

Energy Levels of Light Nuclei $A = 5$

D.R. Tilley ^{a,b}, C.M. Cheves ^{a,c}, J.L. Godwin ^{a,c}, G.M. Hale ^d,
H.M. Hofmann ^e, J.H. Kelley ^{a,b}, C.G. Sheu ^{a,c} and H.R. Weller ^{a,c}

^a*Triangle Universities Nuclear Laboratory, Durham, NC 27708-0308*

^b*Department of Physics, North Carolina State University, Raleigh, NC 27695-8202*

^c*Department of Physics, Duke University, Durham, NC 27708-0305*

^d*Los Alamos National Laboratory, Los Alamos, NM 87545*

^e*Universität Erlangen-Nürnberg, Erlangen, Germany*

Abstract: An evaluation of $A = 5-7$ was published in *Nuclear Physics A708* (2002), p. 3. 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 are in the NNDC/TUNL format.

(References closed August 23, 2001)

This work is supported by the US Department of Energy, Office of High Energy and Nuclear Physics, under: Contract No. DEFG02-97-ER41042 (North Carolina State University); Contract No. DEFG02-97-ER41033 (Duke University).

Table of Contents for $A = 5$

Below is a list of links for items found within the PDF document. The introductory [Table 3](#) is available on this website via the link.

A. Nuclides: [A = 5](#), [\${}^5\text{n}\$](#) , [\${}^5\text{H}\$](#) , [\${}^5\text{He}\$](#) , [\${}^5\text{Li}\$](#) , [\${}^5\text{Be}\$](#)

B. Tables of Recommended Level Energies:

[Table 5.1](#): Energy levels of ${}^5\text{He}$, extended R -matrix prescription

[Table 5.2](#): Energy levels of ${}^5\text{He}$, R -matrix prescription

[Table 5.3](#): Energy levels of ${}^5\text{Li}$, extended R -matrix prescription

[Table 5.4](#): Energy levels of ${}^5\text{Li}$, conventional R -matrix prescription

C. [References](#)

D. General Tables: [\${}^5\text{H}\$](#) , [\${}^5\text{He}\$](#) , [\${}^5\text{Li}\$](#)

E. Figures: [\${}^5\text{He}\$](#) , [\${}^5\text{Li}\$](#) , [Isobar diagram](#)

F. Erratum to the Publication: [PS](#) or [PDF](#)

A = 5

$A = 5$ resonance parameters:

The resonance parameters tabulated here are based on comprehensive multichannel R -matrix analyses of reactions in the ${}^5\text{He}$ and ${}^5\text{Li}$ systems (Hale, Dodder and Witte, private communication¹). These analyses include data from all possible reactions for the two-body channels $d + t$ (or $d + {}^3\text{He}$ in the case of ${}^5\text{Li}$) and $N + {}^4\text{He}$ at cm energies corresponding to $E_x < 23$ MeV. In addition, $N + {}^4\text{He}^*$ channels are included to approximate the effects of three-body breakup processes. The fits obtained to the measurements for the two-body reactions are generally quite good. In the ${}^5\text{He}$ analysis, for example, the χ^2 per degree of freedom for the fit is 1.6, and it includes more than 2600 data points. Similar results were obtained for the ${}^5\text{Li}$ analysis, which includes even more data.

The level information has been obtained from the $A = 5$ R -matrix parameters using two different prescriptions, given in separate tables. The recommended prescription, called the “extended” R -matrix method (1987HA20, 1997CS01), comes from the complex poles and residues of the S matrix. This prescription has been found to give resonance parameters that are free, both formally and practically, of all dependence on the “geometric” parameters of R -matrix theory, such as boundary conditions and channel radii. The parameters are listed in Table 5.1 for ${}^5\text{He}$ and in Table 5.3 for ${}^5\text{Li}$. Positions and widths for the lowest two $A = 5$ states have already been given in (1997CS01), and for the second excited state of ${}^5\text{He}$ ($\frac{3}{2}^+$) in (1987HA20), using this prescription.

For comparison, we also list in Tables 5.2 and 5.4 the more standard R -matrix resonance parameters that were used in the $A = 4$ level compilation (1992TI02), as defined in the Appendix there. This multi-level generalization of the single-level resonance prescription given by Lane and Thomas (1958LA73) is based on the real poles and residues of the “resonant” reactance matrix (K_R), which, because it is not truly an asymptotic quantity as is the S matrix, retains dependence on the channel radii, and on the specification of the “non-resonant” phase shift. Our prescription is based on the usual assumption that the non-resonant phase shifts are the “hard-sphere” phases associated with the complete reflection of ingoing waves at the nuclear surface.

The single-level prescription of Lane and Thomas was used recently by Barker (1997BA72) to obtain an interpretation of the behavior of the cross sections near the $J^\pi = 3/2^+$ resonance in $A = 5$ equivalent to that of the complex S -matrix pole and shadow pole description of (1987HA20).

A comparison of the tables for a given system shows that the resonance parameters from the two prescriptions can be quite different, however. The widths for the resonant reactance-matrix pole prescription tend to be much larger than those of the S -matrix pole prescription, and they do not usually correspond with the experimental values. For that reason, reaction numbers were not given in the Tables (5.2 and 5.4) listing the K_R -based parameters, as defined in (1992TI02).

In some cases, resonances seen using the recommended method are not present in the usual prescription, even though the input R -matrix parameters are identically the same. These differences, which are most evident for light systems having broad resonances, stem from the fact that the resonant K -matrix prescription is based on the *apparent* positions of the S -matrix poles as seen from

¹ For a discussion of the methods used and earlier results, see G.M. Hale and D.C. Dodder, Proc. Int. Conf. on Nuclear Cross Sections for Technology, Knoxville, TN 1979, Eds. J.L. Fowler, C.H. Johnson and C.D. Bowman (NBS Special Publication 594) p.650.

the real axis of the physical sheet. For broad resonances, as is known from the complex-eigenvalue expansion of the level matrix (1958LA73), the apparent pole positions can change rapidly (or even disappear entirely) as the vantage point is varied, causing significant differences with the actual positions (and residues) of the poles in the complex energy plane.

GENERAL: References to articles on general properties of $A = 5$ nuclei published since the previous review (1988AJ01) are grouped into categories and listed, along with brief descriptions of each item, in the General Tables for $A = 5$ located on our website at (www.tunl.duke.edu/nucldata/General_Tables/05.shtml).

${}^5\mathbf{n}$

(Not illustrated)

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

${}^5\mathbf{H}$

(Not illustrated)

The previous review (1988AJ01) noted that the ${}^9\text{Be}({}^{11}\text{B}, {}^{15}\text{O})$ reaction at $E({}^{11}\text{B}) = 52\text{--}76$ MeV showed no evidence for the formation of ${}^5\text{H}$ (1986BE35, 1987BO40). For the earlier work see (1984AJ01). See also (1987KO47, 1988SEZJ). In several experiments on π^- absorption at rest there is some evidence for the formation of a very broad (8 ± 3 MeV) resonance in the ${}^5\text{H}$ system with $E_r = 7.4 \pm 0.7$ MeV in the ${}^9\text{Be}(\pi^-, \text{X})$ reaction [see (1987GO25) and the more recent work of (1991GO19, 1992AM1H)]. Measurements reported in (1990AM04, 1992AM1H) provide evidence for a state at $E_r = 11.8 \pm 0.7$ MeV, $\Gamma = 5.6 \pm 0.9$ MeV from ${}^6\text{Li}(\pi^-, \text{p})$ and a state at $E_r = 9.1 \pm 0.7$ MeV, $\Gamma = 7.4 \pm 0.6$ MeV from ${}^7\text{Li}(\pi^-, \text{d})$. In an experiment on ${}^6\text{Li}(\pi^-, \text{p})$ at $E_\pi = 125$ MeV (1980SE1A) a broad ${}^5\text{H}$ state with $E_r = 11.1 \pm 1.5$, $\Gamma \approx 14$ MeV was observed. Evidence for a dineutron-containing breakup channel was reported in (1991SE06). Work on an experiment on ${}^7\text{Li}({}^6\text{Li}, {}^8\text{B}){}^5\text{H}$ described in (1995ALZU) reported evidence for an unstable ${}^5\text{H}$ nucleus at 5.2 ± 0.4 MeV above the ${}^3\text{H} + 2\text{n}$ dissociation threshold. See also (1995AU04). A recent study of the ${}^1\text{H}({}^6\text{He}, 2\text{p}){}^5\text{H}$ reaction (1997KO07) reported a ${}^5\text{H}$ resonance with decay energy into ${}^3\text{H} + 2\text{n}$ of $1.1 \pm 0.4 \pm 0.3$ MeV (0.3 MeV is the systematic error).

${}^5\text{H}$ 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). A three-body calculation (2000SH23) predicts states in the ${}^3\text{H} + \text{n} + \text{n}$ continuum with $J^\pi = \frac{1}{2}^+$, $E_x = 2.5\text{--}3.0$ MeV, $\Gamma = 3\text{--}4$ MeV; $J^\pi = \frac{3}{2}^+$, $E_x = 6.4\text{--}6.9$ MeV, $\Gamma = 8$ MeV; $J^\pi = \frac{5}{2}^+$, $E_x = 4.6\text{--}5.0$ MeV, $\Gamma = 5$ MeV. A calculation (2001DE02) with the generator-coordinate method using ${}^3\text{H} + \text{n} + \text{n}$ three-cluster state predicts a ${}^5\text{H}$ ground state energy

$E \approx 3$ MeV above the ${}^3\text{H} + n + n$ threshold with $\Gamma_n \approx 1\text{--}4$ MeV and a lifetime longer than the ${}^4\text{H}$ lifetime. See also (1982SM09, 1983ANZQ, 1986BE44, 1987PE1C).

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

GENERAL: References to articles on general properties of ${}^5\text{He}$ published since the previous review (1988AJ01) are grouped into categories and listed, along with brief descriptions of each item, in the General Tables for ${}^5\text{He}$ located on our website at (www.tunl.duke.edu/nuclldata/General_Tables/5he.shtml).

1. ${}^1\text{H}({}^6\text{He}, np){}^5\text{He}$ $Q_m = -1.771$

The quasi-free neutron knockout reaction was studied with ${}^6\text{He}$ beams produced by 115 MeV ${}^{15}\text{N}$ primary beams (1997KOZV, 1997KO07). ${}^5\text{He}$ was observed in the separation energy spectra. The ${}^5\text{He} \rightarrow {}^4\text{He} + n$ decay energy is reported to be consistent with the “known mass of ${}^5\text{He}$ ” and is given as 0.97 MeV.

2. ${}^3\text{H}(d, \gamma){}^5\text{He}$ $Q_m = 16.792$

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 branching ratio $\Gamma_{\gamma_0}/\Gamma_n$ 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 $E_d = 45$ to 146 keV (1984CE08). Assuming Γ_n of ${}^5\text{He}^*(16.7)$ is 37 ± 5 keV (see reaction 8), then $\Gamma_{\gamma_0} = 2.1 \pm 0.4$ eV. (1986MO05) also report branching ratios up to $E_d = 0.72$ MeV and summarize the earlier work to 5 MeV. More recently, a measurement (1993KA01) at $E_d = 100$ keV of the ${}^3\text{H}(d, \gamma){}^5\text{He}/{}^3\text{H}(d, \alpha)n$ ratio gave $(1.2 \pm 0.3) \times 10^{-4}$ which is larger than the results of (1986MO05) and (1984CE08) but includes contribution from decay to both the ground and first excited states.

Differential cross sections, vector- and tensor-analyzing powers were measured at $E_d = 400$ keV for ${}^3\text{H}(d, \gamma){}^5\text{He}$ (1989RI04) and at $E_d = 0.1, 0.45$ and 8.6 MeV for ${}^3\text{H}(d, \gamma)$ and ${}^3\text{He}(d, \gamma)$ by (1994BA02). These results were compared with coupled channels resonating group model (CCRGM) calculations. See also the shell model description of the $\frac{3}{2}^+$ resonance presented in (1993KU02).

The ${}^3\text{H}(d, \gamma){}^5\text{He}$ and ${}^3\text{He}(d, \gamma){}^5\text{Li}$ reactions were used in a measurement (1991BA02) of the ground state widths of ${}^5\text{He}$ and ${}^5\text{Li}$. The results were $\Gamma_n = 1.36 \pm 0.19$ MeV in ${}^5\text{He}$ and $\Gamma_p = 2.44 \pm 0.21$ MeV for ${}^5\text{Li}$. These values lead to reduced widths for ${}^5\text{He}$ and ${}^5\text{Li}$ which are equal (within error). This is consistent with charge symmetry expectations. The ground-state widths

Table 5.1: Energy levels of ${}^5\text{He}$, extended R -matrix prescription ^a

E_x (MeV)	$J^\pi; T$	Γ_{cm} ^b (MeV)	Γ_n (MeV)	Γ_d (MeV)	Γ_{n^*} ^c (MeV)	Decay	Reactions (used in analysis)
g.s. ^d	$\frac{3}{2}^-; \frac{1}{2}$	0.648	0.578	8.80 ^e	66.0 ^e	n, α	5, 8, 13, 23, 24, 25
1.27	$\frac{1}{2}^-; \frac{1}{2}$	5.57	3.18	38.0 ^e	1.27 ^e	n, α	5, 8, 21, 24, 25
16.84	$\frac{3}{2}^+; \frac{1}{2}$	0.0745	0.040	0.025 ^f		γ , n, d, t, α	2, 3, 7, 8, 10, 13, 14, 23, 24, 25
19.14	$\frac{5}{2}^+; \frac{1}{2}$	3.56	0.003	1.62 ^g		n, d, t, α	4, 10, 14, 23
19.26	$\frac{3}{2}^+; \frac{1}{2}$	3.96	0.014	1.83 ^g		n, d, t, α	4, 10, 14, 23
19.31	$\frac{7}{2}^+; \frac{1}{2}$	3.02	0.045	1.89 ^g		n, d, t, α	4, 10, 14
19.96	$\frac{3}{2}^-; \frac{1}{2}$	1.92	0.003	0.325 ^h	0.862	n, p, d, t, α	3, 17, 24, 25
21.25	$\frac{3}{2}^+; \frac{1}{2}$	4.61	0.098	2.38 ⁱ		n, d, t, α	21
21.39	$\frac{5}{2}^+; \frac{1}{2}$	3.95	0.091	2.12 ^l		n, d, t, α	21
21.64	$\frac{1}{2}^+; \frac{1}{2}$	4.03	0.050	0.878 ^j	0.726	n, p, d, t, α	21
23.97	$\frac{7}{2}^+; \frac{1}{2}$	5.44	0.053	2.85 ^g		n, d, t, α	
24.06	$\frac{5}{2}^-; \frac{1}{2}$	5.23	0.013	2.18 ^k		n, d, t, α	
(35.7 ± 0.4) ^l		≈ 2 ^l					21, 25

^a This prescription, based on the complex poles and residues of the S -matrix, is the recommended one (see Introduction). The channel radii are: $a_n = 3.0$ fm, $a_d = 5.1$ fm. The uncertainties in the widths and positions of the first three levels are less than 1%. Above 19 MeV excitation energy, they increase rapidly, varying from about 5% up to as much as 50% for the broad higher levels. Except where noted, all parameters in the table are newly adopted in this evaluation.

^b The fact that the sum of the partial widths is unequal to the total width in the extended R -matrix prescription is characteristic of non-Breit-Wigner resonances as was discussed in the appendix of (1992TI02).

^c The n^* designation indicates $n + \alpha^*$ where the first excited state of the α particle was included as a way to approximate the effects of three-body breakup on the two-body channels.

^d Situated 798 keV above the $n + \alpha$ threshold. This value is in excellent agreement with early measurements reported by (1963SM03; 790 ± 30 keV) and by (1960YO06; 800 ± 100 keV).

^e These large partial widths in closed channels have no meaning as decay widths, but rather as asymptotic normalization constants.

^f Entirely ${}^4S(d)$.

^g Primarily ${}^4D(d)$.

^h Primarily ${}^2P(d)$.

ⁱ Primarily ${}^2D(d)$.

^j Primarily ${}^2S(d)$.

^k Primarily ${}^4P(d)$.

^l Retained from the previous evaluation (1988AJ01).

Table 5.2: Energy levels of ${}^5\text{He}$, R -matrix prescription ^a

E_x (MeV)	$J^\pi; T$	Γ_{cm} (MeV)	Γ_n (MeV)	Γ_d (MeV)	Γ_{n^*} (MeV)
g.s. ^b	$\frac{3}{2}^-; \frac{1}{2}$	0.963	0.963	0	0
6.17	$\frac{1}{2}^-; \frac{1}{2}$	20.61	20.61	0	0
16.66	$\frac{3}{2}^+; \frac{1}{2}$	0.889	0.691	0.198 ^c	
19.97	$\frac{3}{2}^-; \frac{1}{2}$	3.49	0.127	2.85 ^d	0.508
20.32	$\frac{1}{2}^+; \frac{1}{2}$	6.64	0.273	5.08 ^e	1.29
20.48	$\frac{7}{2}^+; \frac{1}{2}$	4.43	0.066	4.37 ^f	
21.67	$\frac{3}{2}^+; \frac{1}{2}$	6.87	0.156	6.72 ^f	
21.77	$\frac{5}{2}^+; \frac{1}{2}$	6.58	0.247	6.33 ^f	
23.52	$\frac{5}{2}^+; \frac{1}{2}$	25.21	0.028	25.18 ^f	
24.10	$\frac{1}{2}^-; \frac{1}{2}$	57.3	0.177	44.8 ^d	12.3
24.58	$\frac{5}{2}^-; \frac{1}{2}$	5.56	0.020	5.54 ^g	

^a See the Introduction for a discussion of the two prescriptions. The prescription used here is defined in (1992TI02). The channel radii are: $a_n = 3.0$ fm, $a_d = 5.1$ fm.

^b Situated 985 keV above the $n + \alpha$ threshold.

^c Entirely ${}^4S(d)$.

^d Primarily ${}^2P(d)$.

^e Primarily ${}^2S(d)$.

^f Primarily ${}^4D(d)$.

^g Primarily ${}^4P(d)$.

given by the conventional R -matrix prescription in Tables 5.2 and 5.4 are 0.963 MeV and 2.11 MeV for ${}^5\text{He}$ and ${}^5\text{Li}$, respectively.

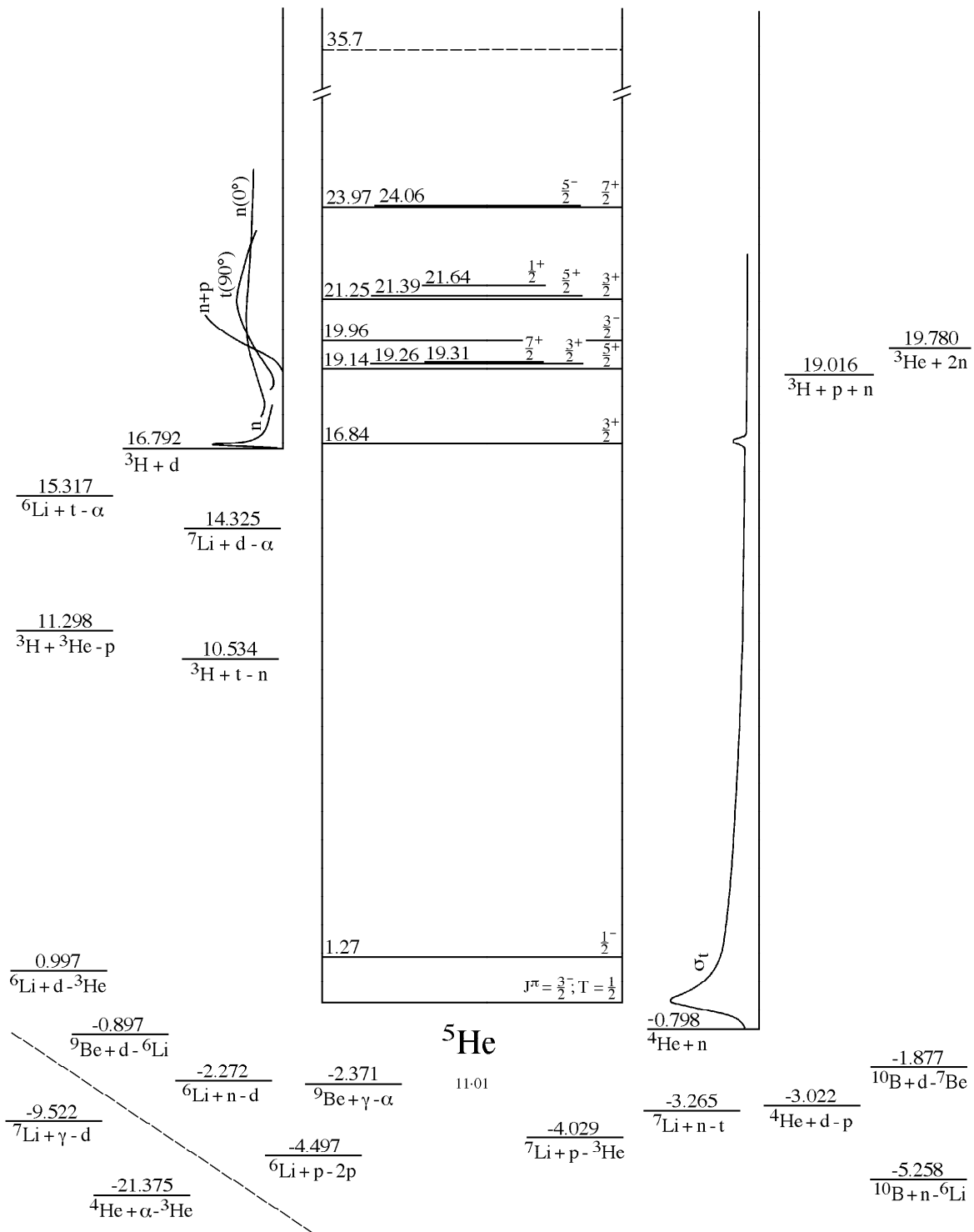
The data of (1991BA02) were used by (1996EF03) in a single-level R -matrix analysis to obtain values of the ground-state energies and widths of ${}^5\text{He}$ and ${}^5\text{Li}$, close to those given by the extended R -matrix prescription in Tables 5.1 and 5.3.

3. (a) ${}^3\text{H}(d, n){}^4\text{He}$	$Q_m = 17.58928$	$E_b = 16.79151$
(b) ${}^3\text{H}(d, 2n){}^3\text{He}$	$Q_m = -2.98834$	
(c) ${}^3\text{H}(d, pn){}^3\text{H}$	$Q_m = -2.22457$	

The cross section for reaction (a) has been measured in the range $E_t = 12.5$ to 117 keV (1984JA08) [$0.525(\pm 4.8\%)$ mb to $3.739(\pm 1.4\%)$ b] and in the range $E_d = 79.913$ to 115.901 keV (± 0.015 keV) (1987BR10) [3.849 to 4.734 b ($\pm 1.6\%$)]. See also (1985FI1G; $E_d = 13.8$ to 114.3 keV). A strong resonance, σ (peak) = 4.88 b, appears at $E_d = 105$ 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). The related work of (1991BO23) uses a resonance coupled channels model to interpret the ${}^5\text{He}$ ($\frac{3}{2}^+$) resonance as a coupled channel pole associated predominantly with the d-t system. A later study by (1993CS02) uses a realistic dynamical microscopic reaction approach and reaches the same conclusion. A more recent analysis of cross section data for $E_d = 8$ –116 keV is described in (1995LA33). Resonance parameters for the ${}^5\text{He}$ $\frac{3}{2}^+$ second excited state were determined.

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. (See however the discussion below.) Measurements of cross sections and angular distributions for reaction (a) have been reported to $E_d = 21$ MeV and $E_t = 20.0$ MeV [see (1974AJ01, 1979AJ01, 1984AJ01)] as well as at 1.0, 1.5 and 2.0 MeV (1987LI07). Neutron yields from reaction (a) above have been measured at $E_d = 140$ –300 keV (1989SH17). Measurements to determine the intensity of intermediate energy neutrons are described in (1989GA21). An absolute measurement of the polarization of 50 MeV neutrons at $\theta_{\text{lab}} = 29.7^\circ$ was reported in (1991SA18).

Figure 1: Energy levels of ${}^5\text{He}$, extended R -matrix prescription (see Table 5.1). In these diagrams, energy values are plotted vertically in MeV, based on the ground state as zero. For the $A = 5$ diagrams all levels are represented by discrete horizontal lines. 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 ${}^5\text{He}$ 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. For reactions in which the present nucleus occurs as a residual product, excitation functions have not been shown. Q values and threshold energies are based on atomic masses from (1995AU04) except for the ground state energies of the $A = 5$ nuclei for which the values from Tables 5.1 and 5.3 are used. Further information on the levels illustrated, including a listing of the reactions in which each has been observed, is contained in Table 5.1.



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. 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 ${}^3\text{He}(d, p){}^4\text{He}$ mirror reaction at corresponding cm 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. Vector polarization transfer coefficients, $K_y^y(0^\circ)$ have been measured for $E_d = 5$ to 11 MeV (1985HOZU, 1986HOIE). For earlier polarization work see (1984AJ01).

An R -matrix formalism was used in a phase shift analysis of $d + {}^3\text{H}$ below 1 MeV to obtain the contribution of ${}^2\text{S}_{1/2}$ - and P-wave channels near the ${}^5\text{He}$ ($\frac{3}{2}^+$) resonance. See also the recent work (1997BA72) in which properties of the $\frac{3}{2}^+$ levels of ${}^5\text{He}$ and ${}^5\text{Li}$ are discussed in terms of conventional R -matrix parameters. The multichannel resonating group model has been used in a study (1990BL08) of partial wave contributions in this energy region.

Improved formulae for fusion cross sections and thermal reactivities utilizing new data and R -matrix techniques are presented in (1992BO47). See also (1989AB21, 1989SC1F, 1989SC19, 1989SC25, 1989SC41).

The ${}^3\text{H}(d, n)$ reactivity in fusion reactors and screening-effect corrections needed for low energy data are discussed in (1989LA29).

(1987BR10) have derived astrophysical S -factors in the range $E_d = 8.3$ to 115.9 keV [$S(0) = 11.71 \pm 0.08$ MeV \cdot b], as well as reactivities. See (1984AJ01) for the earlier work, and (1985CA41, 1987VA36). Angular distributions of α particles were measured for $E_d < 200$ keV (1997BE59) and evidence for a D-wave contribution to the cross section in the vicinity of the $\frac{3}{2}^+$ s-wave resonance in ${}^5\text{He}$ was reported. Thermonuclear reaction rates for this reaction calculated from evaluated data are presented in the compilation (1999AN35).

Reaction (b) has been studied for $E_d = 10.9$ to 83 MeV. A study of reaction (c) leads to the suggestion of a resonance at $E_{\text{cm}} = 2.9 \pm 0.3$ MeV [$E_x = 19.7$ MeV], $\Gamma_{\text{cm}} = 1.9 \pm 0.2$ MeV, consistent with $J^\pi = \frac{3}{2}^-$ [see Table 5.1]: see (1974AJ01, 1979AJ01). See also the references cited in (1988AJ01). For applications and developments in muon-catalyzed fusion see the references cited in (1988AJ01) and the General Table for ${}^5\text{He}$ located on our website at (www.tunl.duke.edu/nuclldata/General_Tables/5he.shtml).

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

$$E_b = 16.792$$

The elastic scattering has been studied for $E_d = 2.6$ to 11.0 MeV: see (1984AJ01). For earlier measurements at other energies see (1966LA04). 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 $\text{D}_{3/2}$ or $\text{D}_{5/2}$ 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 $E_x \approx 19.7$ MeV. Broad structure in the differential cross section near 6 MeV, principally in the even Legendre coefficients, corresponds to an even parity state ${}^5\text{He}^*(20.0)$. Elastic scattering data is also utilized in the S -matrix studies of the ${}^5\text{He}(\frac{3}{2}^+)$ resonance at $E_x = 16.84$ MeV (1988BE1U, 1991BO23, 1993CS02). (See reaction 3.) See also the effective-range expansion and Coulomb renormalization for $d + t$ and related systems (1991KA31, 1996PO26). For earlier references see (1979AJ01, 1988AJ01). For d-t correlations see (1987PO03). See also “Complex reactions” in the General section of (1988AJ01) and (1981PL1A, 1983HAYX, 1986BO01). See also (1997BA72) in which properties of the $\frac{3}{2}^+$ levels of ${}^5\text{He}$ and ${}^5\text{Li}$ are discussed in terms of conventional R -matrix parameters.

$$5. {}^3\text{H}(t, n){}^5\text{He} \quad Q_m = 10.534$$

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 ${}^5\text{He}_{g.s.}$; (iii) sequential decay via a broad excited state of ${}^5\text{He}$. The width of ${}^5\text{He}_{g.s.}$ 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). See also ${}^6\text{He}$ and (1986BA73).

$$6. {}^3\text{H}(\alpha, d\alpha)n \quad Q_m = -6.257$$

A kinematically complete experiment at $E_\alpha = 67.2$ MeV has been reported by (2000GO35). They report observation of ${}^5\text{He}$ excited states at $E_x = 18.9, 19.9$ and 20.7 MeV with widths of $0.3, 0.25$ and 0.25 MeV, respectively.

$$7. {}^3\text{He}(t, p){}^5\text{He} \quad Q_m = 11.298$$

Some evidence is reported at $E_t = 22.25$ MeV 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). See also ${}^6\text{Li}$.

$$8. {}^4\text{He}(n, n){}^4\text{He} \quad E_b = -0.798$$

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

The total cross section has a peak of 7.6 b at $E_n = 1.15 \pm 0.05$ MeV, $E_{\text{cm}} = 0.92 \pm 0.04$ MeV, with a width of about 1.2 MeV: see (1979AJ01). A second resonance is observed at $E_n = 22.133 \pm 0.010$ MeV [$\sigma_{\text{peak}} = 0.9$ b] with a total width of 76 ± 12 keV and $\Gamma_n = 37 \pm 5$ keV (1983HA20). Attempts to detect additional resonances in the total cross section have been unsuccessful: see (1979AJ01). For curves and tables of neutron cross sections see (1988MCZT, 1990NAZH, 1990SH1C).

The $P_{3/2}$ phase shift shows strong resonance behavior near 1 MeV, while the $P_{1/2}$ phase 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 $E_{\text{res}} = 17.669$ MeV ± 10 keV, $\gamma_d^2 = 2.0$ MeV $\pm 25\%$, $\gamma_n^2 = 50$ keV $\pm 20\%$ (see Table 5.2 in (1979AJ01)). See also (1997BA72) in which properties of the $\frac{3}{2}^+$ levels of ${}^5\text{He}$ and ${}^5\text{Li}$ are discussed in terms of conventional R -matrix parameters.

An R -function analysis of the ${}^4\text{He} + n$ 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 ${}^4\text{He} + n$ data alone (rather than also including the ${}^4\text{He} + p$ data). At $a = 3.3$ fm the values obtained for the $P_{1/2}$ and $P_{3/2}$ resonances are, respectively, $E_{\text{cm}} = 1.97$ and 0.77 MeV, $\Gamma_{\text{cm}} = 5.22$ and 0.64 MeV: see (1984AJ01). Angular distributions of A_y have been studied by (1984KL05, 1984KR23, 1986KL04) for $E_n = 15$ to 50 MeV: see also for phase-shift analysis and comparison with ${}^4\text{He}(p, p)$.

The excitation energies and the spectroscopic factors for ${}^5\text{He}$ 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 $E_x \approx 7$ MeV in both ${}^5\text{He}$ and ${}^5\text{Li}$, 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 references cited in (1988AJ01). In more recent work S -matrix studies of the low energy $\frac{3}{2}^-$ and $\frac{1}{2}^-$ states are described in (1997CS01, 1998CS02). See also the calculations of (1999AO01, 1999FI10).

Nucleon- α potentials have been derived from phase shifts by (1991CO05) and constructed from experimental data by the Marchenko inversion method as discussed in (1993HO09). The scattering amplitude in the vicinity of the ${}^5\text{He}$ ($\frac{3}{2}^+$) resonance is expressed in terms of the scattering length and the d-t effective range by (1994MU07). A study of the two-pole structure of the $\frac{3}{2}^+$ resonance is discussed in (1993CS02). See also the discussion of Pauli blocking in this reaction (1990AM07) and an application of an algebraic cluster approach to n- α scattering (1989US02).

9. ${}^4\text{He}(p, \pi^+){}^5\text{He}$ $Q_m = -141.150$

As reported in (1988AJ01), differential cross sections were measured at $E_p = 201$ MeV (1985LE19) and at $E_p = 800$ MeV (1984HO01; also A_y). See also (1987SO1C) and (1985GE06).

More recently differential cross sections and analyzing powers were measured at incident proton energies between 240 and 507 MeV, spanning the region of the Δ_{1232} resonance (1994FU06).

These results were compared with the prediction of a microscopic (p, π^+) model and with a phenomenological model. See (1994FA10).

10. (a) ${}^4\text{He}(d, p){}^5\text{He}$ $Q_m = -3.022$
 (b) ${}^4\text{He}(d, pn){}^4\text{He}$ $Q_m = -2.2246$

A typical proton spectrum (reaction (a)) consists of a peak corresponding to the formation of the ground state of ${}^5\text{He}$, plus a continuum of protons ascribed to reaction (b). A study of the latter reaction shows evidence for sequential decay via ${}^5\text{He}^*(0, 16.7 \pm 0.1 [\Gamma = 80 \pm 30 \text{ keV}])$ and suggests some fine structure near $E_x = 19 \text{ MeV}$ [see also reactions 15 and 23]: see (1979AJ01). Differential cross sections and VAP have been measured for the ground state group at $E_d = 5.4, 6.0, \text{ and } 6.8 \text{ MeV}$ (1985LU08) and at 6 to 11 MeV (1985OS02). Measurements of differential cross sections, analyzing powers, and polarization transfer coefficients at $E_d = 56 \text{ MeV}$ were reported in (1990YOZZ). At $E_\alpha = 28.3 \text{ MeV}$ tensor polarization measurements involving the ground state transitions to ${}^5\text{He}$ (and ${}^5\text{Li}$) deviate from theoretical predictions which assume charge symmetry (1985WI15). See also ${}^6\text{Li}$ (1988PUZZ; $E_d = 2.1 \text{ GeV}$) and other references cited in (1988AJ01).

Cross sections and transverse tensor analyzing powers for reaction (b) at $E_d = 7 \text{ MeV}$ were measured with kinematic conditions chosen to correspond to singlet deuteron production (1988GA14).

Theoretical studies relevant to reaction (b) include: a study of effects of the proton Coulomb field on α, n resonance peaks (1988KA38); comparisons of measured cross sections and polarization observables at $E_d = 12, 17 \text{ MeV}$ with a three-body model (1988SU12); a study of the influence of three-particle Coulomb dynamics on the cross section (1991AS02); a study of the effects of the internal structure of the α particle on the reaction (1990KU27); and a multiconfiguration resonating group study of the six-nucleon system (1991FU01, 1995FU16).

11. ${}^4\text{He}({}^4\text{He}, {}^3\text{He}){}^5\text{He}$ $Q_m = -21.375$

Differential cross sections for this reaction to ${}^5\text{He}_{\text{g.s.}}$ were measured at $E({}^4\text{He}) = 118 \text{ MeV}$, and compared with DWBA predictions (1994WA06). Measurements of angular distributions at $E_\alpha = 158 \text{ and } 200 \text{ MeV}$ were reported by (1996ST25).

12. ${}^4\text{He}({}^7\text{Li}, {}^6\text{Li}){}^5\text{He}$ $Q_m = -8.048$

A study of this reaction and of the ${}^4\text{He}({}^7\text{Li}, {}^6\text{He}){}^5\text{Li}$ reaction at $E({}^7\text{Li}) = 50 \text{ MeV}$, and of the ${}^6\text{Li}({}^{12}\text{C}, {}^{13}\text{N}){}^5\text{He}$ and ${}^6\text{Li}({}^{13}\text{C}, {}^{14}\text{C}){}^5\text{Li}$ reactions at $E(\text{C}) = 90 \text{ MeV}$ was reported by (1988WO10). Properties of the two lowest states of ${}^5\text{He}$ and ${}^5\text{Li}$, from R -matrix parameters ($a = 5.5 \text{ fm}$) are displayed in Table 5.2 of (1988AJ01). As noted there, positive parity states are then predicted to

lie at $E_x \approx 5$ MeV ($\frac{1}{2}^+$) and 12 MeV ($\frac{3}{2}^+$, $\frac{5}{2}^+$) in ${}^5\text{He}$ - ${}^5\text{Li}$ (1988WO10). See also the analysis in (1988BA75).

- | | |
|---|----------------|
| 13. (a) ${}^6\text{Li}(\gamma, p){}^5\text{He}$ | $Q_m = -4.497$ |
| (b) ${}^6\text{Li}(e, ep){}^5\text{He}$ | $Q_m = -4.497$ |
| (c) ${}^6\text{Li}(\pi^+, \pi^+p){}^5\text{He}$ | $Q_m = -4.497$ |
| (d) ${}^6\text{Li}(\pi^-, \pi^-p){}^5\text{He}$ | $Q_m = -4.497$ |

At $E_\gamma = 60$ MeV, the proton spectrum shows two prominent peaks. In early work cited in (1979AJ01) these peaks are attributed to ${}^5\text{He}^*(0 + 4.0, 20 \pm 2)$: see (1979AJ01). The (γ, 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). A review of photodisintegration data for energies up to $E_\gamma = 50$ MeV was presented in (1990VA16). More recently, measurements were made at $E_\gamma = 60$ MeV (1994RY01), at $E_\gamma = 61, 77$ MeV (1994NI04), and at $E_\gamma = 59$ –75 MeV (1995DI01). In reaction (b) the missing energy spectrum shows strong peaks due to ${}^5\text{He}^*(0, 16.7)$ and possibly some strength in the region $E_x = 5$ –15 MeV (1986LAZH). See also ${}^6\text{Li}$, and see the recent triple cross section measurements of (1999HO02). Reviews of $(e, e'p)$ data are presented in (1990DE16, 1991VA05). See also (1989LA13, 1990DE06, 1990LA06). A microscopic cluster model used to interpret these experiments is discussed in (1990LO14). For reaction (c) at $E_{\pi^+} = 130$ and 150 MeV, ${}^5\text{He}^*(0, 16.7)$ are populated (1987HU02). Measurements at $E_{\pi^+} = 500$ MeV were made by (1998PA31) to search for Δ components. Reaction (d) was studied at GeV energies by (2000AB25) to deduce Fermi momentum distributions.

- | | |
|--|----------------|
| 14. ${}^6\text{Li}(n, d){}^5\text{He}$ | $Q_m = -2.272$ |
|--|----------------|

Angular distributions of d_0 have been studied at $E_n = 6.6$ to 56.3 MeV. At $E_n = 56.3$ MeV angular distributions have also been obtained to ${}^5\text{He}^*(16.7)$ and, possibly, to two higher states: see (1979AJ01, 1984AJ01). Measured cross sections and analysis for $E_n = 14.1$ MeV are presented in (1989SHZS). See also (1986BOZG). A Multiconfiguration Resonating-Group Method calculation applied to this reaction is discussed in (1995FU16).

- | | |
|---|----------------|
| 15. ${}^6\text{Li}(p, 2p){}^5\text{He}$ | $Q_m = -4.497$ |
|---|----------------|

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. Measurements were reported at $E_p = 47$ and 70 MeV (1983VD03), 70 MeV (1983GO06), 392 MeV (1996KAZZ, 1997HA15, 1998NO04), and 1 GeV (1985BE30,

1985DO16, 2000MI17). See also (1984AJ01). Experimental and theoretical studies for $E_p = 30$ – 150 MeV were reviewed in (1987VD1A). See also (1987VD01). The influence of noncoplanarity on information obtained from these reactions was studied by (1990GO34).

16. ${}^6\text{Li}(d, {}^3\text{He}){}^5\text{He}$ $Q_m = 0.997$

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

17. ${}^6\text{Li}(\alpha, \alpha p){}^5\text{He}$ $Q_m = -4.497$

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

18. ${}^6\text{Li}({}^6\text{Li}, {}^7\text{Be}){}^5\text{He}$ $Q_m = 1.109$

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

19. ${}^6\text{Li}({}^{12}\text{C}, {}^{13}\text{N}){}^5\text{He}$ $Q_m = -2.553$

See reaction 12 and (1988WO10).

20. ${}^7\text{Li}(\gamma, d){}^5\text{He}$ $Q_m = -9.522$

Cross sections and excitation functions were calculated by (1988DU04). Also see ${}^7\text{Li}$.

21. (a) ${}^7\text{Li}(\pi^+, 2p){}^5\text{He}$ $Q_m = 128.606$

(b) ${}^7\text{Li}(\pi^-, 2n){}^5\text{He}$ $Q_m = 127.041$

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

DWIA calculations of cross sections and analyzing powers for population of ${}^5\text{He}(\frac{3}{2}^-, \text{g.s.})$ are described in (1992KH04).

22. ${}^7\text{Li}(n, t){}^5\text{He}$ $Q_m = -3.265$

The angular distribution of t_0 has been measured at $E_n = 14.4$ MeV: see (1979AJ01) and ${}^8\text{Li}$ in (1988AJ01). See also (1986BOZG, 1989SHZS).

23. (a) ${}^7\text{Li}(p, {}^3\text{He}){}^5\text{He}$ $Q_m = -4.029$
 (b) ${}^7\text{Li}(p, \text{pd}){}^5\text{He}$ $Q_m = -9.522$

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 analog 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 ${}^4\text{D}_{3/2}$ or ${}^4\text{D}_{5/2}$ [compare ${}^3\text{H}(\text{d}, \text{d})$]. 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). Measurements of angular distributions at $E_p = 29.1$ – 44.6 MeV are reported in (1989BA88). In reaction (b) ${}^5\text{He}^*(0 + 4, 16.7, 25)$ appear to be involved at $E_p = 670$ MeV (1981ER10) while at 200 MeV some structure at $E_x \approx 20$ MeV is reported in addition to the ground state (1986WA11).

24. (a) ${}^7\text{Li}(\text{d}, \alpha){}^5\text{He}$ $Q_m = 14.325$
 (b) ${}^7\text{Li}(\text{d}, \text{n}){}^4\text{He}{}^4\text{He}$ $Q_m = 15.1223$

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. Measurements of the α -particle energy spectra at $E_d = 13.6$ MeV were reported in (1993PAZP). An analysis of cross section data measured at $E_d = 0$ – 12 MeV is reported in (1997HAZX). Astrophysical S factors were measured at $E_{\text{cm}} = 57$ – 141 keV by (1997YA08). Measurements of the reaction rate at low energies for ${}^7\text{Li}$ implanted in Pd foil were reported by (2000BAZO). Reaction (b) proceeds mainly via excited states of ${}^8\text{Be}$ and ${}^5\text{He}_{\text{g.s.}}$ and possibly as well ${}^5\text{He}^*(4.)$: see (1979AJ01). Measurements at $E_d = 4.35$ MeV have been reported by (2000MIZU). See also (1987WA21) and ${}^8\text{Be}$ in (1988AJ01).

Measurements of $\sigma(\theta)$ at $E_d = 6.8$ MeV were reported in (1989AR04). Parameters of the resonance for the ${}^5\text{He}$ state at $E_x = 16.76$ MeV were extracted. Analysis (1991AR10, 1993FA12) of coincidence measurements at $E_d = 1.4, 2.1$ and 2.5 MeV gave $E_x = 4.1 \pm 0.2$ MeV, $\Gamma = 2.9 \pm 0.4$ MeV for the ${}^5\text{He}$ $p_{1/2}$ first excited state.

25. (a) ${}^7\text{Li}({}^3\text{He}, p\alpha){}^5\text{He}$ $Q_m = 8.831$
 (b) ${}^7\text{Li}({}^3\text{He}, {}^3\text{He}d){}^5\text{He}$ $Q_m = -9.522$

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 ${}^5\text{He}$, in addition to ${}^5\text{He}^*(0, 16.7, 20.0)$, including a state at 35.7 ± 0.4 MeV with a width of ≈ 2 MeV (1985FR01).

26. ${}^8\text{Li}(p, \alpha){}^5\text{He}$ $Q_m = 14.516$

Differential cross sections were measured at $E_{\text{cm}} = 1.5$ MeV with a ${}^8\text{Li}$ beam, and the data were used to calculate thermonuclear reaction rates for ${}^8\text{Li}$ destruction (1992BEZZ, 1992BE46).

27. (a) ${}^9\text{Be}(p, p\alpha){}^5\text{He}$ $Q_m = -2.371$
 (b) ${}^9\text{Be}(p, d{}^3\text{He}){}^5\text{He}$ $Q_m = -20.724$

Both reactions have been studied at $E_p = 26.0$ to 101.5 MeV [see (1984AJ01)]. Reaction (a) was studied at $E_p = 150.5$ MeV (1985WA13) and at $E_p = 200$ MeV (1989NA10), who analyzed the data in terms of DWIA. Absolute spectroscopic factors were derived. See also (1985VD03). More recently, cross sections and polarization observables were measured at $E_p = 296$ MeV by (1996YOZZ, 1997YOZQ, 1998YO09). Alpha spectroscopic factors were deduced.

28. ${}^9\text{Be}(d, {}^6\text{Li}){}^5\text{He}$ $Q_m = -0.897$

The angular distribution to ${}^5\text{He}_{\text{g.s.}}$ has been measured at $E_d = 13.6$ MeV (1984SH1F). See also (1989VAZJ).

29. (a) ${}^9\text{Be}({}^3\text{He}, {}^7\text{Be}){}^5\text{He}$ $Q_m = -0.785$
 (b) ${}^9\text{Be}({}^3\text{He}, \alpha){}^4\text{He}{}^4\text{He}$ $Q_m = 19.0041$

See (1984AJ01) and (1990MAYW). A coupled-channel model analysis of data at $E_{{}^3\text{He}} = 60$ MeV is described in (1996RU13). For reaction (b) see ${}^8\text{Be}$ in (1988AJ01) and (1987WA25).

30. ${}^9\text{Be}(\alpha, 2\alpha){}^5\text{He}$ $Q_m = -2.371$

Measurements at $E_\alpha = 197$ MeV of energy-sharing distributions were reported by (1994CO16). Spectroscopic factors were extracted. See (1984AJ01) for earlier work. Cross section measurements at $E_\alpha = 580$ MeV with DWIA calculations are described in (1999NA05).

$$31. \ ^9\text{Be}(^7\text{Li}, ^7\text{Li}\alpha)^5\text{He} \quad Q_m = -2.371$$

This reaction was studied at $E_{^7\text{Li}} = 52$ MeV (1998SO05, 1998SO26), and decay from ^9Be excited state into the $\alpha + ^5\text{He}$ channel was observed.

$$32. \ ^9\text{Be}(^{18}\text{O}, ^{22}\text{Ne})^5\text{He} \quad Q_m = 7.296$$

Cross sections were measured and the mass excess was extracted by (1990BEYY).

$$33. \ ^{10}\text{B}(n, ^5\text{He})^6\text{Li} \quad Q_m = -5.258$$

See ^6Li .

$$34. \ ^{10}\text{B}(d, ^7\text{Be})^5\text{He} \quad Q_m = -1.877$$

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

$$35. \text{ (a) } ^{11}\text{B}(^7\text{Li}, ^{13}\text{C})^5\text{He} \quad Q_m = 9.157$$

$$\text{ (b) } ^{11}\text{B}(^9\text{Be}, ^{15}\text{N})^5\text{He} \quad Q_m = 8.620$$

At $E(^{11}\text{B}) = 88$ MeV a broad structure is observed at $E_x = 5.2 \pm 0.3$ MeV, $\Gamma = 2.0 \pm 0.5$ MeV (1988BE34). For reaction (b) see (1990BEYX).

$$36. \ ^{12}\text{C}(^6\text{He}, ^5\text{He} n)^{12}\text{C} \quad Q_m = -1.771$$

Peripheral fragmentation of 240 MeV/A ^6He was studied by (1997CH24, 1997CH1P). It was found that one-neutron stripping to ^5He is the dominant mechanism.

⁵Li
(Figs. 2 and 3)

GENERAL: References to articles on general properties of ⁵Li published since the previous review (1988AJ01) are grouped into categories and listed, along with brief descriptions of each item, in the General Tables for ⁵Li located on our website at (www.tunl.duke.edu/nuclldata/General_Tables/5li.shtml).



Gamma rays were measured over a large dynamic range for $E_\alpha = 200$ MeV (2000HO18). Both inclusive and exclusive (coincidence with either α particle, proton or both) measurements were performed. A pronounced contribution from capture into the unbound ground and first excited states of ⁵Li was observed. For the measured parameters of the ⁵Li resonances, see Table 5.5.



Angular distributions and analyzing powers for polarized ³He on ²H at $E_{^3\text{He}} = 22.5, 24, 27, 30, 33$ MeV were measured and analyzed by (2000OK01). Based on the phase shifts, they report the following resonances identified with ⁵Li with excitation energies between 15 and 30 MeV: “(i) the well-established (1988AJ01) ⁴S_{3/2} state at 16.7 MeV; (ii) a broad ²S_{1/2} state around 19 MeV; (iii) quartet D states around 20 MeV, [$\frac{5}{2}^+$ and $\frac{3}{2}^+$ assigned before (1988AJ01)]; (iv) two doublet P states ($\frac{3}{2}^-$, $\frac{1}{2}^-$) around 25 MeV; and (v) at least one negative parity state around 29 MeV.”

The results are compared with shell model calculations. See also reaction 5 below.



The previous review (1988AJ01) describes the earlier work as follows: “The ratio $\Gamma_\gamma/\Gamma_{p\alpha}$ has been determined for $E(^3\text{He}) = 63$ to 150 keV [$E_{\text{cm}} = 25$ 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 $E_x = 3.0 \pm 1.0$ MeV for the excited state. $\Gamma_{\gamma_0}/\Gamma_{p\alpha}$ is roughly constant for $E_{\text{cm}} = 25$ to 60 keV at $(4.5 \pm 1.2) \times 10^{-5}$ and $\Gamma_{\gamma_1}/\Gamma_{p\alpha} = (8 \pm 3) \times 10^{-5}$ at $E(^3\text{He}) = 150$ keV (1985CE13)”. For applications see (1985CE13, 1985CE16, 1988CE04, 1992LI32).

“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 $E_d = 0.45 \pm 0.04$

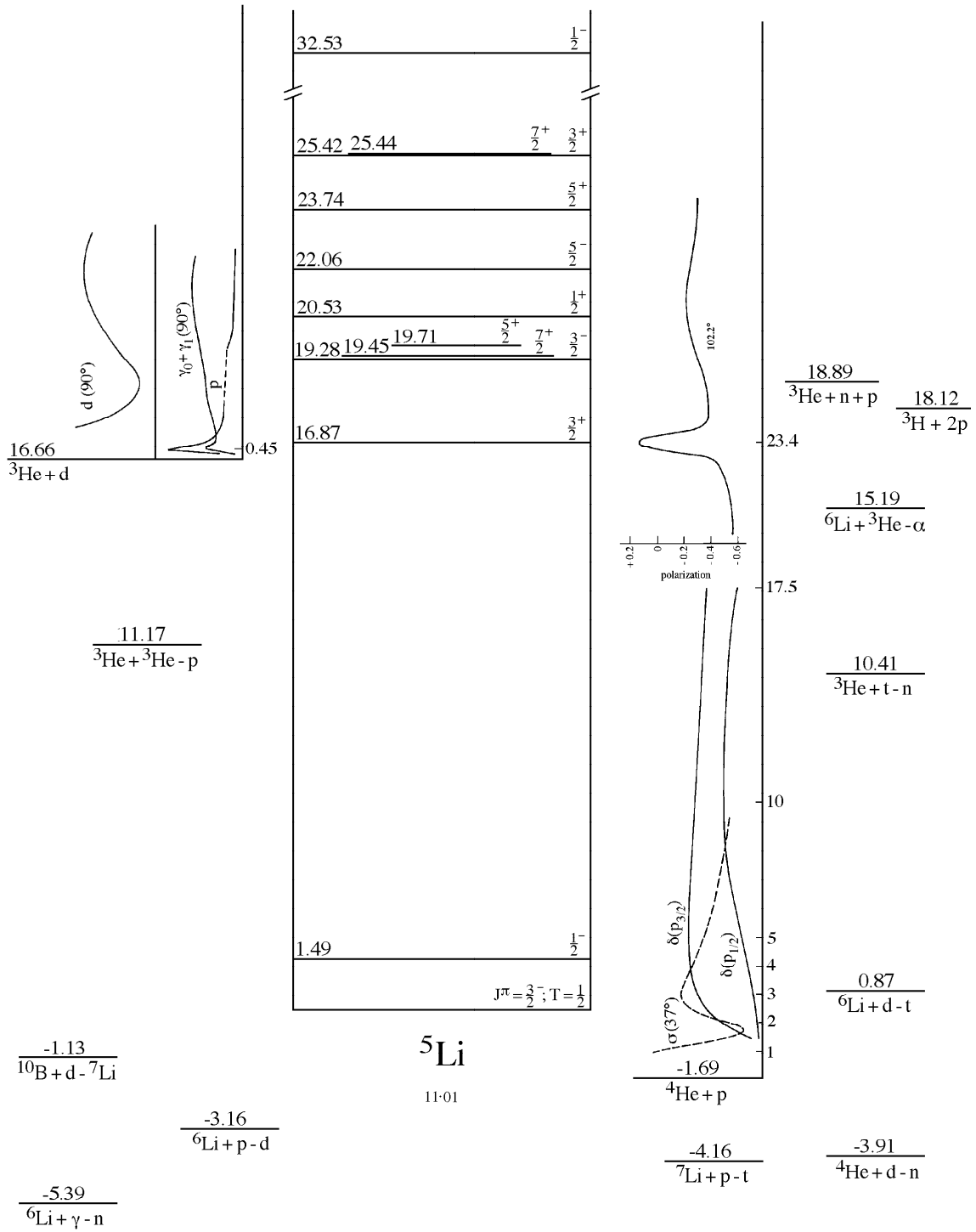


Figure 2: Energy levels of ${}^5\text{Li}$, extended R -matrix prescription (see Table 5.3). For notation see Fig. 1.

Table 5.3: Energy levels of ${}^5\text{Li}$, extended R -matrix prescription ^a

E_x (MeV)	$J^\pi; T$	Γ_{cm}^b (MeV)	Γ_p (MeV)	Γ_d (MeV)	$\Gamma_{p^*}^c$ (MeV)	Decay	Reactions (used in analysis)
g.s. ^d	$\frac{3}{2}^-; \frac{1}{2}$	1.23	1.06	43.1 ^e	0.009 ^e	p, α	3, 6, 9, 13, 18, 20, 23
1.49	$\frac{1}{2}^-; \frac{1}{2}$	6.60	3.78	16.4 ^e		p, α	3, 9, 13, 18, 20
16.87	$\frac{3}{2}^+; \frac{1}{2}$	0.267	0.055	0.134 ^f		γ , p, d, ${}^3\text{He}$, α	3, 4, 5, 18, 20
19.28	$\frac{3}{2}^-; \frac{1}{2}$	0.959	0.001	0.040 ^g	0.741	n, p, d, ${}^3\text{He}$, α	4, 5, 9
19.45	$\frac{7}{2}^+; \frac{1}{2}$	3.28	0.040	1.82 ^h		p, d, ${}^3\text{He}$, α	5
19.71	$\frac{5}{2}^+; \frac{1}{2}$	4.31	0.011	2.03 ^h		p, d, ${}^3\text{He}$, α	3, 5
20.53	$\frac{1}{2}^+; \frac{1}{2}$	5.00	0.026	1.53 ⁱ	0.196	n, p, d, ${}^3\text{He}$, α	6
22.06	$\frac{5}{2}^-; \frac{1}{2}$	15.5	0.928	2.33 ^j		p, d, ${}^3\text{He}$, α	23, 24
23.74	$\frac{5}{2}^+; \frac{1}{2}$	5.43	0.234	2.49 ^k		p, d, ${}^3\text{He}$, α	
25.42	$\frac{3}{2}^+; \frac{1}{2}$	0.534	0.023	0.467 ^l		p, d, ${}^3\text{He}$, α	
25.44	$\frac{7}{2}^+; \frac{1}{2}$	2.63	0.043	1.94 ^h		p, d, ${}^3\text{He}$, α	23
32.53	$\frac{1}{2}^-; \frac{1}{2}$	35.7	8.75	0.013 ^m		p, d, ${}^3\text{He}$, α	23, 24

^a This prescription, based on the complex poles and residues of the S -matrix, is the recommended one (see Introduction). The channel radii are $a_p = 2.9$ fm, $a_d = 4.8$ fm. The uncertainties in the widths and positions of the first three levels are less than 1%. Above 19 MeV excitation energy, they increase rapidly, varying from about 5% up to as much as 50% for the broader levels. All parameters in this table are newly adopted in this evaluation.

^b The fact that the sum of the partial widths is unequal to the total width in the extended R -matrix prescription is characteristic of non-Breit-Wigner resonances as was discussed in the appendix of (1992TI02).

^c The p^* designation indicates $p + \alpha^*$ where the first excited state of the α particle was included as a way to approximate the effects of three-body breakup on the two-body channels.

^d Situated 1.69 MeV above the $p + \alpha$ threshold.

^e These partial widths in closed channels have no meaning as decay widths, but rather as asymptotic normalization constants.

^f Primarily ${}^4S(d)$.

^g Primarily ${}^2P(d)$.

^h Primarily ${}^4D(d)$.

ⁱ Primarily ${}^2S(d)$.

^j Primarily ${}^2F(d)$.

^k Primarily ${}^2D(d)$.

^l Mixture of ${}^4S(d)$ and ${}^4D(d)$.

^m Mixture of ${}^4P(d)$ and ${}^2P(d)$.

MeV [${}^5\text{Li}^*(16.7)$]. $\sigma_{\gamma_0} = 21 \pm 4 \mu\text{b}$, $\Gamma_{\gamma_0} = 5 \pm 1 \text{ eV}$. The radiation at resonance is isotropic, consistent with s-wave capture. Study of γ_0 and γ_1 yields $\Gamma = 2.6 \pm 0.4 \text{ MeV}$ for the ground-state width (but see below), and $E_x = 7.5 \pm 1.0 \text{ MeV}$, $\Gamma = 6.6 \pm 1.2 \text{ MeV}$ for the $\frac{1}{2}^-$ state: see (1979AJ01, 1988AJ01). An excess in the cross section at higher bombarding energies is interpreted as being due to a state at $E_x \approx 18 \text{ MeV}$: even parity is deduced from the relative intensity of γ_0 and γ_1 . A broad peak is also observed at $E_x \approx 20.7 \text{ MeV}$ 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 (1979AJ01)”. In more recent measurements at $E_d = 8.6 \text{ MeV}$ a ground state width $\Gamma_p = 2.44 \pm 0.21 \text{ MeV}$ was extracted from the γ_0 spectrum (1991BA02). An analysis of these data with single level R -matrix fits (1996EF03) gave values for the energies and widths of the ground states of ${}^5\text{Li}$ and ${}^5\text{He}$. Cross section and analyzing power measurements in the $\frac{3}{2}^+$ fusion resonance region ($E_d = 0.45 \text{ MeV}$) and $E_d = 8.6 \text{ MeV}$ were reported by (1991WEZZ, 1992BA04, 1994BA02, 1998WE07), and comparisons with the results of coupled-channels resonating group model calculations were discussed. See also the shell model description of the $\frac{3}{2}^+$ resonance discussed in (1993KU02). Potential model descriptions of this reaction are discussed in (1990NE14, 1992LI32, 1992NE03, 1995DU13). Analyzing power formulae derived in a model-independent way are presented in (1996TA09).

Measurements of high-energy ($> 20 \text{ MeV}$) gamma ray production in the reaction are described in (1992PI04).

4. (a) ${}^3\text{He}(d, p){}^4\text{He}$	$Q_m = 18.35304$	$E_b = 16.66292$
(b) ${}^3\text{He}(d, np){}^3\text{He}$	$Q_m = -2.22457$	
(c) ${}^3\text{He}(d, 2p){}^3\text{H}$	$Q_m = -1.46081$	
(d) ${}^3\text{He}(d, 2d){}^1\text{H}$	$Q_m = -5.49349$	
(e) ${}^3\text{He}(d, tp){}^1\text{H}$	$Q_m = -1.46081$	

Excitation functions and angular distributions have been measured for $E_{\text{cm}} = 6.95$ to 171.3 keV , and values of $S(E)$ have been deduced: $S(0) = 6.3 \pm 0.6 \text{ MeV} \cdot \text{b}$ (1987KR18). See also (1984AJ01, 1988AJ01). S -factors have been obtained down to $E_{\text{cm}} = 5.88 \text{ keV}$. The effect on S of electron screening at low energies has been studied by (1988EN03, 1988SCZG, 1988SC1F). See also the calculations of (1989BE08, 1990BR12).

A pronounced resonance occurs at $E_d = 430 \text{ keV}$, $\Gamma \approx 450 \text{ keV}$. The peak cross section is $695 \pm 14 \text{ mb}$: see Table 5.2 in (1979AJ01). The recent work of (1997BA72) discusses a description of the $\frac{3}{2}^+$ levels of ${}^5\text{Li}$ and ${}^5\text{He}$ in terms of conventional R -matrix parameters. 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 (1979AJ01)]. 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 has been suggested at $E_x = 16.6, 17.5, 20.0, 20.9$ and 22.4 MeV : see (1979AJ01).

Table 5.4: Energy levels of ${}^5\text{Li}$, conventional R -matrix prescription ^a

E_x (MeV)	$J^\pi; T$	Γ_{cm} (MeV)	Γ_p (MeV)	Γ_d (MeV)	Γ_{p^*} (MeV)
g.s. ^b	$\frac{3}{2}^-; \frac{1}{2}$	2.11	2.11	0	0
6.18	$\frac{1}{2}^-; \frac{1}{2}$	19.8	19.8	0	0
16.63	$\frac{3}{2}^+; \frac{1}{2}$	2.09	0.570	1.52 ^c	
19.17	$\frac{3}{2}^-; \frac{1}{2}$	1.50	0.0006	0.136 ^d	1.36
20.30	$\frac{1}{2}^+; \frac{1}{2}$	4.64	0.208	3.72 ^e	0.709
21.09	$\frac{7}{2}^+; \frac{1}{2}$	7.47	0.115	7.36 ^f	
22.60	$\frac{5}{2}^+; \frac{1}{2}$	12.5	0.010	12.5 ^f	
24.27	$\frac{5}{2}^+; \frac{1}{2}$	8.15	1.11	7.04 ^g	
26.86	$\frac{3}{2}^+; \frac{1}{2}$	24.2	0.009	24.2 ^f	

^a See the Introduction for a discussion of the two prescriptions. The channel radii are $a_p = 2.9$ fm, $a_d = 4.8$ fm.

^b Situated 2.08 MeV above the $p + \alpha$ threshold.

^c Entirely ${}^4S(d)$.

^d Primarily ${}^2P(d)$.

^e Primarily ${}^2S(d)$.

^f Primarily ${}^4D(d)$.

^g Primarily ${}^2D(d)$.

In early work, tensor analyzing power measurements were 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.] Measurements of angular distributions and analyzing powers at $E({}^3\text{He}) = 27$ 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 $E_d = 1.0$ to 13.0 MeV (1986BI1C, 1986BIZP) and 18, 20 and 22 MeV (1986SA1L). See also (1986RO1J) and Tables 5.6 in (1979AJ01) and 5.4 in (1979AJ01). In recent work of (1999GE19), angular distributions and complete sets of analyzing powers were measured at five energies between $E_d = 60$ and 641 keV. The data were included in an R -matrix analysis of the ${}^5\text{Li}$ system (see Table 5.6). Multichannel resonating group model calculations for this reaction are presented in (1988GU07, 1990BL02, 1990BL08). A model-independent description of the $d + {}^3\text{He}$ system near the low energy $\frac{3}{2}^+$ resonance using the effective range expansion is described in (1996PO26).

Differential cross sections for reaction (b) were measured at $E_d = 23.08$ MeV (1988BR27, 1990BR14). Triple differential cross sections and vector analyzing powers were measured at $E_d = 17$ MeV (1989AYZZ, 1990AYZW) and at $E({}^3\text{He}) = 32.25$ MeV (1988DA18, 1991DA06).

The $d + {}^3\text{He}$ fusion process in reactors is discussed in (1988DA26, 1988MI29, 1988MO36). Applications of the reaction in studying deuterium diffusion behavior in materials is discussed in

Table 5.5: Parameters of ${}^5\text{Li}$ resonances deduced from $\alpha + \text{p}$ gamma spectra

J^π	Quantity	Experimental	Conventional ^b	Extended ^b
		result ^a	R -matrix	R -matrix
$\frac{3}{2}^-$	σ (μb)	8.0 ± 0.7	–	–
	E_x (MeV) ^c	2.9 ± 0.2	2.08	1.69
	Γ (MeV)	1 ± 0.2	2.11	1.23
$\frac{1}{2}^-$	σ (μb)	4.5 ± 0.4	–	–
	E_x (MeV) ^c	9.3 ± 0.4	8.26	3.18
	Γ (MeV)	10 ± 1	19.8	6.60

^a From Table I of (2000HO18). These results were obtained by fitting the photon spectrum to a background plus two Gaussian peaks representing the two resonances.

^b See Tables 5.3 and 5.4.

^c These energies are relative to the $\alpha + \text{p}$ threshold.

Table 5.6: A scheme of ${}^5\text{Li}$ levels below $E_x = 17$ MeV obtained from an R -matrix analysis ^a of ${}^3\text{He}(\text{d}, \text{d}){}^3\text{He}$, ${}^3\text{He}(\text{d}, \text{p}){}^4\text{He}$, and ${}^4\text{He}(\text{p}, \text{p}){}^4\text{He}$ data and comparison with the present evaluation ^b

(1999GE19) scheme ^a			Present evaluation ^b		
E_x (MeV)	J^π	Γ_{cm} (MeV)	E_x (MeV)	J^π	Γ_{cm} (MeV)
g.s.	$\frac{3}{2}^-$	1.25	g.s.	$\frac{3}{2}^-$	1.23
1.28	$\frac{1}{2}^-$	6.29	1.49	$\frac{1}{2}^-$	6.60
16.86	$\frac{3}{2}^+$	0.25	16.87	$\frac{3}{2}^+$	0.27
16.88 ^c	$\frac{1}{2}^+$	2.26	20.53	$\frac{1}{2}^+$	5.00
17.65 ^{c, d}	$\frac{3}{2}^-$	2.57	19.28	$\frac{3}{2}^-$	0.96
			19.45	$\frac{7}{2}^+$	3.28

^a See Tables II and III of (1999GE19).

^b See Table 5.3.

^c Weak resonance.

^d Above the range of the analysis.

(1989PA26, 1990QIZZ). See also (1990LE30, 1990WI1L).

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 ${}^5\text{Li}$ located 0.8 ± 0.2 MeV above threshold [i.e., $E_x = 18.9 \pm 0.2$ MeV]: see (1979AJ01). Other 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 other references cited in (1988AJ01). For a descriptive list of theoretical work on this reaction see the General Table for ${}^5\text{Li}$ located on our website at (www.tunl.duke.edu/nucldata/General_Tables/5li.shtml).

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

$$E_b = 16.66292$$

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 ${}^2\text{D}_{3/2}$ or (${}^2\text{D}$, ${}^4\text{D}_{5/2}$ 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 [${}^2\text{P}_{3/2}$, ${}^4\text{D}_{7/2}$, ${}^4\text{D}_{5/2}$, ${}^4\text{D}_{3/2}$ and, possibly, ${}^4\text{D}_{1/2}$]: 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; $E_d = 10$ MeV) and (1987YAZJ; $E_d = 29.5$ MeV on polarized ${}^3\text{He}$). For d- ${}^3\text{He}$ correlations see (1987PO03). See also “Complex reactions” in the ${}^5\text{Li}$ General section of (1988AJ01). The R -matrix formalism was used by (1990TR08) to calculate the $S(\frac{1}{2}^+)$ -wave cross section for $d + {}^3\text{He}$, using $p + {}^4\text{He}$ cross section data and $d + {}^3\text{He}$ analyzing power data from the ${}^5\text{Li}(\frac{3}{2}^+)$ region. See also the work of (1997BA72). A generalized potential model description of ${}^3\text{He} + d$ scattering is discussed in (1991NE01). For earlier theoretical work see references cited in (1988AJ01).

6. ${}^3\text{He}(t, n){}^5\text{Li}$

$$Q_m = 10.41$$

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

7. ${}^3\text{He}({}^3\text{He}, p){}^5\text{Li}$

$$Q_m = 11.17$$

The spectrum of protons at $E({}^3\text{He}) = 3$ to 18 MeV shows a pronounced peak corresponding to ${}^5\text{Li}_{\text{g.s.}}$ superposed on a continuum: see (1979AJ01). The angular distribution of p_0 has been measured at $E({}^3\text{He}) = 26$ MeV (1983KI10; polarized target). See also ${}^6\text{Be}$ and (1986OS1D).

8. ${}^3\text{He}(\alpha, d){}^5\text{Li}$

$$Q_m = -7.18$$

The contribution of unbound ${}^6\text{Li}$ nuclear states to deuteron spectra from this reaction was calculated by (1993GO16).

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

$$E_b = -1.69012$$

Differential cross sections and polarization measurements have been carried out at many energies: see (1966LA04, 1974AJ01, 1979AJ01, 1984AJ01) for the earlier work. More recent measurements were reported (1988AJ01) at $E_p = 65$ MeV (1986FU05; A_y), 100 MeV (1983NAZV, 1985GUZX; $\sigma(\theta)$, A_y) and 495 MeV (1988STZZ) and at $E_p = 695, 793, 890, 991$ MeV (1985VE13; $\sigma(\theta)$) and 1 GeV (1985AL09; $\sigma(\theta)$). Cross sections and A_y at $E_p = 98.7$ and 149.3 MeV for the continuum were reported by (1985WE06). In experimental work reported since the previous review (1988AJ01), differential cross sections were measured for $E_p = 695, 793, 890, 991$ MeV by (1989GR20) with phase shift analysis and at 607 MeV/c by (1991BA1V). Differential cross sections and analyzing powers at 71.9 MeV were measured (1989BU01) and combined with existing data for $E_p = 30$ –65 MeV for a phase shift analysis. Measurements of analyzing power at $E_p = 180$ MeV were reported by (1990WEZY). Cross sections for the $p + {}^4\text{He}$ interaction at GeV energies have been measured at 2.7 GeV/c (1993AB07), at 8.6 and 13.6 GeV/c (1989BR30, 1993GL09), and at $\sqrt{s} = 31.5$ GeV (1989AK05). For earlier work at very high energies, see references cited in (1988AJ01). The previous review (1988AJ01) summarizes the analyses reported prior to 1988 as follows:

“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 the $P_{1/2}$ 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). (1986TH1C; prelim.) have measured A_y for $1.1 \leq E_p \leq 2.15$ MeV: $A_y = 1$ for $E_p = 1.89$ MeV, $\theta_{cm} = 87.0^\circ$.”

“A phase-shift analysis for $E_p = 21.8$ to 55 MeV is presented by (1978HO17) [see also 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 a measurement of the spin rotation parameter, R , at $E_p = 500$ MeV see (1983MO01). See also (1986SA1J; prelim.; $E_p = 65$ MeV).”

Theory and analyses reported since the previous review (1988AJ01) include: the S -matrix studies of resonances in the $A = 5$ system of (1998CS02); the S -matrix and R -matrix determination of the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states of ${}^5\text{Li}$ of (1997CS01); and the study of the $\frac{3}{2}^+$ levels of ${}^5\text{Li}$ on ${}^5\text{He}$ based on conventional R -matrix parameters (1997BA72). See also the study of the cluster potential model (1997DU15), and the calculation of interaction potentials by inversion of scattering phase shifts (1996AL01). See also (1996CO20).

Other theoretical work reported since the previous review (1988AJ01) includes calculations for p - α potentials derived from phase shifts for $E_p \leq 23$ MeV (1991CO05) and at $E_p = 64.9$ MeV (1989CO11). Multichannel resonating group calculations are presented in (1989KA39, 1990BL02). The resonating group method was applied in the region $E_p = 50$ – 120 MeV by (1993KA47). See also the dynamic microscopic model calculation reported by (1993CS02). Glauber theory calculations of cross sections at intermediate energies were reported by (1993MA47). Other theoretical work related to ${}^4\text{He} + p$ scattering is included in the descriptive list in the General Table for ${}^5\text{Li}$ located on our website at (www.tunl.duke.edu/nuclldata/General_Tables/5li.shtml).

In earlier work PNC effects were studied via the elastic scattering of 46 MeV longitudinally polarized protons on ${}^4\text{He}$: 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) and (1986ADZT, 1986HA1Q, 1988NA18). For $\alpha + p$ correlations see (1987PO03).

In application-related work, a method for precise absolute calibration of polarization effects is applied to p - α scattering at $E_p = 25.68$ MeV by (1989CL04). Measurements of recoil cross sections for α particles on protons in connection with depth profiling were reported at $E({}^3\text{He}) = 0.9$ – 3.4 MeV (1989SZ04) and at $E({}^3\text{He}) = 1.3$ – 2.1 MeV (1988WA22).

10. (a) ${}^4\text{He}(p, d){}^3\text{He}$	$Q_m = -18.35304$	$E_b = -1.69012$
(b) ${}^4\text{He}(p, pn){}^3\text{He}$	$Q_m = -20.57762$	
(c) ${}^4\text{He}(p, 2p){}^3\text{H}$	$Q_m = -19.81385$	
(d) ${}^4\text{He}(p, pd){}^2\text{H}$	$Q_m = -23.84653$	

As reported in (1988AJ01) angular distributions of deuterons and 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, 1984AJ01)]. Angular distributions and analyzing powers were measured at $E_p = 100$ MeV (1983NAZV), 200 and 400 MeV (1986AL01). Excitation functions are reported at several energies in the range $E_p = 38.5$ to 44.6 MeV and 200 to 500 MeV. Continuum yields and analyzing powers

have been studied at $E_p = 98.7$ and 149.3 MeV by (1985WE06). For polarization measurements to 500 MeV see above and (1979AJ01, 1984AJ01, 1988BAZH). More recently, analyzing powers and differential cross sections were measured at $E_p = 32, 40, 50$ and 52.5 MeV by (1991SA17).

For reactions (b), (c) and (d) see (1974AJ01, 1979AJ01, 1984AJ01). The breakup of ${}^4\text{He}$ via reaction (c) has been studied by (1986FU05): large values of A_y in the FSI region were reported. In more recent work on reactions (b), (c) and (d), quasi-free knockout of charged particles for ${}^4\text{He}$ was studied at $E_p = 100$ MeV by (1990WH01). For astrophysics-related theoretical work see (1989GU28, 1990BI06). For breakup processes at high energies, including pion production, see (1988AJ01).

11. ${}^4\text{He}(\bar{p}, \bar{p}){}^4\text{He}$

In early work, antiproton interactions with ${}^4\text{He}$ were studied by (1984BA60, 1985BA76, 1987BA12, 1987BA47, 1987BA69). See also (1983FA16, 1984BA74, 1984FA14, 1986DO20, 1987NA23). More recently, the production rate of ${}^1\text{H}$, ${}^2\text{H}$, ${}^3\text{H}$ in \bar{p} - ${}^4\text{He}$ annihilation was studied between 0–600 MeV/ c by (1988BA62), the annihilation cross section near 45 MeV/ c was measured (1989BA59), and the cross section for production of Λ hyperons and K_s^0 mesons at 600 MeV/ c was measured by (1989BA94).

Calculations for the knockout and annihilation reactions were presented by (1989NA16), and a study of the change of the branching ratio of channels for \bar{p} - ${}^4\text{He}$ annihilation in the nuclear medium is discussed in (1989NA16).

$$\begin{array}{ll} 12. (a) {}^4\text{He}(d, n){}^5\text{Li} & Q_m = -3.91 \\ (b) {}^4\text{He}(d, np){}^4\text{He} & Q_m = -2.22457 \end{array}$$

For reaction (a) see reaction 10 in ${}^5\text{He}$, (1985WI15) and (1987KAZL; $E_d = 15$ MeV; n_0). Early work on reaction (b) reported in (1988AJ01) includes measurements at $E_d = 12$ to 17 MeV and at $E_\alpha = 18.0$ to 140 MeV: see (1979AJ01, 1984AJ01), ${}^6\text{Li}$ and (1985DO03, 1987KUZI).

More recently, measurements of cross sections and analyzing powers at $E_d = 7$ MeV were reported by (1988GA14). Comparison of data at $E_d = 12$ and 17 MeV with predictions of the three-body model are made by (1988SU12). The effects of the internal structure of the α particle in a three-body description of the $d + \alpha$ reaction are explored by (1990KU27). Multi-configuration resonating group calculations are discussed in (1991FU01, 1992FU10).

$$\begin{array}{ll} 13. (a) {}^4\text{He}({}^3\text{He}, d){}^5\text{Li} & Q_m = -7.18 \\ (b) {}^4\text{He}({}^3\text{He}, pd){}^4\text{He} & Q_m = -5.49349 \end{array}$$

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 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).

$$14. {}^4\text{He}(\alpha, t){}^5\text{Li} \quad Q_{\text{m}} = -21.50$$

Measurements were made at $E_\alpha = 120, 160$ and 200 MeV (1998ST07). Differential cross sections were extracted from measured triton energy spectra. Line shapes of the ${}^5\text{Li}$ ground state resonance was well reproduced by DWBA calculations.

$$15. {}^4\text{He}({}^7\text{Li}, {}^6\text{He}){}^5\text{Li} \quad Q_{\text{m}} = -11.67$$

See reaction 12 in ${}^5\text{He}$ and (1988WO10).

$$16. {}^6\text{Li}(\gamma, n){}^5\text{Li} \quad Q_{\text{m}} = -5.39$$

Available experimental data at energies up to $E_\gamma = 50$ MeV are reviewed and analyzed (1990VA16) to explore cluster effects and final-state interactions.

$$17. {}^6\text{Li}(\pi^+, p){}^5\text{Li} \quad Q_{\text{m}} = 134.96$$

In early work, differential cross sections have been measured at $T_\pi = 75$ and 150 MeV for p_0 : see (1984AJ01). More recently cross section measurements at $E_\pi = 50, 100, 150$ and 200 MeV were reported by (1992RA01). DWIA calculations presented in (1992KH04) provide predictions of cross sections at $T_\pi = 115, 165$ and 255 MeV.

$$\begin{aligned} 18. (a) {}^6\text{Li}(p, d){}^5\text{Li} & \quad Q_{\text{m}} = -3.16 \\ (b) {}^6\text{Li}(p, pd){}^4\text{He} & \quad Q_{\text{m}} = -1.4743 \\ (c) {}^6\text{Li}(p, pn){}^5\text{Li} & \quad Q_{\text{m}} = -5.39 \end{aligned}$$

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 ${}^5\text{Li}_{\text{g.s.}}$, a narrow peak [${}^5\text{Li}^*(16.7)$] and a broad peak at $E_x \approx 20$ MeV. DWBA analysis leads to $C^2S = 0.64$ and 0.57 for ${}^5\text{Li}^*(0, 16.7)$. The first excited state of ${}^5\text{Li}$ is also reported to be populated: see (1984AJ01).

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

19. (a) ${}^6\text{Li}(d, t){}^5\text{Li}$ $Q_m = 0.87$
 (b) ${}^6\text{Li}(d, pt){}^4\text{He}$ $Q_m = 2.5583$

In early work, angular distributions of the t_0 group were measured at $E_d = 15$ and 20 MeV: see (1979AJ01). More recently the production cross section for triton was measured by radiochemical methods (1997ABZY). Calculations of differential cross sections for $E_d < 30$ MeV are described in (1997HAZK, 1997HAZY). Reaction (b) has been studied at $E_d = 0.12$ to 10.5 MeV: see (1984AJ01). See also ${}^8\text{Be}$ in (1988AJ01).

20. (a) ${}^6\text{Li}({}^3\text{He}, \alpha){}^5\text{Li}$ $Q_m = 15.19$
 (b) ${}^6\text{Li}({}^3\text{He}, p\alpha){}^4\text{He}$ $Q_m = 16.8787$

In early work reviewed in (1988AJ01) at $E({}^3\text{He}) = 25.5$ MeV, ${}^5\text{Li}^*(0, 16.7)$ and two broad peaks at $E_x \approx 19.8$ and 22.7 MeV [$\Gamma_{\text{cm}} = 2$ and 1 MeV] are populated: see (1979AJ01). At $E({}^3\text{He}) = 33.3$ MeV angular distributions and analyzing powers have been studied for ${}^5\text{Li}^*(0, 16.7)$ [$\Gamma \approx 1.6$ and ≈ 0.4 MeV]: see (1984AJ01). More recently, in experiments at $E({}^3\text{He}) = 8, 11, 13$ and 14 MeV (1989ARZI, 1990AR17), the ${}^5\text{Li}$ state at $E_x = 16.7$ MeV was observed and the width measured to be $\Gamma = 150 \pm 40$ keV.

In reaction (b) an analysis (1989AR20) of data at $E({}^3\text{He}) = 2.5$ MeV gave $\Gamma = 1.55 \pm 0.2$ MeV for ${}^5\text{Li}_{\text{g.s.}}$. Measurements at $E({}^3\text{He}) = 1.6, 3.5, 7.0$ and 9.0 (1992AR20) found the ${}^5\text{Li}_{\text{g.s.}}$ width consistent with (1988AJ01) and independent of ${}^3\text{He}$ incident energy. Work reported for $E({}^3\text{He}) = 1.6$ MeV (1991AR25) and $E({}^3\text{He}) = 7$ and 9 MeV (1993AR12) determined that the ground state width is independent of detector angle. In early work reviewed in (1988AJ01) the parameters of the first excited state are deduced to be $E_x = 5.0 \pm 0.7$ MeV, $\Gamma_{\text{cm}} = 5.7 \pm 0.7$ MeV (1984AR17; $E({}^3\text{He}) = 1.7$ and 2.3 MeV), $E_x = 5.8 \pm 0.5$ MeV, $\Gamma_{\text{cm}} = 5.2 \pm 0.5$ MeV (1987FA11; $E({}^3\text{He}) = 1.65$ MeV). More recently an experiment at $E({}^3\text{He}) = 2.0$ and 2.2 MeV (1992DA1K) found values in line with those measured at $E({}^3\text{He}) = 1.65$ and 1.7 MeV. Measurements at $E({}^3\text{He}) = 11, 13$ and 14 MeV reported by (1989AR08) determined parameters for $E_x \approx 18$ MeV and found a level at $E_x = 17.9 \pm 0.4$ MeV, $\Gamma = 3.5 \pm 0.8$ MeV. Angular distributions of protons from the decay of ${}^5\text{Li}_{\text{g.s.}}$ are reported by (1988BU04; $E({}^3\text{He}) = 1.5$ MeV). See also references cited in (1988AJ01).

A recent theoretical study (1996FA05) of the properties of resonance scattering in two fragment systems calculates parameters for the $E_x = 16.66$ MeV states formed in reaction (b).

$$21. \text{}^6\text{Li}(\text{}^6\text{Li}, \text{}^7\text{Li})\text{}^5\text{Li} \quad Q_m = 1.86$$

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

$$22. \text{}^6\text{Li}(\text{}^{13}\text{C}, \text{}^{14}\text{C})\text{}^5\text{Li} \quad Q_m = 2.79$$

See reaction 12 in ${}^5\text{He}$ and (1988WO10).

$$23. \text{(a) } \text{}^7\text{Li}(\text{p}, \text{t})\text{}^5\text{Li} \quad Q_m = -4.16$$

$$\text{(b) } \text{}^7\text{Li}(\text{p}, \text{nd})\text{}^5\text{Li} \quad Q_m = -10.41$$

At $E_p = 43.7$ MeV, a triton group is observed to ${}^5\text{Li}_{\text{g.s.}}$ ($\Gamma = 1.55 \pm 0.15$ 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 ${}^5\text{Li}^*(16.7)({}^4\text{S}_{3/2})$ 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 23 in ${}^5\text{He}$]. 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). Measurements of angular distributions and differential cross sections at $E_p = 29.1$ and 35 MeV are reported in (1989BA88). See also (1988BAZH). For reaction (b) at $E_p = 670$ MeV see (1984AJ01). See also (1985NEZW).

$$24. \text{}^7\text{Li}(\text{}^3\text{He}, \text{dt})\text{}^5\text{Li} \quad Q_m = -9.65$$

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).

$$25. \text{}^7\text{Li}(\text{}^6\text{Li}, \text{}^8\text{Li})\text{}^5\text{Li} \quad Q_m = -3.36$$

See (1984KO25).

$$26. \text{}^9\text{Be}(\alpha, \text{}^8\text{Li})\text{}^5\text{Li} \quad Q_m = -18.58$$

Table 5.7: Mirror states in $A = 5$ nuclei ^a

⁵ He		⁵ Li		ΔE_x (MeV) ^b
E_x (MeV)	J^π	E_x (MeV)	J^π	
0	$\frac{3}{2}^-$	0	$\frac{3}{2}^-$	—
1.27	$\frac{1}{2}^-$	1.49	$\frac{1}{2}^-$	+0.22
16.84	$\frac{3}{2}^+$	16.87	$\frac{3}{2}^+$	+0.03
19.14	$\frac{5}{2}^+$	19.71	$\frac{5}{2}^+$	+0.57
19.26	$\frac{3}{2}^+$	25.42	$\frac{3}{2}^+$	+6.16
19.31	$\frac{7}{2}^+$	19.45	$\frac{7}{2}^+$	+0.14
19.96	$\frac{3}{2}^-$	19.28	$\frac{3}{2}^-$	-0.68

^a As taken from Tables 5.1 and 5.3.

^b Defined as $E_x(^5\text{Li}) - E_x(^5\text{He})$.

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).

$$27. \ ^{10}\text{B}(\text{d}, ^7\text{Li})^5\text{Li} \quad Q_m = -1.13$$

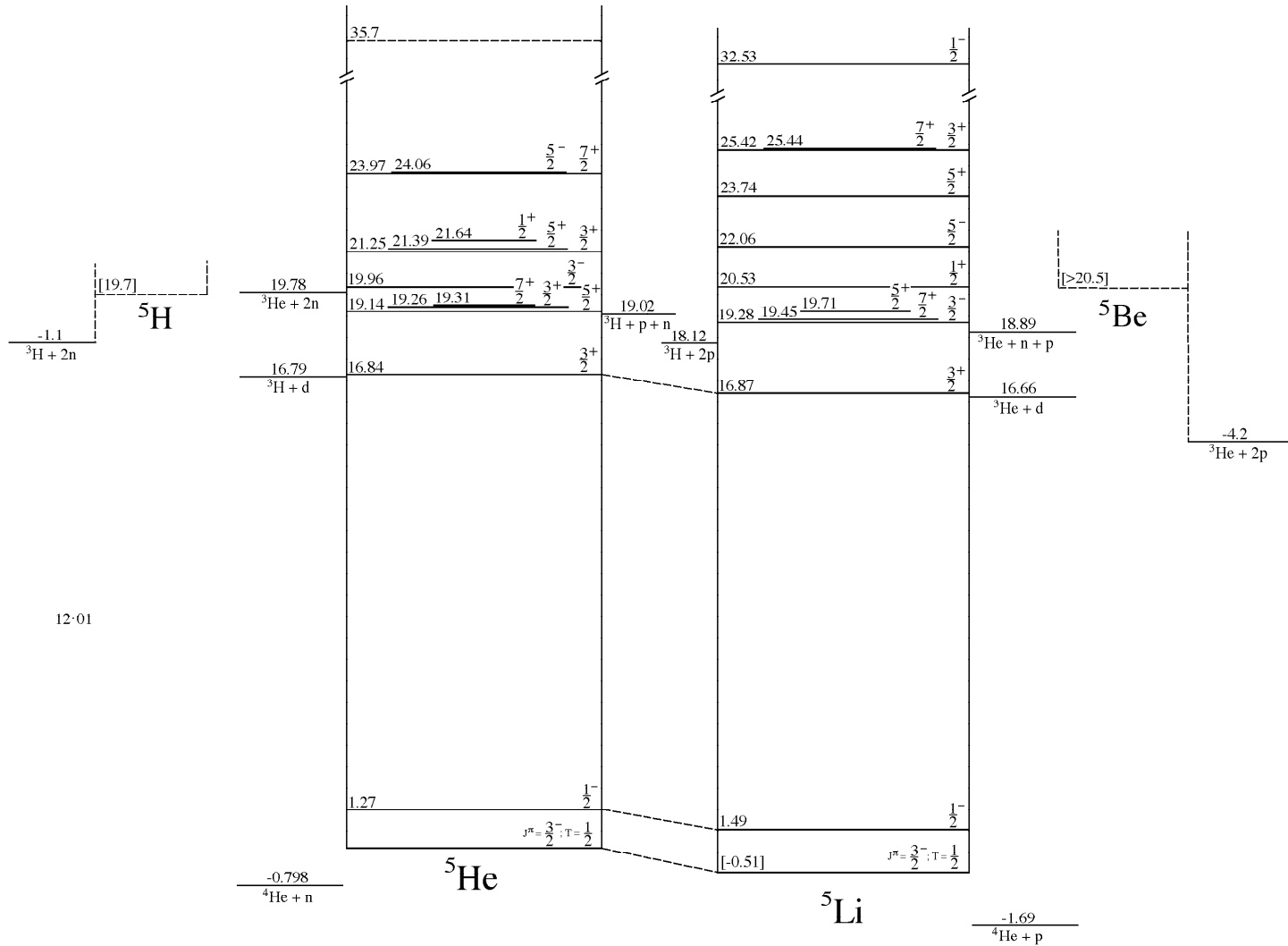
An angular distribution is reported at $E_d = 13.6$ MeV (1983DO10). See also (1984SHZJ).

$$28. \ ^{10}\text{B}(^3\text{He}, 2\alpha)^5\text{Li} \quad Q_m = 10.73$$

At $E(^3\text{He}) = 2.3$ and 5.0 MeV the reaction is reported to proceed via $^9\text{B}^*(4.9)$ to $^5\text{Li}_{\text{g.s.}}$ (1986AR14). See also (1988AR05) and ^9B in (1988AJ01).

⁵Be (Fig. 3)

The absence of any group structure in the neutron spectrum in the reaction $^3\text{He}(^3\text{He}, \text{n})^5\text{Be}$ at $E(^3\text{He}) = 18.0$ to 26.0 MeV indicates that $^5\text{Be}_{\text{g.s.}}$ 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 ^5He – ^5Li , this observation places the first $T = \frac{3}{2}$ level in these nuclei above $E_x = 21.4$ MeV: see (1979AJ01).



12:01

Figure 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 $E_C = 0.60Z(Z - 1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_N = M(Z, A) - ZM(\text{H}) - NM(\text{n}) - E_C$, minus the corresponding quantity for ${}^5\text{He}$: here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

References

(Closed 23 August 2001)

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.

- 1958LA73 A.M. Lane and R.G. Thomas, *Rev. Mod. Phys.* 30 (1958) 257
- 1960YO06 L.G. Youn, G.M. Osetinskii, N. Sodnom, A.M. Govorov, I.V. Sizov and V.I. Salatskii, *Zh. Eksp. Teor. Fiz.* 39 (1960) 225; *JETP (Sov. Phys.)* 12 (1961) 163
- 1963SM03 D.B. Smith, N. Jarmie and A.M. Lockett, *Phys. Rev.* 129 (1963) 785
- 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
- 1974AJ01 F. Ajzenberg-Selove and T. Lauritsen, *Nucl. Phys.* A227 (1974) 1
- 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
- 1978HO17 A. Houdayer, N.E. Davison, S.A. Elbakt, A.M. Sourkes, W.T.H. van Oers and A.D. Bacher, *Phys. Rev.* C18 (1978) 1985
- 1979AJ01 F. Ajzenberg-Selove, *Nucl. Phys.* A320 (1979) 1
- 1980DR01 L.J. Dries, H.W. Clark, R. Detoma, Jr., J.L. Regner and T.R. Donoghue, *Phys. Rev.* C21 (1980) 475
- 1980GR14 W. Gruebler, P.A. Schmelzbach and V. Konig, *Phys. Rev.* C22 (1980) 2243
- 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
- 1980SE1A K.K. Seth, in *Berkeley* (1980) 659
- 1981ER10 J. Ero, Z. Fodor, P. Koncz, Z. Seres, M. Csatos, B.A. Khomenko, N.N. Khovanskij, Z.V. Krumstein, Yu.P. Merekov and V.I. Petrukhin, *Nucl. Phys.* A372 (1981) 317
- 1981PL1A G.R. Plattner, *Nukleonika* 26 (1981) 1005
- 1982COZO P.C. Colby and W. Haeberli, *Bull. Amer. Phys. Soc.* 27 (1982) 700, AE7
- 1982NE09 O.F. Nemets, A.M. Yasnogorodsky, V.V. Ostashko, O.M. Povozhnik and V.N. Unn, *Pisma Zh. Eksp. Teor. Fiz.* 35 (1982) 537; *JETP Lett.* 35 (1982) 666
- 1982SM09 P.F. Smith, J.R.J. Bennett, G.J. Homer, J.D. Lewin, H.E. Walford and W.A. Smith, *Nucl. Phys.* B206 (1982) 333

- 1983ANZQ Y. Ando, M. Uno and M. Yamada, JAERI-M-83-025 (1983)
- 1983CA13 G. Calvi, M. Lattuada, F. Riggi, C. Spitaleri, D. Vinciguerra and D. Miljanic, *Lett. Nuovo Cim.* 37 (1983) 279
- 1983COZR P.C. Colby and W. Haeberli, *Bull. Amer. Phys. Soc.* 28 (1983) 987, DB3
- 1983DO10 V.N. Dobrikov, O.F. Nemets, A.S. Gass and A.A. Shvedov, *Izv. Akad. Nauk. SSSR, Ser. Fiz.* 47 (1983) 943; *Bull. Acad. Sci. USSR Phys. Ser.* 47 (1983) 114
- 1983FA16 I.V. Falomkin, F. Nichtigiu and G. Piragino, *Lett. Nuovo Cim.* 38 (1983) 211
- 1983GO06 O.K. Gorpnich, E.P. Kadkin, S.N. Kondratev, Yu.N. Lobach, M.V. Pasechnik, L.S. Saltykov and V.V. Tokarevsky, *Izv. Akad. Nauk. SSSR Ser. Fiz.* 47 (1983) 185; *Bull. Acad. Sci. USSR Phys. Ser.* 47 (1983) 179
- 1983HA20 B. Haesner, W. Heeringa, H.O. Klages, H. Dobiasch, G. Schmalz, P. Schwarz, J. Wilczynski, B. Zeitnitz and F. Kappeler, *Phys. Rev. C* 28 (1983) 995
- 1983HAYX G.M. Hale, D.C. Dodder and J.C. DeVeaux, in *Antwerp (1983)* 326; *Phys. Abs.* 37643 (1984)
- 1983KI10 U. Kirchner, R. Beckmann, U. Holm and H.-G. Korber, *Nucl. Phys.* A405 (1983) 159
- 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
- 1983NAZV A. Nadasen, P.G. Roos, G. Ciangaru, D. Mack, L. Rees, A.A. Cowley, K. Kwiatkowski, P. Schwandt and R.E. Warner, *Bull. Amer. Phys. Soc.* 28 (1983) 987
- 1983VD03 A.I. Vdovin, E.P. Kadkin, I.I. Loshchakov, M.V. Pasechnik and L.S. Saltykov, *Izv. Akad. Nauk. SSSR, Ser. Fiz.* 47 (1983) 2219
- 1984AJ01 F. Ajzenberg-Selove, *Nucl. Phys.* A413 (1984) 1
- 1984AR17 N. Arena, S. Cavallaro, A.S. Figuera, P. D'Agostino, G. Fazio, G. Giardina and F. Mezzanares, *Lett. Nuovo Cim.* 41 (1984) 59
- 1984BA60 F. Balestra, Yu.A. Batusov, G. Bendiscioli, M.P. Bussa, L. Busso, I.V. Falomkin, L. Ferrero, V. Filippini, G. Fumagalli, G. Gervino et al., *Phys. Lett.* B149 (1984) 69
- 1984BA74 Yu.A. Batusov and the Dubna-Frascati-Padpva-Pavia-Torino Collaboration, *Lett. Nuovo Cim.* 41 (1984) 223
- 1984CE08 F.E. Cecil and F.J. Wilkinson III, *Phys. Rev. Lett.* 53 (1984) 767
- 1984DE52 F.W.N. de Boer, R. van Dantzig, M. Daum, J. Jansen, P.J.S. Watson, L. Felawka, C. Grab, A. van der Schaaf, T. Kozlowski, J. Martino and A.I. Smirnov, *Phys. Rev. Lett.* 53 (1984) 423
- 1984FA14 I.V. Falomkin, G.B. Pontecorvo, M.G. Sapozhnikov, M.Yu. Khlopov, F. Balestra and G. Piragino, *Nuovo Cim.* A79 (1984) 193
- 1984HO01 B. Hoistad, M. Gazzaly, B. Aas, G. Igo, A. Rahbar, C. Whitten, G.S. Adams and R. Whitney, *Phys. Rev. C* 29 (1984) 553

- 1984JA08 N. Jarmie, R.E. Brown and R.A. Hardekopf, Phys. Rev. C29 (1984) 2031; Erratum Phys. Rev. C33 (1986) 385
- 1984KL05 H.O. Klages, H. Dobiasch, P. Doll, H. Krupp, M. Oexner, P. Plischke, B. Zeitnitz, F.P. Brady and J.C. Hiebert, Nucl. Instrum. Meth. Phys. Res. A219 (1984) 269
- 1984KO25 I. Koenig, D. Fick, S. Kossionides, P. Egelhof, K.-H. Mobius and E. Steffens, Z. Phys. A318 (1984) 135
- 1984KR23 H. Krupp, J.C. Hiebert, H.O. Klages, P. Doll, J. Hansmeyer, P. Plischke, J. Wilczynski and H. Zankel, Phys. Rev. C30 (1984) 1810
- 1984SH1F Shvedov, Dobrikov and Nemets, in *Jurmala* (1984) 333
- 1984SHZJ A.A. Shvedov, V.N. Dobrikov and O.F. Nemets, in *Alma-Ata* (1984) 332
- 1984VA06 A.G.M. van Hees and P.W.M. Glaudemans, Z. Phys. A315 (1984) 223
- 1985AL09 G.D. Alkhasov, S.L. Belostotsky, Yu.V. Dotsenko, O.A. Domchenkov, N.P. Kuropatkin and V.N. Nikulin, *Yad. Fiz.* 41 (1985) 561; *Sov. J. Nucl. Phys.* 41 (1985) 357
- 1985BA68 F.C. Barker and C.L. Woods, *Aust. J. Phys.* 38 (1985) 563
- 1985BA76 F. Balestra, S. Bossolasco, M.P. Bussa, L. Ferrero, D. Panzieri, G. Piragino, F. Tosello, C. Guaraldo, A. Maggiora, Yu.A. Batusov et al., *Phys. Lett.* B165 (1985) 265
- 1985BE30 S.L. Belostotsky, S.S. Volkov, A.A. Vorobyev, Yu.V. Dotsenko, L.G. Kudin, N.P. Kuropatkin, O.V. Miklukho, V.N. Nikulin and O.E. Prokofyev, *Yad. Fiz.* 41 (1985) 1425; *Sov. J. Nucl. Phys.* 41 (1985) 903
- 1985CA41 G.R. Caughlan, W. A. Fowler, M.J. Harris and B.A. Zimmerman, *At. Data Nucl. Data Tables* 32 (1985) 197
- 1985CE13 F.E. Cecil, D.M. Cole, R. Philbin, N. Jarmie and R.E. Brown, *Phys. Rev.* C32 (1985) 690
- 1985CE16 F.E. Cecil, D.M. Cole, F.J. Wilkinson III and S.S. Medley, *Nucl. Instrum. Meth. Phys. Res.* B10-11 (1985) 411
- 1985DO03 P. Doleschall, Gy. Bencze, M. Bruno, F. Cannata and M. D'Agostino, *Phys. Lett.* B152 (1985) 1
- 1985DO16 Yu.V. Dotsenko and V.E. Starodubsky, *Yad. Fiz.* 42 (1985) 107; *Sov. J. Nucl. Phys.* 42 (1985) 66.
- 1985FI1G First Research Group, First Research Div., *Phys. Energ. Fortis Phys. Nucl.* 9 (1985) 723
- 1985FR01 R. Franke, K. Kochskamper, B. Steinheuer, K. Wingender, W. Von Witsch and H. Machner, *Nucl. Phys.* A433 (1985) 351
- 1985GE06 J.-F. Germond and C. Wilkin, *J. Phys.* G11 (1985) 1131

- 1985GUZX G. Gunderson, S. Villanueva, A. Judd, A. Nadasen, P.G. Roos, D. Mack, F. Khazaie, J. Templon, K. Kwiatkowski, P. Schwandt et al., *Bull. Amer. Phys. Soc.* 30 (1985) 1268
- 1985HOZU D. Holslin, J. Sromicki and W. Haeberli, *Bull. Amer. Phys. Soc.* 30 (1985) 1267
- 1985LA01 J. Lang, Th. Maier, R. Muller, F. Nessi-Tedaldi, Th. Roser, M. Simonius, J. Sromicki and W. Haeberli, *Phys. Rev. Lett.* 54 (1985) 170; Erratum *Phys. Rev. Lett.* 54 (1985) 2729
- 1985LE19 Y. Le Bornec, L. Bimbot, M.P. Combes-Comets, J.C. Jourdain, F. Reide, A. Willis and N. Willis, *J. Phys.* G11 (1985) 1125
- 1985LU08 R.C. Luhn, S. Sen, N.O. Gaiser, S.E. Darden and Y. Koike, *Phys. Rev.* C32 (1985) 11
- 1985NEZW O.F. Nemets, V.V. Ostashko and A.M. Yasnogorodsky, in *Leningrad 85* (1985) 320
- 1985OK03 A. Okihana, *Nucl. Phys.* A443 (1985) 435
- 1985OS02 H. Oswald, M. Buballa, J. Helten, M. Karus, B. Laumann, R. Melzer, P. Niessen, G. Rauprich, J. Schulte-Uebbing, H. Paetz gen. Schieck and Y. Koike, *Nucl. Phys.* A435 (1985) 77
- 1985PA03 M.V. Pasechnik, L.S. Saltykov, E.P. Kadkin, I.I. Loshchakov and A.I. Vdovin, *Izv. Akad. Nauk. SSSR Ser. Fiz.* 49 (1985) 53; *Bull. Acad. Sci. USSR Phys. Ser.* 49 (1985) 55
- 1985PO10 N.A.F.M. Poppelier, L.D. Wood and P.W.M. Glaudemans, *Phys. Lett.* B157 (1985) 120.
- 1985VD03 A.I. Vdovin, A.V. Golovin and I.I. Loshchakov, *Yad. Fiz.* 42 (1985) 134; *Sov. J. Nucl. Phys.* 42 (1985) 84
- 1985VE13 G.N. Velichko, A.A. Vorobyov, A.V. Dobrovolsky, G.A. Korolev, S.I. Manayenkov, J. Saudinos and A.V. Khanzadeev, *Yad. Fiz.* 42 (1985) 1325; *Sov. J. Nucl. Phys.* 42 (1985) 837
- 1985WA13 C.W. Wang, P.G. Roos, N.S. Chant, G. Ciangaru, F. Khazaie, D.J. Mack, A. Nadasen, S.J. Mills, R.E. Warner, E. Norbeck et al., *Phys. Rev.* C31 (1985) 1662
- 1985WE06 W.-M. Wendler and M. Micklinghoff, *Nucl. Phys.* A439 (1985) 13
- 1985WI15 K. Wick, U. Berghaus, H. Bruckmann, P. Lara, W. Schutte, B. Anders and Y. Koike, *Nucl. Phys.* A444 (1985) 49
- 1986ADZT E.G. Adelberger, in *AIP Conf. Proc.* 150 (1986) 1177
- 1986AL01 P.W.F. Alons, J.J. Kraushaar, J.R. Shepard, J.M. Cameron, D.A. Hutcheon, R.P. Liljestrang, W.J. McDonald, C.A. Miller, W.C. Olsen, J.R. Tinsley et al., *Phys. Rev.* C33 (1986) 406
- 1986AR14 N. Arena, Seb. Cavallaro, G. Fazio, G. Giardina, A. Italiano and F. Mezzanares, *Phys. Rev. Lett.* 57 (1986) 1839

- 1986BA73 A.G. Baryshnikov, L.D. Blokhintsev, R. Kapote and D.A. Savin, *Izv. Akad. Nauk SSSR Ser. Fiz.* 50 (1986) 1962; *Bull. Acad. Sci. USSR Phys. Ser.* 50 (1986) 90
- 1986BE35 A.V. Belozyorov, C. Borcea, Z. Dlouhy, A.M. Kalinin, R. Kalpakchieva, Nguyen Hoai Chau, Yu.Ts. Oganessian and Yu.E. Penionzhkevich, *Nucl. Phys.* A460 (1986) 352
- 1986BE44 A.V. Belozorov, K. Borchia, Z. Dlouhy, A.M. Kalinin, Nguen Khoai Tyau and Yu.E. Penionzhkevich, *Izv. Akad. Nauk SSSR Ser. Fiz.* 50 (1986) 1936; *Bull. Acad. Sci USSR Phys. Ser.* 50 (1986) 64
- 1986BI1C M. Bittcher, V. Konig, P.A. Schmelzbach, C. Forstner, W. Gruebler, B. Vuaridel, D. Singy and J. Ulbricht, *J. Phys. Soc. Jpn. Suppl.* 55 (1986) 906
- 1986BIZP M. Bittcher, V. Konig, P.A. Schmelzbach, Ch. Forstner, W. Gruebler, B. Vuaridel, D. Singy and J. Ulbricht, in *Harrogate* (1986) 333; C146
- 1986BO01 D.H. Boal and J.C. Shillcock, *Phys. Rev.* C33 (1986) 549
- 1986BOZG I.M. Bondarenko and E.E. Petrov, *INDC(CCP)-265/L* (1986)
- 1986BR1J M. Bruno, F. Cannata, M. D'Agostino, M.L. Fiandri, M. Frisoni and M. Lombardi, *Few-Body Syst.* 1 (1986) 63
- 1986DO20 C.B. Dover, *Czech. J. Phys.* B36 (1986) 329
- 1986FU05 K. Fukunaga, S. Kakigi, T. Ohsawa, A. Okihana, T. Sekioka, H. Nakamura-Yokota and S. Tanaka, *Nucl. Phys.* A456 (1986) 48
- 1986HA1Q Haxton, in *Harrogate* (1986) 415
- 1986HO1E D. Holslin, J. Sromicki and W. Haeberli, *J. Phys. Soc. Jpn. Suppl.* 55 (1986) 904
- 1986KL04 H.O. Klages, F.P. Brady, P. Doll, R. Garrett, J. Hansmeyer, W. Heeringa, J.C. Hiebert, K. Hofmann, P. Jany, H. Krupp et al., *Radiat. Eff.* 94 (1986) 195
- 1986LA29 J. Lang, Th. Maier, R. Muller, F. Nessi-Tedaldi, Th. Roser, M. Simonius, J. Sromicki and W. Haeberli, *Phys. Rev.* C34 (1986) 1545
- 1986LAZH J.B.J.M. Lanen, A.M. van den Berg, J.F.J. van den Brand, J.A. Hendriks, J.W.A. den Herder, E. Jans, P.H.M. Keizer, G.J. Kramer, L. Lapikas, E.N.M. Quint et al., in *Harrogate* (1986) 361, C174
- 1986MO05 G.L. Morgan, P.W. Lisowski, S.A. Wender, R.E. Brown, N. Jarmie, J.F. Wilkerson and D.M. Drake, *Phys. Rev.* C33 (1986) 1224
- 1986NI1B P. Niessen, M. Buballa, D. Gola, H.J. Hahn, B. Laumann, K.R. Nyga, H. Oswald, B. Polke, G. Rauprich, J. Schulte-Uebbing et al., *J. Phys. Soc. Jpn. Suppl.* 55 (1986) 794
- 1986OS1D A. Osman, *J. Phys. Soc. Jpn. Suppl.* 55 (1986) 744
- 1986RI01 R. Rieder, P.D. Barnes, B. Bassalleck, R.A. Eisenstein, G. Franklin, R. Grace, C. Maher, P. Pile, J. Szymanski, W.R. Wharton et al., *Phys. Rev.* C33 (1986) 614
- 1986RO1J R. Roy, J. Pouliot, P. Bricault, C. Rioux, R.J. Slobodrian, H.E. Conzett and R.M. Larimer, *J. Phys. Soc. Jpn. Suppl.* 55 (1986) 1142

- 1986SA1J H. Sakaguchi, M. Yosoi, M. Nakamura, T. Noro, H. Sakamoto, T. Ichihara, M. Ierei, Y. Takeuchi, H. Togawa, T. Tsutsumi et al., J. Phys. Soc. Jpn. Suppl. 55 (1986) 61
- 1986SA1L T. Sakai, K. Hashimoto, M. Takei, M. Kurokawa, A. Manabe, K. Aoki, Y. Aoki, Y. Tagishi and K. Yagi, J. Phys. Soc. Jpn. Suppl. 55 (1986) 652
- 1986TH1C S. Tharraketta, W. Arnold, H. Baumgart, J. Gunzl, A. Hofmann, E. Huttel, N. Kniest and G. Clausnitzer, J. Phys. Soc. Jpn. Suppl. 55 (1986) 880
- 1986WA11 R.E. Warner, B.A. Vaughan, D.L. Friesel, P. Schwandt, J.-Q. Yang, G. Caskey, A. Galonsky, B. Remington and A. Nadasen, Nucl. Phys. A453 (1986) 605
- 1986YA01 A.M. Yasnogorodsky, Yad. Fiz. 43 (1986) 281; Sov. J. Nucl. Phys. 43 (1986) 178
- 1987BA12 F. Balestra, M.P. Busa, L. Busso, L. Fava, L. Ferrero, D. Panzieri, G. Piragino, F. Tosello, G. Bendiscioli, A. Rotondi et al., Nucl. Phys. A465 (1987) 714
- 1987BA47 F. Balestra, R. Barbieri, Yu.A. Batusov, G. Bendiscioli, S. Bossolasco, M.P. Busa, L. Busso, I.V. Falomkin, L. Ferrero, C. Guaraldo et al., Phys. Lett. B194 (1987) 343
- 1987BA69 F. Balestra, S. Bossolasco, M.P. Busa, L. Busso, L. Fava, L. Ferrero, D. Panzieri, G. Piragino, F. Tosello, G. Bendiscioli et al., Nucl. Phys. A474 (1987) 651
- 1987BO40 C. Borcea, A.V. Belozyorov, Z. Dlouhy, A.M. Kalinin, N.H. Chau and Yu.E. Penionzhkevich, Rev. Roum. Phys. 32 (1987) 497
- 1987BR10 R.E. Brown, N. Jarmie and G.M. Hale, Phys. Rev. C35 (1987) 1999; Erratum Phys. Rev. C36 (1987) 1220
- 1987FA1I G. Fazio, S. Femino, G. Giardina, A. Italiano, F. Mezzanares and R. Palamara, Hadronic J. 10 (1987) 21
- 1987GO25 M.G. Gornov, Yu.B. Gurov, V.P. Koptev, P.V. Morokhov, K.O. Oganesyanyan, B.P. Osipenko, V.A. Pechkurov, V.I. Savelev, F.M. Sergeev, A.A. Khomutov et al., Pisma Zh. Eksp. Teor. Fiz. 45 (1987) 205; JETP Lett. (USSR) 45 (1987) 252
- 1987HA20 G.M. Hale, R.E. Brown and N. Jarmie, Phys. Rev. Lett. 59 (1987) 763
- 1987HA44 G.M. Hale, R.E. Brown and N. Jarmie, Phys. Rev. Lett. 59 (1987) 2819
- 1987HU02 J.R. Hurd, J.S. Boswell, R.C. Minehart, L.B. Rees, Y. Tzeng, H.J. Ziock and K.O.H. Ziock, Nucl. Phys. A462 (1987) 605
- 1987KAZL F. Kadirov, M.A. Kayumov, Sh. Kayumov, A.M. Mukhamedzhanov, U.I. Faizullaev, K. Khamidova and R. Yarmukhamedov, in Yurmala (1987) 343
- 1987KO47 A.A. Korshennikov, E.Yu. Nikolsky and A.A. Ogloblin, Pisma Zh. Eksp. Teor. Fiz. 46 (1987) 306; JETP Lett. (USSR) 46 (1987) 384
- 1987KR18 A. Krauss, H.W. Becker, H.P. Trautvetter, C. Rolfs and K. Brand, Nucl. Phys. A465 (1987) 150
- 1987KUZU V.I. Kukulkin, in Yurmala (1987) 151

- 1987LI07 J. Li, H. Lu, H. Ma, W. Zhao, Y. Cui, P. Fan and D. Wang, Nucl. Instrum. Meth. Phys. Res. A255 (1987) 115
- 1987MI34 S. Micek, H. Rebel, H.J. Gils, H. Klewe-Nebenius, S. Zagromski and D.K. Srivastava, Z. Phys. A328 (1987) 467
- 1987MO1K D. Morgan, M.R. Pennington, G.M. Hale, R.E. Brown and N.Jarmie, Phys. Rev. Lett. 59 (1987) 2818
- 1987NA23 V.I. Nazaruk, Yad. Fiz. 46 (1987) 80; Sov. J. Nucl. Phys. 46 (1987) 51
- 1987PE1C Penionshkevich, in Dubna (1987) 364
- 1987PO03 J. Pochodzalla, C.K. Gelbke, W.G. Lynch, M. Maier, D. Ardouin, H. Delagrange, H. Doubre, C. Gregoire, A. Kyanowski, W. Mittig et al., Phys. Rev. C35 (1987) 1695
- 1987SO1C Soundranayagam, Seth and Parker, in Panic (1987) 292
- 1987VA36 V.S. Vasilevsky, I.F. Gutich and I.P. Okhrimenko, Yad. Fiz. 46 (1987) 757; Sov. J. Nucl. Phys. 46 (1987) 427
- 1987VD01 A.I. Vdovin and I.N. Loshchakov, Yad. Fiz. 45 (1987) 67; Sov. J. Nucl. Phys. 45 (1987) 42
- 1987VD1A A.I. Vdovin, A.V. Golovin and I.I. Loschakov, Sov. J. Part. Nucl. 18 (1987) 573
- 1987WA21 R.E. Warner, B.A. Vaughan, J.A. Ditusa, J.W. Rovine, R.S. Wakeland, C.P. Browne, S.E. Darden, S. Sen, A. Nadasen, A. Basak et al., Nucl. Phys. A470 (1987) 339
- 1987WA25 R.E. Warner, F.G. Johnson, C.P. Browne, A. Rollefson, A. Galonsky and A. Nadasen, Nucl. Phys. A472 (1987) 522
- 1987YAZJ A.M. Yasnogorodsky, V.V. Ostashko, V.N. Urin and A.N. Nenakhov, in Yurmala (1987) 321
- 1988AJ01 F. Ajzenberg-Selove, Nucl. Phys. A490 (1988) 1
- 1988AR05 N. Arena, Seb. Cavallaro, G. Fazio, G. Giardina, A. Italiano and F. Mezzanares, Euophys. Lett. 5 (1988) 517
- 1988BA62 F. Balestra, S. Bossolasco, M.P. Bussa, L. Busso, L. Fava, L. Ferrero, D. Panzieri, G. Piragino, F. Tosello, R. Barbieri et al., Nuovo Cim. A100 (1988) 323
- 1988BA75 F.C. Barker, Aust. J. Phys. 41 (1988) 743
- 1988BAZH I.Ya. Barit, S.V. Zuev, V.A. Simonov and A.M. Yasnogorodsky, in Baku (1988) 277
- 1988BE1U P. Bem, V. Presperin, M. Trginova, B.P. Adyasevich and V.G. Antonenko, Muon Catal. Fus. 3 (1988) 389
- 1988BE34 A.V. Belozarov, K. Borchia, Z. Dlougy, A.M. Kalinin, Nguyen Hoai Thiau and Yu.E. Penionzhkevich, Izv. Akad. Nauk SSSR Ser. Fiz. 52 (1988) 100; Bull. Acad. Sci. USSR Phys. Ser. 52 (1988) 94
- 1988BR27 M. Bruno, F. Cannata, M. D'Agostino, M.L. Fiandri, M. Frisoni and M. Lombard, J. Phys. (London) G14 (1988) L235

- 1988BU04 S. Burzynski, J. Turkiewicz, K. Rusek, I.M. Turkiewicz and P. Zupranski, Nucl. Phys. A480 (1988) 51
- 1988CA11 P.J. Carlos, Ph. Bourgeois, J. Fagot, J.L. Fallou, P. Garganne, J.M. Laget, A. Lepretre, A. de Miniac, A. Veysiére, J. Jury et al., Phys. Lett. B203 (1988) 33
- 1988CE04 F.E. Cecil and S.S. Medley, Nucl. Instrum. Meth. Phys. Res. A271 (1988) 628
- 1988DA18 S.E. Darden, O. Karban, C. Blyth, J.B.A. England, J.M. Nelson and S. Roman, Nucl. Phys. A486 (1988) 285
- 1988DA26 A.E. Dabiri, Nucl. Instrum. Meth. Phys. Res. A271 (1988) 71
- 1988DU04 E.I. Dubovoy and G.I. Chitanava, Yad. Fiz. 47 (1988) 75; Sov. J. Nucl. Phys. 47 (1988) 48.
- 1988EN03 S. Engstler, A. Krauss, K. Neldner, C. Rolfs, U. Schroder and K. Langanke, Phys. Lett. B202 (1988) 179
- 1988GA14 N.O. Gaiser, S.E. Darden, R.C. Luhn, H. Paetz gen. Schieck and S. Sen, Phys. Rev. C38 (1988) 1119
- 1988GU07 I.F. Gutich and I.P. Okhrimenko, Yad. Fiz. 47 (1988) 1238; Sov. J. Nucl. Phys. 47 (1988) 788
- 1988KA38 V.I. Karmanov, V.V. Komarov, A.M. Popova, N.A. Sotnikova and V.L. Shablov, Izv. Akad. Nauk SSSR Ser. Fiz. 52 (1988) 936; Bull. Acad. Sci. USSR Phys. Ser. 52 (1988) 99
- 1988MCZT V. McLane, C.L. Dunford and P.F. Rose, Neutron Cross Sections, Vol. 2 (Academic Press, New York, 1988)
- 1988MI29 G.H. Miley, Nucl. Instrum. Meth. Phys. Res. A271 (1988) 197
- 1988MO36 H. Momota, M. Okamoto, Y. Nomura, M. Ohnishi, H.L. Berk and T. Tajima, Nucl. Instrum. Meth. Phys. Res. A271 (1988) 7
- 1988NA18 V.A. Nazarenko, J. Phys. (London) G14 (1988) S381
- 1988PUZZ V. Punjabi, C.F. Perdrisat, C. Lyndon, P. Ulmer, J. Yonnet, R. Beurtey, M. Boivin, A. Boudard, F. Plouin, J.P. Didelez et al., Bull. Amer. Phys. Soc. 33 (1988) 962, DI7
- 1988SC1F U. Schroder, S. Engstler, A. Krauss, K. Neldner, C. Rolfs, E. Somorjai and K. Langanke, Nucl. Instrum. Meth. Phys. Res. B40-41 (1988) 466
- 1988SCZG U. Schroder, Bull. Amer. Phys. Soc. 33 (1988) 1712
- 1988SEZJ K.K. Seth, AIP Conf. Proc. 164 (1988) 324
- 1988STZZ S.M. Sterbenz, D. Dehnhard, M.K. Jones, C.E. Parman, Y.F. Yen, K.W. Jones and S.K. Nanda, Bull. Amer. Phys. Soc. 33 (1988) 961
- 1988SU12 I. Supek, I. Slaus, Y. Koike, P.A. Treado and J.M. Lambert, Few-Body Syst. 4 (1988) 39
- 1988WA22 Wang Hong and Zhou Guo Qing, Nucl. Instrum. Meth. Phys. Res. B34 (1988) 145

- 1988WO10 C.L. Woods, F.C. Barker, W.N. Catford, L.K. Fifield and N.A. Orr, *Aust. J. Phys.* 41 (1988) 525
- 1989AB21 S.N. Abramovich, B.Ya. Guzhovsky, S.A. Dunaeva and A.G. Zvenigorodsk, *Izv. Akad. Nauk SSSR Ser. Fiz.* 53 (1989) 2116; *Bull. Acad. Sci. USSR Phys. Ser.* 53 (1989) 54
- 1989AK05 T. Akesson and the Axial Field Spectrometer Collaboration, *Phys. Lett.* B231 (1989) 359
- 1989AR04 N. Arena, Seb. Cavallaro, G. Fazio, G. Giardina, A. Italiano, M. Herman, M. Bruno, F. Cannata, M. D'Agostino and M. Lombardi, *Phys. Rev.* C40 (1989) 55
- 1989AR08 N. Arena, Seb. Cavallaro, A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano, M. Herman and M. Lombardi, *Phys. Rev.* C40 (1989) 1126
- 1989AR20 N. Arena, Seb. Cavallaro, P. D'Agostino, G. Fazio, G. Giardina, A. Italiano, F. Mezzanares, M. Herman and M. Lombardi, *Nuovo Cim.* A102 (1989) 1327
- 1989ARZI N. Arena, S. Cavallaro, A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano, R. Palamara and A. Taccone, in *Sao Paulo* (1989) 379
- 1989AYZZ Z. Ayer, S.E. Darden, S. Sen and R.E. Warner, *Bull. Amer. Phys. Soc.* 34 (1989) 1140
- 1989BA59 F. Balestra, R. Barbieri, Yu.A. Batusov, G. Bendiscioli, S. Bossolasco, F.O. Breivik, M.P. Bussa, L. Busso, C. Guaraldo, I.V. Falomkin et al., *Phys. Lett.* B230 (1989) 36
- 1989BA88 I.Ya. Barit, S.V. Zuev, V.V. Ostashko, V.N. Urin and A.M. Yasnogorodsky, *Izv. Akad. Nauk SSSR Ser. Fiz.* 53 (1989) 2455; *Bull. Acad. Sci. USSR Phys. Ser.* 53 (1989) 179
- 1989BA94 Yu.A. Batusov and the Dubna-Turin-Frascati-Brescia-Bergen-Oslo Collaboration PS179, *Yad. Fiz.* 50 (1989) 1524; *Sov. J. Nucl. Phys.* 50 (1989) 945
- 1989BE08 Gy. Bencze, *Nucl. Phys.* A492 (1989) 459
- 1989BR30 H. Braun, A. Dirner, J.P. Gerber, V.V. Glagolev, J. Hlavacova, P. Juillot, A.K. Kacharava, K.U. Khairtdinov, R.M. Lebedev, G. Martinska et al., *Czech. J. Phys.* B39 (1989) 1267
- 1989BU01 S. Burzynski, J. Campbell, M. Hammans, R. Henneck, W. Lorenzon, M.A. Pickar and I. Sick, *Phys. Rev.* C39 (1989) 56
- 1989CL04 M. Clajus, P. Egun, W. Gruebler, P. Hautle, A. Weber, P.A. Schmelzbach, W. Kretschmer, M. Haller, C.J. Prenzel, A. Rauscher et al., *Nucl. Instrum. Meth. Phys. Res.* A281 (1989) 17
- 1989CO11 S.G. Cooper and R.S. Mackintosh, *Phys. Rev.* C40 (1989) 502
- 1989GA21 C.A. Gagliardi and A.C. Betker, *Nucl. Instrum. Meth. Phys. Res.* A284 (1989) 356
- 1989GR20 O.G. Grebenyuk, A.V. Khanzadeev, G.A. Korolev, S.I. Manayenkov, J. Saudinos, G.N. Velichko and A.A. Vorobyov, *Nucl. Phys.* A500 (1989) 367
- 1989GU28 N. Guessoum and R.J. Gould, *Astrophys. J.* 345 (1989) 356.

- 1989KA39 H. Kanada, T. Kaneko and Y.C. Tang, Nucl. Phys. A504 (1989) 529
- 1989LA13 J.B.J.M. Lanen, A.M. van den Berg, H.P. Blok, J.F.J. van den Brand, C.T. Christou, R. Ent, A.G.M. van Hees, E. Jans, G.J. Kramer, L. Lapikas et al., Phys. Rev. Lett. 62 (1989) 2925
- 1989LA29 K. Langanke and C. Rolfs, Mod. Phys. Lett. A4 (1989) 2101
- 1989NA10 A. Nadasen, P.G. Roos, N.S. Chant, C.C. Chang, G. Ciangaru, H.F. Breuer, J. Wesick and E. Norbeck, Phys. Rev. C40 (1989) 1130
- 1989NA16 V.I. Nazaruk, Phys. Lett. B229 (1989) 348
- 1989PA26 R.S. Payne, A.S. Clough, P. Murphy and P.J. Mills, Nucl. Instrum. Meth. Phys. Res. B42 (1989) 130
- 1989RI04 J.C. Riley, H.R. Weller and D.R. Tilley, Phys. Rev. C40 (1989) 1517
- 1989SC19 A. Scalia, Nuovo Cim. A101 (1989) 795
- 1989SC1F A. Scalia, Sao Paulo (1989) 462
- 1989SC25 A. Scalia, Nuovo Cim. A102 (1989) 953
- 1989SC41 A. Scalia, Nuovo Cim. A102A (1989) 1101
- 1989SH17 S. Shirato, S. Shibuya, Y. Ando, T. Kokubu and K. Hata, Nucl. Instrum. Meth. Phys. Res. A278 (1989) 477
- 1989SHZS S. Shirato, S. Shibuya, K. Hata, Y. Ando and K. Shibata, JAERI-M 89-107 (Jpn. Atomic Energy Res.) (1989)
- 1989SZ04 E. Szilagyi, F. Paszti, A. Manuaba, C. Hajdu and E. Kotai, Nucl. Instrum. Meth. Phys. Res. B43 (1989) 502
- 1989US02 M.N. Ustinin and V.D. Efros, Yad. Fiz. 49 (1989) 1297; Sov. J. Nucl. Phys. 49 (1989) 807
- 1989VAZJ Yu.O. Vasilev, Yu.N. Pavlenko and V.M. Pugach, in Tashkent (1989) 335
- 1990AM04 A.I. Amelin, M.G. Gornov, Yu.B. Gurov, A.I. Ilin, V.P. Koptev, P.V. Morokhov, K.O. Oganesyan, V.A. Pechkurov, V.I. Savelev, F.M. Sergeev et al., Pisma Zh. Eksp. Teor. Fiz. 51 (1990) 607; JETP Lett. (USSR) 51 (1990) 688
- 1990AM07 R.D. Amado, F. Cannata and J.P. Dedonder, Phys. Rev. C41 (1990) 1289
- 1990AR17 N. Arena, Seb. Cavallaro, A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano and A. Taccone, J. Phys. G16 (1990) 1511
- 1990AYZW Z. Ayer, S.E. Darden, S. Sen and R.E. Warner, Bull. Amer. Phys. Soc. 35 (1990) 1659
- 1990BEYX A.V. Belozerov, I. Vintsour, R.G. Kalpakchieva, I.V. Kuznetsov, Yu.E. Penionzhkevich, Sh. Piskorz and N.K. Skobelev, in Leningrad 90 (1990) 364
- 1990BEYY A.V. Belozerov, I. Vintsour, R.G. Kalpakchieva, I.V. Kuznetsov, Yu.E. Penionzhkevich and Sh. Piskorz, in Leningrad (1990) 359

- 1990BI06 L. Bildsten, I. Wasserman and E.E. Salpeter, Nucl. Phys. A516 (1990) 77
- 1990BL02 G. Bluge and K. Langanke, Phys. Rev. C41 (1990) 1191
- 1990BL08 G. Bluge, K. Langanke, M. Plagge, K.R. Nyga and H. Paetz gen. Schieck, Phys. Lett. B238 (1990) 137
- 1990BR12 L. Bracci, G.Fiorentini, V.S. Melezhik, G. Mezzorani and P. Quarati, Nucl. Phys. A513 (1990) 316
- 1990BR14 M. Bruno, F. Cannata, M. D'Agostino and M.L. Fiandri, Phys. Rev. C42 (1990) 448
- 1990DE06 P.K.A. De Witt Huberts, Nucl. Phys. A507 (1990) 189c.
- 1990DE16 P.K.A. de Witt Huberts, J. Phys. (London) G16 (1990) 507
- 1990GO34 I.G. Golikov, A.V. Golovin, K.A. Gridnev and I.I. Loshchakov, Yad. Fiz. 52 (1990) 718; Sov. J. Nucl. Phys. 52 (1990) 460
- 1990KU27 Yu.A. Kuperin, Yu.B. Melnikov and A.K. Motovilov, Yad. Fiz. 52 (1990) 433; Sov. J. Nucl. Phys. 52 (1990) 276
- 1990LA06 J.B.J.M. Lanen, H.P. Blok, E. Jans, L. Lapikas, G. van der Steenhoven and P.K.A. de Witt Huberts, Phys. Rev. Lett. 64 (1990) 2250
- 1990LE30 S.R. Lee, D.S. Walsh and B.L. Doyle, Nucl. Instrum. Meth. Phys. Res. B45 (1990) 285
- 1990LO14 R.G. Lovas, A.T. Kruppa and J.B.J.M. Lanen, Nucl. Phys. A516 (1990) 325
- 1990MAYW Yu.G. Mashkarov, E.I. Koshchy, N.T. Burtebaev, A.D. Duisebaev, G.N. Ivanov, V.I. Kanashevich, V.A. Khaimin and V.V. Adodin, in Leningrad 90 (1990) 317
- 1990NAZH T. Nakagawa, T. Asami and T. Yoshida, JAERI-M 90-099 (Jpn. Atomic Energy Res.) (1990)
- 1990NE14 V.G. Neudachin, V.N. Pomerantsev and A.A. Sakharuk, Yad. Fiz. 52 (1990) 738; Sov. J. Nucl. 52 (1990) 473
- 1990QIZZ Q. Qiu, Bull. Amer. Phys. Soc. 35 (1990) 1700
- 1990SH1C K. Shibata, Report JEARI-M-90-024 (Jpn. At. Energy Res.) (1990)
- 1990TR08 M. Trginova, P. Bem and V. Presperin, Izv. Akad. Nauk SSSR, Ser. Fiz. 54 (1990) 982; Bull. Acad. Sci. USSR, Phys. Ser. 52 (1990) 165
- 1990VA16 V.V. Varlamov, B.S. Ishkhanov and A.P. Chernyaev, Izv. Akad. Nauk SSSR, Ser. Fiz. 54 (1990) 561; Bull. Acad. Sci. USSR, Phys. Ser. 54 (1990) 181
- 1990WEZY S.P. Wells, S.W. Wissink, A.D. Bacher, P. Li, J. Lisantti, C. Olmer, A.K. Opper, R. Sawafta, P. Schwandt, J. Sowinski and E.J. Stephenson, Bull. Amer. Phys. Soc. 35 (1990) 1037
- 1990WH01 D.M. Whittal, A.A. Cowley, J.V. Pilcher, S.V. Fortsch, F.D. Smit and J.J. Lawrie, Phys. Rev. C42 (1990) 309

- 1990WI1L Wielunski and Moller, Nucl. Instrum. Meth. Phys. Res. B50 (1990) 23
- 1990YOZZ M. Yosoi, H. Sakaguchi, M. Nakamura, H. Togawa, S. Hirata, T. Nakano, O. Kami-gaito, Y. Nakai, H. Kaneko, F. Hiei et al., RCNP (Osaka), Ann. Rept. 1989 (1990) 49
- 1991AR10 N. Arena, S. Cavallaro, A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano, F. Mezzanares, R. Palamara and A. Taccone, J. Phys. Soc. Jpn. 60 (1991) 100
- 1991AR25 N. Arena, Seb. Cavallaro, A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano, A. Taccone, V.D. Chesnokova, V.S. Olkhovsky and A.K. Zaichenko, Nuovo Cim. A104 (1991) 1809
- 1991AS02 A.R. Ashurov, D.A. Zubarev, A.M. Mukhamedzhanov and R. Yarmukhamedov, Yad. Fiz. 53 (1991) 151; Sov. J. Nucl. Phys. 53 (1991) 97
- 1991BA02 M.J. Balbes, G. Feldman, L.H. Kramer, H.R. Weller and D.R. Tilley, Phys. Rev. C43 (1991) 343
- 1991BA1V F. Balestra, Yu.A. Batusov, G. Bendiscioli, S. Bossolasco, F.O. Breivik, S.A. Bunyatov, M.P. Bussa, L. Busso, C. Guaraldo, I.V. Falomkin et al., in Stockholm 90 (1991) 245
- 1991BO23 L.N. Bogdanova, G.M. Hale and V.E. Markushin, Phys. Rev. C44 (1991) 1289
- 1991CO05 S.G. Cooper and R.S. Mackintosh, Phys. Rev. C43 (1991) 1001
- 1991DA06 S.E. Darden, O. Karban, C. Blyth, J.B.A. England, J.M. Nelson and S. Roman, Nucl. Phys. A526 (1991) 45
- 1991FU01 Y. Fujiwara and Y.C. Tang, Phys. Rev. C43 (1991) 96
- 1991GO19 M.G. Gornov, Yu.B. Gurov, P.V. Morokhov, V.A. Pechkurov, V.I. Savelyev, F.M. Sergeev, B.A. Chernyshev, R.R. Shafigullin, A.V. Shishkov, V.P. Koptev et al., Nucl. Phys. A531 (1991) 613
- 1991KA31 B.M. Karnakov, V.D. Mur, S.G. Pozdnyakov and V.S. Popov, Pisma Zh. Eksp. Teor. Fiz. 54 (1991) 131; JETP Lett. (USSR) 54 (1991) 127
- 1991NE01 V.G. Neudatchin, V.I. Kukulín, V.N. Pomerantsev and A.A. Sakharuk, Phys. Lett. B255 (1991) 482
- 1991SA17 A.L. Sagle, B.E. Bonner, F.P. Brady, N.S.P. King and J.L. Romero, Nucl. Phys. A530 (1991) 370
- 1991SA18 A.L. Sagle, B.E. Bonner, F.P. Brady, N.S.P. King, M.W. McNaughton, J.L. Romero and J.L. Ullmann, Nucl. Phys. A530 (1991) 387
- 1991SE06 K.K. Seth and B. Parker, Phys. Rev. Lett. 66 (1991) 2448
- 1991VA05 G. van der Steenhoven, Nucl. Phys. A527 (1991) 17c.
- 1991WEZZ H.R. Weller, G. Feldman, M.J. Balbes, L.H. Kramer, J.Z. Williams and D.R. Tilley, AIP Conf. Proc. 238 (1991) 587

- 1992AM1H A.I. Amelin, B.A. Chernyshev, M.G. Gornov, Yu.B. Gurov, P.V. Morokhov, V.A. Pechkurov, V.I. Savel'ev, R.R. Shafigullin, A.V. Shishkov and V.P. Koptev, in *Penyscola* (1992) 516
- 1992AR20 N. Arena, Seb. Cavallaro, A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano and A. Taccone, *J. Phys. G18* (1992) 2003
- 1992BA04 M.J. Balbes, G. Feldman, H.R. Weller and D.R. Tilley, *Phys. Rev. C45* (1992) R487
- 1992BE46 F.D. Becchetti, J.A. Brown, W.Z. Liu, J.W. Janecke, D.A. Roberts, J.J. Kolata, R.J. Smith, K. Lamkin, A. Morsad, R.E. Warner et al., *Nucl. Phys. A550* (1992) 507
- 1992BEZZ F.D. Becchetti, J.A. Brown, W.Z. Liu, J.W. Janecke, D.A. Roberts, J.J. Kolata, R.J. Smith, K. Lamkin, A. Morsad, R.E. Warner et al., *Bull. Amer. Phys. Soc. 37* (1992) 868
- 1992BO47 H.-S. Bosch and G.M. Hale, *Nucl. Fusion 32* (1992) 611
- 1992DA1K A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano, M. Lombardi, V.S. Olkhovsky, A. Taccone, V.D. Tchesnokova and A.K. Zaichenko, *Hadronic J. 15* (1992) 303
- 1992FU10 Y. Fujiwara and Y.C. Tang, *Few-Body Syst. 12* (1992) 21
- 1992KH04 M.G. Khayat, N.S. Chant, P.G. Roos and T.-S.H. Lee, *Phys. Rev. C46* (1992) 2415
- 1992LI32 J.R. Lierzer, K.W. Wenzel, R.D. Petrasso, D.H. Lo, J.W. Coleman, C.K. Li, E. Hsieh and T. Bernat, *Rev. Sci. Instrum. 63* (1992) 4847
- 1992NE03 V.G. Neudatchin, V.I. Kukulín, V.N. Pomerantsev and A.A. Sakharuk, *Phys. Rev. C45* (1992) 1512
- 1992PI04 J.A. Pinston, V. Bellini, W. Cassing, S. Drissi, J. Guillot, J. Julien, H. Nifenecker, F. Schussler and M.L. Sperduto, *Nucl. Phys. A536* (1992) 321
- 1992RA01 R.D. Ransome, C.L. Morris, V.R. Cupps, R.W. Ferguson, J.A. McGill, D.L. Watson, J.D. Zumbro, B.G. Ritchie, J.R. Comfort, J.R. Tinsley et al., *Phys. Rev. C45* (1992) R509
- 1992TI02 D.R. Tilley, H.R. Weller and G.M. Hale, *Nucl. Phys. A541* (1992) 1
- 1993AB07 S.K. Abdullin, A.V. Blinov, I.A. Vanyushin, V.E. Grechko, V.A. Ergakov, S.M. Zombkovskii, I.L. Kiselevich, Y.V. Korolev and Y.M. Selektor, *Phys. At. Nucl. 56* (1993) 536; *Yad. Fiz. 56* (1993) 204
- 1993AR12 N. Arena, S. Cavallaro, A. D'Arrigo, G. Fazio, G. Giardina, A. Italiano, A. Taccone, D.Q. Hung and V.S. Olkhovsky, *Nuovo Cim. A106* (1993) 1007
- 1993CS02 A. Csoto, R.G. Lovas and A.T. Kruppa, *Phys. Rev. Lett. 70* (1993) 1389
- 1993FA12 G. Fazio, G. Giardina and R. Palamara, *J. Phys. Soc. Jpn. 62* (1993) 1804
- 1993GL09 V.V. Glagolev, R.M. Lebedev, G.D. Pestova, S.S. Shimansky, M. Kravcikova, M. Se-man, L. Sandor, A. Dirner, J. Hlavacova, G. Martinska et al., *Z. Phys. C60* (1993) 421

- 1993GO16 O.K. Gorpinich, Yu.N. Pavlenko, O.M. Povoroznik and B.G. Struzhko, *Izv. Akad. Nauk Ser. Fiz.* 57 (1993) 121; *Bull. Russ Acad Sci.* 57 (1993) 112
- 1993HO09 L.L. Howell, S.A. Sofianos, H. Fiedeldey and G. Pantis, *Nucl. Phys.* A556 (1993) 29
- 1993KA01 J.E. Kammeraad, J. Hall, K.E. Sale, C.A. Barnes, S.E. Kellogg and T.R. Wang, *Phys. Rev.* C47 (1993) 29
- 1993KA47 H. Kanada, T. Kaneko and S. Nagata, *Prog. Theor. Phys.* 89 (1993) 1103
- 1993KU02 D. Kurath, *Phys. Rev.* C47 (1993) 1306
- 1993MA47 S.I. Manayenkov, *Phys. At. Nucl.* 56 (1993) 1525
- 1993PAZP Yu.N. Pavlenko, V.M. Pugach, A.G. Prokopets, V.N. Dobrikov, V.S. Zaritsky, V.A. Kiva, A.A. Klipenshtein and I.N. Kolomiets, in *Dubna 93* (1993) 245
- 1994BA02 M.J. Balbes, J.C. Riley, G. Feldman, H.R. Weller and D.R. Tilley, *Phys. Rev.* C49 (1994) 912
- 1994CO16 A.A. Cowley, G.F. Steyn, S.V. Fortsch, J.J. Lawrie, J.V. Pilcher, F.D. Smit and D.M. Whittal, *Phys. Rev.* C50 (1994) 2449
- 1994FA10 W.R. Falk, *Phys. Rev.* C50 (1994) 1574
- 1994FU06 K.M. Furutani, W.R. Falk, H. Guan, J.R. Campbell, F.A. Duncan, P.L. Walden, S. Yen, G.M. Huber, R.D. Bent, G.J. Lolos, E. Korkmaz, A. Trudel and A. Celler, *Phys. Rev.* C50 (1994) 1561
- 1994MU07 V.D. Mur, B.M. Karnakov, S.G. Pozdnyakov and V.S. Popov, *Phys. At. Nucl.* 57 (1994) 769; *Yad. Fiz.* 57:5 (1994) 820
- 1994NI04 D. Nilsson, J.-O. Adler, B.-E. Andersson, K.I. Blomqvist, L. Isaksson, A. Sandell, B. Schroder, K. Ziakas, L. Van Hoorebeke, D. Ryckbosch and R. Van de Vyver, *Phys. Scr.* 49 (1994) 397
- 1994RY01 D. Ryckbosch, L. Van Hoorebeke, R. Van de Vyver, C. Van den Abeele, J. Dias, J.-O. Adler, K.I. Blomqvist, D. Nilsson, B. Schroder and K. Ziakas, *Nucl. Phys.* A568 (1994) 52
- 1994WA06 R.E. Warner, J.M. Getter, R.A. Swartz, A. Okihana, T. Konishi, R. Yoshimura, P.D. Kunz, M. Fujiwara, K. Fukunaga, S. Kasagi and N. Koori, *Phys. Rev.* C49 (1994) 1534
- 1995ALZU D.V. Aleksandrov, E.Yu. Nikolsky, B.G. Novatsky and D.N. Stepanov, in *Arles* (1995) 329
- 1995AU04 G. Audi and A.H. Wapstra, *Nucl. Phys.* A595 (1995) 409
- 1995DI01 J.F. Dias, D. Ryckbosch, R. Vandevyver, C. Vandenebeele, G. Demeyer, L. Vanhoorebeke, J.O. Adler, K.I. Blomqvist, D. Nilsson, H. Ruijter et al., *Nucl. Phys.* A587 (1995) 434
- 1995DU13 S.B. Dubovichenko, *Phys. At. Nucl.* 58 (1995) 1174; *Yad. Fiz.* 58 (1995) 1253

- 1995FU16 Y. Fujiwara and Y.C. Tang, *Prog. Theor. Phys. (Kyoto)* 93 (1995) 711
- 1995LA33 L.M. Lazarev, *Bull. Russ. Acad. Sci. Phys.* 59 (1995) 866; *Izv. Ross. Akad. Nauk Ser. Fiz.* 59 (1995) 171
- 1996AL01 N. Alexander, K. Amos, B. Apagyi and D.R. Lun, *Phys. Rev. C* 53 (1996) 88
- 1996CO20 S.G. Cooper, R.S. Mackintosh, *Phys. Rev. C* 54 (1996) 3133
- 1996EF03 V.D. Efros and H. Oberhummer, *Phys. Rev. C* 54 (1996) 1485
- 1996FA05 G. Fazio, G. Giardina, F.I. Karmanov and V.L. Shablov, *Int. J. Mod. Phys. E* 5 (1996) 175
- 1996KAZZ M. Kawabata, H. Akimune, H. Akiyoshi, Y. Arimoto, T. Baba, I. Daito, K. Hatanaka, F. Ihara, H. Kohri, Y. Maeda et al., *RCNP Osaka Ann. Rept. 1995* (1996) 35
- 1996PO26 V.S. Popov, B.M. Karnakov and V.D. Mur, *Hyperfine Interactions* 102 (1996) 401
- 1996RU13 A.T. Rudchik, E.I. Koshchy, A. Budzanowski, R. Siudak, A. Szczurek, I. Skwirczynska, Yu.G. Mashkarov, L. Glowacka, J. Turkiewicz, I.I. Zalyubovsky et al., *Nucl. Phys. A* 609 (1996) 147
- 1996ST25 G.F. Steyn, S.V. Fortsch, J.J. Lawrie, F.D. Smit, R.T. Newman, A.A. Cowley and R. Lindsay, *Phys. Rev. C* 54 (1996) 2485
- 1996TA09 M. Tanifuji and H. Kameyama, *Nucl. Phys. A* 602 (1996) 1
- 1996YOZZ T. Yoshimura, A. Okihana, R.E. Warner, N.S. Chant, P.G. Roos, C. Samanta, S. Kakigi, N. Koori, M. Fujiwara, N. Matsuoka et al., *RCNP Osaka Ann. Rept. 1995* (1996) 38
- 1997ABZY S.N. Abramovich, L.N. Generalov, and A.G. Zvenigorodsky, in *Trieste* (1997) 632
- 1997BA72 F.C. Barker, *Phys. Rev. C* 56 (1997) 2646
- 1997BE59 P. Bem, V. Kroha, J. Mares, E. Simeckova, M. Trinova and P. Vercimak, *Few-Body Syst.* 22 (1997) 77
- 1997CH1P L.V. Chulkov, T. Aumann, D. Aleksandrov, L. Axelsson, T. Baumann, M.J.G. Borge, R. Collatz, J. Cub, W. Dostal, B. Eberlein et al., in *Darmstadt* (1997) 4
- 1997CH24 L.V. Chulkov et al., *Phys. Rev. Lett.* 79 (1997) 201
- 1997CS01 A. Csoto and G.M. Hale, *Phys. Rev. C* 55 (1997) 536
- 1997DU15 S.B. Dubovichenko and A.V. Dzhazairov-Kakhramanov, *Fiz. Elem. Chastits At. Yadra* 28 (1997) 1529; *Phys. Part. Nucl.* 28 (1997) 615
- 1997HA15 K. Hatanaka, M. Kawabata, N. Matsuoka, Y. Mizuno, S. Morinobu, M. Nakamura, T. Noro, A. Okihana, K. Sagara, K. Takahisa et al., *Phys. Rev. Lett.* 78 (1997) 1014
- 1997HAZK Y. Han, Q. Shen, and J. Zhang, in *Trieste* (1997) 958
- 1997HAZX Y. Han, Q. Shen, J. Zhang, Z. Zhang and X. Sun, *INDC(CPR)-042/L* (1997) 45
- 1997HAZY Y. Han, Q. Shen, J. Zhang, Z. Zhang and X. Sun, *INDC(CPR)-042/L* (1997) 27

- 1997KO07 T. Kobayashi, K. Yoshida, A. Ozawa, I. Tanihata, A. Korshennikov, E. Nikolsky and T. Nakamura, *Nucl. Phys. A*616 (1997) 223c.
- 1997KOZV T. Kobayashi, A. Ozawa, K. Yoshida, A. Korshennikov, I. Tanihata, E.Y. Nikolsky and T. Nakamura, *RIKEN-96* (1997) 53
- 1997YA08 J. Yan, F.E. Cecil, J.A. McNeil and M.A. Hofstee, *Nucl. Phys. A*621 (1997) 127c.
- 1997YOZQ T. Yoshimura, A. Okihana, R.E. Warner, N.S. Chant, P.G. Roos, C. Samanta, S. Kakigi, N. Koori, N. Fujiwara, N. Matsuoka et al., *RCNP (Osaka) Ann. Rept.* 1996 (1997) 43
- 1998CS02 A. Csoto and G.M. Hale, *Nucl. Phys. A*631 (1998) 783c.
- 1998NO04 T. Noro, T. Baba, K. Hatanaka, M. Ito, M. Kawabata, N. Matsuoka, Y. Mizuno, S. Morinobu, M. Nakamura, A. Okihana et al., *Nucl. Phys. A*629 (1998) 324c.
- 1998PA31 E.A. Pasyuk, C.L. Morris, J.L. Ullman, J.D. Zumbro, L.W. Kwok, J.L. Matthews and Y. Tan, *Acta Phys. Pol. B*29 (1998) 2335
- 1998SO05 N. Soic, D. Cali, S. Cherubini, E. Costanzo, M. Lattuada, D. Miljanic, S. Romano, C. Spitaleri and M. Zadro, *Europhys. Lett.* 41 (1998) 489
- 1998SO26 N. Soic, D. Cali, S. Cherubini, E. Costanzo, M. Lattuada, M. Milin, D. Miljanic, S. Romano, C. Spitaleri and M. Zadro, *Eur. Phys. J. A*3 (1998) 303
- 1998ST07 G.F. Steyn, S.V. Fortsch, A.A. Cowley, S. Karataglidis, R. Lindsay, J.J. Lawrie, F.D. Smit and R.T. Newman, *Phys. Rev. C*57 (1998) 1817
- 1998WE07 H.R. Weller, M.J. Balbes, *Nucl. Instrum. Meth. Phys. Res. A*402 (1998) 428
- 1998YO09 T. Yoshimura, A. Okihana, R.E. Warner, N.S. Chant, P.G. Roos, C. Samanta, S. Kakigi, N. Koori, M. Fujiwara, N. Matsuoka et al., *Nucl. Phys. A*641 (1998) 3
- 1999AN35 C. Angulo, M. Arnould, M. Rayet, P. Descouvemont, D. Baye, C. Leclercq-Willain, A. Coc, S. Barhoumi, P. Auger, C. Rolfs et al., *Nucl. Phys. A*656 (1999) 3
- 1999AO01 S. Aoyama, *Phys. Rev. C*59 (1999) 531
- 1999FI10 G.F. Filippov, A.D. Bazavov and K. Kato, *Phys. At. Nucl.* 62 (1999) 1642; *Yad. Fiz.* 62 (1999) 1763
- 1999GE19 W.H. Geist, C.R. Brune, H.J. Karwowski, E.J. Ludwig, K.D. Veal and G.M. Hale, *Phys. Rev. C*60 (1999) 054003
- 1999HO02 T. Hotta, T. Tamae, T. Miura, H. Miyase, I. Nakagawa, T. Suda, M. Sugawara, T. Tadokoro, A. Takahashi, E. Tanaka and H. Tsubota, *Nucl. Phys. A*645 (1999) 492
- 1999NA05 A. Nadasen, J. Brusoe, J. Farhat, K.A.G. Rao, D. Sisan, J. Williams, P.G. Roos, F. Adimi, T. Gu, M. Khayat et al., *Phys. Rev. C*59 (1999) 760
- 2000AB25 B.M. Abramov, Yu.A. Borodin, S.A. Bulychiev, I.A. Dukhovskoy, A.P. Krutenkova, V.V. Kulikov, M.A. Matsyuk, I.A. Radkevich, E.N. Turdakina and A.I. Khanov, *Pisma Zh. Eksp. Teor. Fiz.* 71 (2000) 524; *JETP Lett.* 71 (2000) 359

- 2000BAZO T. Baba, T. Noda, M. Shimokawa, J. Taguchi, H. Yuki and J. Kasagi, Res. Rep. Lab. Nucl. Sci., Tohoku Univ. 33 (2000) 19
- 2000GO35 O.K. Gorpinich, O.M. Povoroznik, A.P. Pshedzyl and B.G. Struzhko, Bull. Russ. Acad. Sci. Phys. 64 (2000) 82; Izv. Ross. Akad. Nauk. Ser. Fiz. 64 (2000) 100
- 2000HO18 M. Hoefman, L. Aphecette, J.C.S. Bacelar, H. Delagrange, P. Descouvemont, J. Diaz, D. d'Enterria, M.-J. van Goethem, R. Holzmann, H. Huisman et al., Phys. Rev. Lett. 85 (2000) 1404
- 2000MI17 O.V. Miklukho, N.P. Aleshin, S.L. Belostotsky, O.G. Grebenyuk, O.Ya. Fedorov, A. A. Izotov, A.Yu. Kisselev, Yu.G. Naryshkin, V.V. Nelyubin et al., Yad. Fiz. 63 (2000) 894; Phys. At. Nucl. 63 (2000) 824
- 2000MIZU D. Miljanic, S. Blagus, M. Bogovac, M. Milin, D. Rendic, N. Soic, M. Zadro, M. Aliotta, D. Cali, E. Costanzo et al., in Croatia (2000) 241
- 2000OK01 N.T. Okumusoglu and C.O. Blyth, Nucl. Phys. A671 (2000) 33
- 2000SH23 N.B. Shulgina, B.V. Danilin, L.V. Grigorenko, M.V. Zhukov and J.M. Bang, Phys. Rev. C62 (2000) 014312
- 2001DE02 P. Descouvemont and A. Kharbach, Phys. Rev. C63 (2001) 027001