, 1986BA88, 1986ST1D), (1984SP1A; applications), (1984KR1B; muon fusion) and (1981PL1A, 1983AL1C, 1983BI1C, 1983GR20, 1983PA1B, 1983SA38, 1983ZA1A, 1983ZE06, 1983ZE1B, 1984AH03, 1984BL21, 1984CAZW, 1984DE1G, 1984FI20, 1984KW01, 1984LA1B, 1984PR1A, 1984SC1A, 1985BA68, 1985BLZX, 1985DA1A, 1985FL04, 1985HA04, 1985HE1D, 1985HO1B, 1985JA1F, 1985KI11, 1985KO05, 1985KO37, 1985MI1F, 1985NEZW, 1985RO16, 1985SO06, 1985SO08, 1985TE02, 1986AU05, 1986BA2L, 1986BL02, 1986BO01, 1986FR12, 1986GUZZ, 1986KA1G, 1986KA1H, 1986KA35, 1986KO1J, 1986OK06, 1986OR03, 1986SA05, 1986SA30, 1986WA21, 1987DU1B, 1987FO1C, 1987FR1D, 1987FU10, 1987KR16, 1987LI1K, 1987LI1L, 1987PO1G, 1987PR08, 1987QI01, 1987WA11, 1988FR06, 1988HE1C; theor.).

7. (a) ^{4}He(p, d)^{3}He	$Q_\mathrm{m} = -18.35320$	$E_\mathrm{b} = -1.97$
(b) ^{4}He(p, pn)^{3}He	$Q_\mathrm{m} = -20.57778$	
(c) ^{4}He(p, 2p)^{3}H	$Q_\mathrm{m} = -19.81403$	
(d) ^{4}He(p, pd)^{2}H	$Q_\mathrm{m} = -23.84674$	

Angular distributions of deuterons and of ^{3}He ions (reaction (a)) have been measured for $E_\mathrm{p} = 27.9$ to 770 MeV and at $E_\alpha = 3.98$ GeV/c [see (1979AJ01, 1984AJ01)] as well as at $E_{\vec{\mathrm{p}}} = 100$ MeV (1983NAZV; prelim.; also A_y), 200 and 400 MeV (1986AL01; also A_y). Excitation functions are reported at several energies in the range $E_\mathrm{p} = 38.5$ to 44.6 MeV and 200 to 500 MeV. Continuum yields and A_y have been studied at $E_{\vec{\mathrm{p}}} = 98.7$ and 149.3 MeV by (1985WE12). For polarization measurements to 500 MeV see above and (1979AJ01, 1984AJ01). See also (1988BAZH).

For reactions (b), (c) and (d) see (1974AJ01, 1979AJ01, 1984AJ01). The breakup of ^{4}He via reaction (c) has recently been studied by (1986FU05): large values of A_y in the FSI region are reported. For breakup processes at high energies, including pion production, see (1983AN13, 1983MO14, 1984WA1K, 1985BA1H, 1985GL1B, 1986BA2E, 1986BA2M). See also (1983AN18, 1987MUZZ, 1987TEZZ, 1988PA1E), (1983CH1B, 1987MU1B), (1983ZH04, 1984KO1E, 1984LI1B, 1986GO1J, 1987LY1C, 1987MI1N; theor.).

8. ^{4}He($\bar{\mathrm{p}}$, $\bar{\mathrm{p}}$)^{4}He

Antiproton interactions with ^{4}He have been studied by (1984BA60, 1985BA76, 1987BA12, 1987BA47, 1987BA69). See also (1984BA74, 1984FA14; astrophysics) and (1983FA16, 1986DO20, 1987NA23; theor.).

9. (a) ^{4}He(d, n)^{5}Li $Q_m = -4.19$
(b) ^{4}He(d, np)^{4}He $Q_m = -2.22459$

For reaction (a) see reaction 8 in ^{5}He (1985WI15) and (1987KAZL; $E_d = 15$ MeV; n_0; prelim.). Reaction (b) has been studied at $E_d = 12$ to 17 MeV and at $E_\alpha = 18.0$ to 140 MeV: see (1979AJ01, 1984AJ01), ^{6}Li and (1985DO03, 1987KUZI; theor.).

10. (a) ^{4}He(^{3}He, d)^{5}Li $Q_m = -7.46$
(b) ^{4}He(^{3}He, pd)^{4}He $Q_m = -5.49354$

At $E_\alpha = 26.3$ MeV, ^{5}Li$_{g.s.}$ is reported to have a width of 1.9 ± 0.25 MeV while the first excited state is suggested to lie at $E_x = 2.82 \pm 0.35$ MeV, $\Gamma = 1.64 \pm 0.25$ MeV [reaction (b)]: see (1982NE09, 1986YA01). See also (1985NEZW).

11. ^{4}He(^{7}Li, ^{6}He)^{5}Li $Q_m = -11.94$

See reaction 9 in ^{5}He (1988WO10).

12. ^{6}Li(π^+, p)^{5}Li $Q_m = 134.69$

Differential cross sections have been measured at $E_\pi = 75$ and 150 MeV for p_0: see (1984AJ01).

13. (a) ^{6}Li(p, d)^{5}Li $Q_m = -3.44$
(b) ^{6}Li(p, pd)^{4}He $Q_m = -1.4750$
(c) ^{6}Li(p, pn)^{5}Li $Q_m = -5.66$

Angular distributions have been measured at $E_p = 18.6$ to 185 MeV. At the highest energy, the spectra are characterized by a broad asymmetric peak corresponding to ^{5}Li$_{g.s.}$, a narrow peak [^{5}Li* (16.7)] and a broad peak at $E_x \approx 20$ MeV. DWBA analysis leads to $C^2S = 0.64$ and 0.57 for ^{5}Li*(0, 16.7). The first excited state of ^{5}Li is also reported to be populated: see (1984AJ01).

Reaction (b) has been studied at $E_{\rm p} = 9$ to 50 MeV: the p-α FSI corresponding to ^{5}Li$_{\rm g.s.}$ is observed [see (1979AJ01)]. See also (1983CA13, 1986NI1B). At 1 GeV (reaction (c)) the separation energy between 4–5 MeV broad $1{\rm p}_{3/2}$ and $1{\rm s}_{1/2}$ peaks is reported to be 17.7 ± 0.5 MeV (1985BE30, 1985DO16). See also (1985PA03; $E_{\rm p} = 70$ MeV).

14. (a) ^{6}Li(d, t)^{5}Li $\quad Q_{\rm m} = 0.59$
(b) ^{6}Li(d, pt)^{4}He $\quad Q_{\rm m} = 2.5577$

Angular distributions of the $\rm t_0$ group have been measured at $E_{\rm d} = 15$ and 20 MeV: see (1974AJ01). Reaction (b) has been studied at $E_{\rm d} = 0.12$ to 10.5 MeV: see (1984AJ01). See also ^{8}Be.

15. (a) ^{6}Li(^{3}He, α)^{5}Li $\quad Q_{\rm m} = 14.91$
(b) ^{6}Li(^{3}He, pα)^{4}He $\quad Q_{\rm m} = 16.8782$

At E(^{3}He) $= 25.5$ MeV, ^{5}Li*(0, 16.7) and two broad peaks at $E_{\rm x} \approx 19.8$ and 22.7 MeV [$\Gamma_{\rm c.m.} = 2$ and 1 MeV] are populated: see (1979AJ01). At E(^{3}He) $= 33.3$ MeV angular distributions and analyzing powers have been studied for ^{5}Li*(0, 16.7) [$\Gamma \approx 1.6$ and ≈ 0.4 MeV]: see (1984AJ01). In reaction (b) the parameters of the first excited state are deduced to be $E_{\rm x} = 5.0 \pm 0.7$ MeV, $\Gamma_{\rm c.m.} = 5.7 \pm 0.7$ MeV (1984AR17; E(^{3}He) $= 1.7$ and 2.3 MeV), $E_{\rm x} = 5.8 \pm 0.5$ MeV, $\Gamma_{\rm c.m.} = 5.2 \pm 0.5$ MeV (1987FA1I; E(^{3}He) $= 1.65$ MeV). Angular distributions of protons from the decay of ^{5}Li$_{\rm g.s.}$ are reported by (1988BU04; E(^{3}He) $= 1.5$ to 3.5 MeV). See also (1985BA1U, 1987ZA07), (1984AJ01) and ^{8}Be.

16. ^{6}Li(^{6}Li, ^{7}Li)^{5}Li $\quad Q_{\rm m} = 1.58$

Angular distributions have been measured at E(^{6}Li) $= 156$ MeV to ^{5}Li$_{\rm g.s.}$. Unresolved states at $E_{\rm x} = 16$–20 MeV are also populated (1987MI34).

17. ^{6}Li(^{13}C, ^{14}C)^{5}Li $\quad Q_{\rm m} = 2.51$

See reaction 9 in ^{5}He (1988WO10).

18. (a) ^{7}Li(p, t)^{5}Li $\quad Q_{\rm m} = -4.43$
(b) ^{7}Li(p, nd)^{5}Li $\quad Q_{\rm m} = -10.69$

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 20 in ^{5}He]. 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). See also (1988BAZH). For reaction (b) at $E_p = 670$ MeV see (1984AJ01). See also (1985NEZW; theor.).

19. ^{7}Li(^{3}He, dt)^{5}Li $\qquad Q_m = -9.93$

A kinematically complete experiment is reported at $E(^3\text{He}) = 120$ MeV. The missing mass spectrum shows the ground-state peak and a 4 MeV wide bump at $E_x \approx 34$ MeV, and some slight indication of a small bump at 22.0 ± 0.5 MeV (1985FR01).

20. ^{7}Li(^{6}Li, ^{8}Li)^{5}Li $\qquad Q_m = -3.63$

See (1984KO25).

21. ^{9}Be(α, ^{8}Li)^{5}Li $\qquad Q_m = -18.85$

At $E_\alpha = 90$ MeV differential cross sections have been measured for the transitions to $^5\text{Li}_{\text{g.s.}} + {^8\text{Li}_{\text{g.s.}}}$: see (1984AJ01).

22. ^{10}B(d, ^{7}Li)^{5}Li $\qquad Q_m = -1.40$

An angular distribution is reported at $E_d = 13.6$ MeV (1983DO10). See also (1984SH1E; theor.).

23. ^{10}B(^{3}He, 2α)^{5}Li $\qquad Q_m = 10.45$

At $E(^3\text{He}) = 2.3$ and 5.0 MeV the reaction is reported to proceed via ^{9}B*(4.9) to $^5\text{Li}_{\text{g.s.}}$ (1986AR14). See also (1988AR05) and ^{9}B.

^{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 $E(^3\text{He}) = 18.0$ to 26.0 MeV indicates that ^{5}Be(0) is at least 4.2 MeV unstable with respect to $^3\text{He}+2\text{p}$ $[(M-A) > 33.7$ 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 $E_\text{x} = 21.4$ MeV: see (1979AJ01).

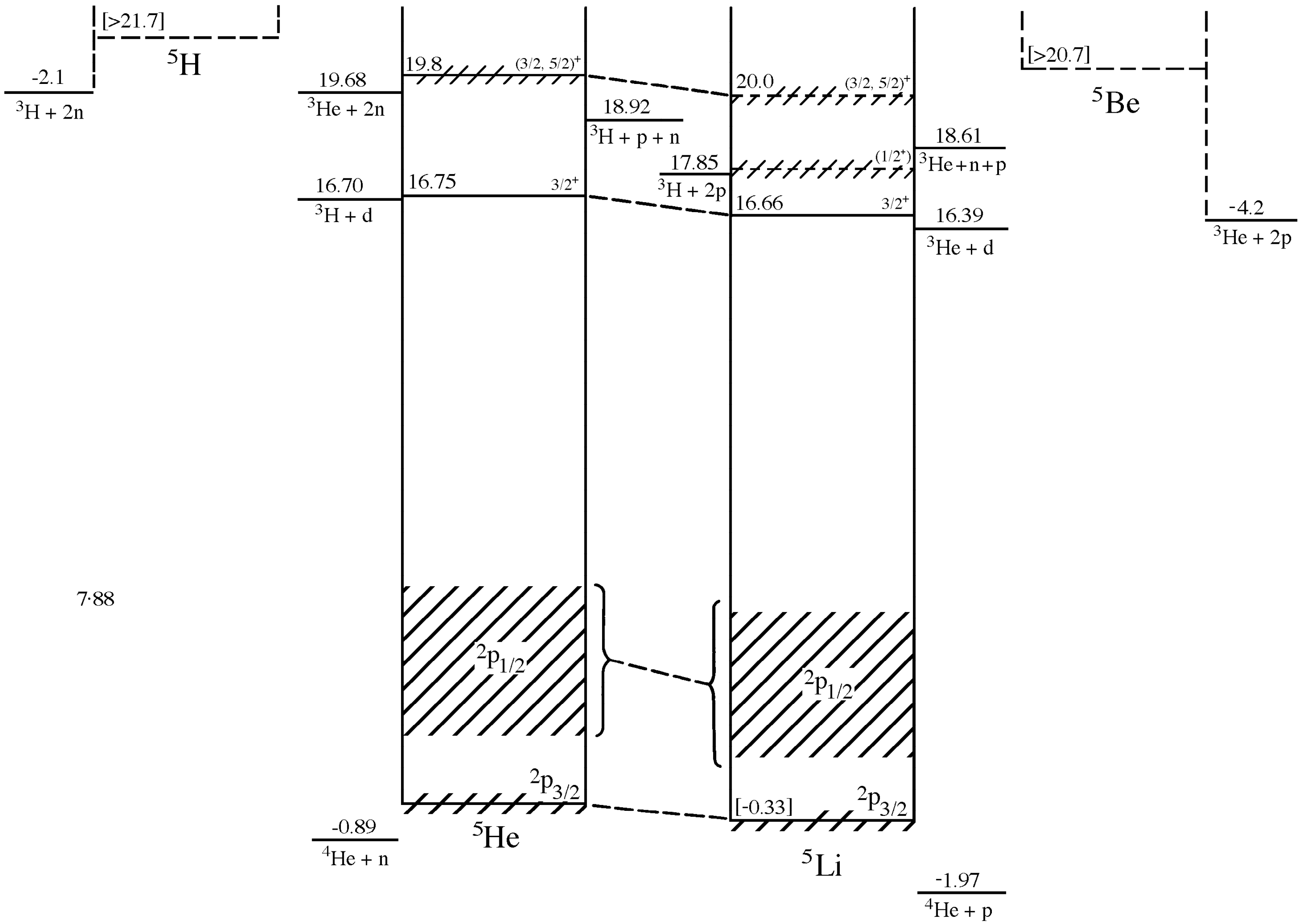


Fig. 3: Isobar diagram, $A = 5$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron-proton mass difference and the Coulomb energy, taken as $E_{\rm C} = 0.60Z(Z-1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_{\rm N} = M(Z,A) - ZM({\rm H}) - NM({\rm n}) - E_{\rm C}$, minus the corresponding quantity for ^{5}He: here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

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