Energy Levels of Light Nuclei
$A = 8$

T. Lauritsen [a] and F. Ajzenberg-Selove [b]

[a] *California Institute of Technology, Pasadena, California*
[b] *University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396*

Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics* 78 (1966), p. 1. This version of $A = 8$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and ntroductory tables have been omitted from this manuscript. Reference key numbers have been changed to the TUNL/NNDC format.

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^{8}He

(Not illustrated)

GENERAL: See (1960GO1B, 1960ZE03, 1961BA1C, 1961LO07, 1961YA04, 1964GO25, 1965BA1A).

Mass of ^{8}*He* : From the systematics of neutron binding energies (1960GO36) and from the calculated mass excess of ^{7}He, the mass excess of ^{8}He is estimated as 31.6 to 32.4 MeV. It is thus stable against ^{6}He + 2n by 1.3 to 2.1 MeV and should exhibit β^--decay to ^{8}Li*(0.98) with E_β(max) $= 9.7$ to 10.5 MeV (1965DE08).

1. ^{8}He(β^-)^{8}Li* $\qquad Q_m \approx 10$

An activity with half-life 30 ± 20 msec, E_β(max) $= 13 \pm 2$ MeV, observed in ^{11}B + γ (320 MeV), is ascribed to ^{8}He (1963NE07). See also (1965PO03).

2. ^{11}B(γ, 3p)^{8}He $\qquad Q_m \approx -45$

At E_γ(max) $= 320$ MeV, the production cross section is > 6 μb (1963NE07).

^{8}Li

(Figs. 11 and 14)

GENERAL: See (1955LA1D, 1956KU1A, 1957FR1B, 1960TA1C, 1962IN02, 1963LO1E, 1963NA1E, 1964BE1N, 1964GR1J, 1964LO1F, 1964ST1B).

Ground state :

$$\mu = +1.6532 \pm 0.0008 \text{ nm: see } ^{7}\text{Li(n, }\gamma)^{8}\text{Li, (1965FU1G).}$$

1. ^{8}Li(β^-)^{8}Be $\qquad Q_m = 16.002$

The beta decay leads mainly to ^{8}Be*(2.9): see ^{8}Be. Reported half-lives are listed in Table 8.2; taking $\tau_{1/2} = 0.849$ sec and $Q = 16.002 - 2.90$, $ft = 4.14 \times 10^5$ (1966BA1A). The distribution of recoil momenta indicates $J^\pi = 2^+$ (see ^{8}Be).

The asymmetry of the β-decay has been exploited as an indicator of ^{8}Li nuclear polarization: see ^{7}Li(n, γ)^{8}Li.

Table 8.1: Energy levels of ^{8}Li

E_x (MeV ± keV)	$J^\pi; T$	Γ (keV)	Decay	Reactions
g.s.	$2^+; 1$	$\tau_{1/2} = 849 \pm 4$ msec	β^-	1, 2, 3, 9, 10, 12, 14, 19, 20, 21
0.975 ± 12	$1^+, 2^+; 1$	$\tau < 0.2$ psec	γ	2, 9, 12
2.258 ± 3	$3^+; 1$	31 ± 5	γ, n	3, 4, 9
3.21	$(1^\pm, 2^+); 1$	≈ 1000	n, n_1	5
(5.0)	$(2^-); 1$	broad	n	4
(6.4)		≈ 2000	n	4
6.53 ± 20	$T = 1$	< 40		16
(8.9 ± 400)	$(1^-, 2^-)$	≈ 4000		14

Table 8.2: The half-life of ^{8}Li

$\tau_{1/2}$ (sec)	Reference
0.89 ± 0.02	(1947HU06)
0.825 ± 0.02	(1951RA12)
0.89 ± 0.01	(1953BU35)
0.875 ± 0.02	(1953BR1B)
0.85 ± 0.016	(1952SH44)
0.84 ± 0.04	(1954WI25)
0.841 ± 0.004	(1954KL36)
0.84 ± 0.02	(1959FA02)
0.88 ± 0.03	(1959IM04)
0.82 ± 0.02	(1962NE14)
0.87 ± 0.02	(1965BE1P)
0.849 ± 0.004	weighted mean

2. ^{6}Li(t, p)^{8}Li $\qquad Q_{\rm m} = 0.803$

Ground-state protons have been observed with $E_{\rm t}$ up to 3.3 MeV: see (1952MO19, 1952PE02, 1954AL35, 1955CU17).

At $E(^{6}{\rm Li}) = 4.5$ MeV, the 0.98 MeV γ-ray has been observed. Doppler shift measurements give $\tau < 0.2$ psec for ^{8}Li*(0.98). The transition is thus dipole in character, with a maximum E2 admixture of 2×10^{-3} in intensity (1965MO1P).

3. ^{7}Li(n, γ)^{8}Li $\qquad Q_{\rm m} = 2.033$

The thermal capture cross section is 37 ± 4 mb (1964ST25); capture γ-rays of energy $E_{\gamma} = 2.02$, 1.06 and 0.96 MeV are reported with intensity ratios 0.8/0.2/0.3 (1961JA19; prelim. values). See also (1959BO1C).

The cross section for capture radiation has been measured for $E_{\rm n} = 40$ to 1000 keV: it decreases from 50 μb at $E_{\rm n} = 40$ keV to 5 μb at 1000 keV. A maximum in the cross section appears at $E_{\rm n} = 250$ keV corresponding to the known resonance in ^{7}Li(n, n); $\Gamma_{\gamma} = 0.07 \pm 0.03$ eV (1959IM04).

Measurement of the asymmetry of β-decay of ^{8}Li produced by capture of polarized neutrons indicate that the thermal capture takes place $> 80\%$ in the $J_{\rm c} = 2$ channel (1959CO68, 1961WA03, 1962AB01). An NMR determination yields $g = 0.8265 \pm 0.0004$ nm/$\hbar$, or with $J = 2$, $\mu = +1.653 \pm 0.0008$ nm (1959CO68, 1962CO08). Shell model calculations give this value with $a/K = 2.1$ (1959KU1E).

4. ^{7}Li(n, n)^{7}Li $\qquad E_{\rm b} = 2.033$

Total cross sections for Li and for ^{7}Li are reported in (1960HU08, 1964ST25). Recent measurements of the total cross section have been reported for $E_{\rm n} = 1$ to 390 keV (1964HI04), 10 to 155 keV (1959BI19), 0.2 to 2.2 MeV (1961LA1A, 1964LA19), 1.5 to 7.5 MeV (1963BA50), 14 MeV (1964AR25), and 18 to 28 MeV (1960PE25). Angular distribution information is summarized in (1963GO1M). See also (1964LA19). A measurement at $E_{\rm n} = 96$ MeV (1960SA25) has been analyzed in terms of the optical model by (1960HO14). See also (1962BA1W, 1963LU10). The thermal cross section is 1.07 ± 0.04 b (1960HU08); the coherent scattering length (thermal, bound) is $a = -2.1$ fm (1964ST25). See also (1961ME02). A pronounced resonance is observed at $E_{\rm n} = 256$ keV with $J = 3^{+}$, formed by p-waves (Table 8.3). Polarization measurements confirm the assignment and indicate that the background s-wave scattering is contributed mainly by channel spin $J_{\rm c} = 2$ (1961DA04, 1962EL01: see also (1961LA1A)) in agreement with earlier results of (1956TH06) but in conflict with (1956WI04). In this case, the coherent scattering length in the $J_{\rm c} = 1$ channel is $a_1 = [+1.2]$, $a_2 = [-3.6]$ fm, suggesting an s-wave, $J^{\pi} = 2^{-}$, resonance at positive neutron energy (1956TH06, 1960LA1C). A good account of the polarization is given by

Table 8.3: ^{7}Li(n, n)^{7}Li resonance parameters [a]

	(1956WI04)	(1956TH06, 1960HU08)
E_{res} (keV)	256	258 ± 3 [c]
Γ (keV)	32	32 [d]
$\Gamma_n(E_r)$ (keV)	35.8	
Γ_γ (eV)(cm)	0.07 ± 0.03 [b]	
γ_n^2 (keV)	351	307
E_λ (keV)	-49	-43
radius (fm)	4.08	4.0
σ_{max} (b)	11.2 [e]	12.0

[a] Energies in laboratory system, except for Γ_γ.
[b] (1959IM04).
[c] $E_{res} = 275$ keV, $\sigma_{max} = 7.0 \pm 0.2$ b (1956GO62).
[d] 35 ± 5 keV (1960HU08).
[e] (1961LA1A).

the assumption of levels at $E_n = 0.25$ and 3.4 MeV, with $J^\pi = 3^+$ and 2^-, together with a broad $J^\pi = 3^-$ level at higher energy (1964LA19). It is noted that the polarization near the $J = 3^+$ resonance is similar in shape to that of ^{7}Li(p, n)^{7}Be at the presumptive mirror level, but opposite in sign (1962EL01). A broad maximum centering at $E_n \approx 5$ MeV may indicate a level at $E_x \approx 6.4$ MeV (1956GO62, 1960HU08, 1963BA50, 1964ST25).

See also (1960PE02, 1962FO1E, 1962OT01, 1963AL1J, 1963GL1E, 1963HA1G, 1963WE20).

5. ^{7}Li(n, n$'$)^{7}Li* $\qquad E_b = 2.033$

The excitation function for 0.48 MeV γ-rays shows an abrupt rise from threshold (indicating s-wave formation and emission) and a broad maximum ($\Gamma \approx 1$ MeV) at $E_n = 1.35$ MeV. The rise above threshold indicates the existence of a $J = 1^-$ level, which may be identified with the 1.35 MeV resonance, if a strong d-wave contribution is included. Other odd parity assignments to this resonance lead to excessive reduced widths. A good fit is obtained with either $J = 1^-$ or 1^+, $\Gamma_{lab} = 1.14$ MeV, $J^\pi = 2^+$ is not excluded (1955FR10). In the range $E_n = 1.5$ to 4 MeV, the cross section for emission of 0.48 MeV γ-rays remains constant at first and then increases to 280 mb at $E_n = 4$ MeV (1963BA50). The cross section for emission of 0.48 MeV γ-rays is ≈ 80 mb ($\pm 12\%$) over the range $E_n = 13.6$ to 14.3 MeV (1962BE35). See also (1963GO1M, 1963MA61).

6. ^{7}Li(n, 2n)^{6}Li $\quad Q_m = -7.253 \quad E_b = 2.033$

The cross section is 27 ± 15 mb at $E_n = 10.2$ MeV and 56 ± 5 mb at 14.1 MeV (1963AS01). See also (1964ST25).

7. ^{7}Li(n, d)^{6}He $\quad Q_m = -7.755 \quad E_b = 2.033$

At $E_n = 14$ MeV, the cross section is 9.8 ± 1.1 mb (1953BA04), 14 ± 1.5 mb (1963BA56).

8. ^{7}Li(n, t)^{4}He + n $\quad Q_m = -2.467 \quad E_b = 2.033$

The cross section rises to 450 mb at $E_n \approx 8$ MeV and thereafter decreases slowly to 300 mb at 15 MeV (1964ST25). The large cross section, comparable to the geometric value, supports the hypothesis that ^{7}Li may be described as an (α + t) cluster (1962RO12). See also (1963AL1J, 1963BA50, 1963BR28, 1964VA19).

9. ^{7}Li(d, p)^{8}Li $\quad Q_m = -0.192$

Observed proton groups indicate levels at 974 ± 15 (1955LE24), 977 ± 20 keV (1955KH35) and at 2.28 MeV (1955LE24, 1960HA14). At $E_d = 3.5$ MeV, no excited states are observed below the 0.97 MeV level with an intensity $> \frac{1}{160}$ of the ground-state group (1961ER01). At $E_d = 15$ MeV, no states observed in the region $2.28 < E_x < 8$ MeV: a limit of 0.6 mb/sr is placed on groups with widths $\lesssim 100$ keV ($\theta = 10°$, $14°$ and $25°$) (1960HA14). See also (1965WA12).

Angular distributions at $E_d = 14$ to 15 MeV have been analyzed by PWBA: see Table 8.4. At low bombarding energies, $E_d = 0.5$ to 4 MeV, angular distributions show striking agreement with simple PWBA theory. The applicability of the theory in this range is ascribed to the proximity of a pole in the stripping cross section when Q and E_d are small (1960SE08, 1960WA1G, 1963SE1F). Analysis in both PWBA and DWBA is reported by (1961HA1G): the latter leads to nearly ten times larger θ_n^2.

The cross section for ^{7}Li(d, p)^{8}Li*(γ)^{8}Li has been measured for $E_d = 1.9$ to 3.3 MeV: no resonances appear. The γ-ray angular distribution, very nearly isotropic for $E_d > 2.3$ MeV, indicates that stripping dominates. If the transition is M1 (see ^{6}Li(t, p)^{8}Li), the 0.97 MeV state has $J = 1^+$ or 2^+: $E_\gamma = 980 \pm 10$ keV (1962CH14).

The polarization of recoil ^{8}Li nuclei has been studied at $E_d = 10$ MeV (1963LE1K).

See also (1959BO1C, 1959HA29, 1959SE1A, 1960PR1D, 1960SE13, 1963AL19, 1963GL1C, 1963SE1G).

Table 8.4: Reduced widths from ^{7}Li(d, p)^{8}Li

E_x in ^{8}Li (MeV)	J^π	l	r_0 [a] (fm)	θ^2_n [a]	r_0 [b] (fm)	θ^2_n [b]	θ^2_n [c]	θ^2_n [d]
0	2^+	1	3.8	0.066	4.2	0.053	$0.038 - 0.07$	$0.49 - 0.60$
0.97	(1^+)	1	3.5	0.040	4.2	0.028		
2.28	3^+	1	3.0	0.012	4.0	0.015		

[a] (1960HA14): PWBA.
[b] (1960MA32): PWBA.
[c] (1961HA1G): PWBA.
[d] (1961HA1G): DWBA.

10. ^{7}Li(t, d)^{8}Li $\quad Q_m = -4.225$

See (1965AJ01).

11. ^{7}Li(α, ^{3}He)^{8}Li $\quad Q_m = -18.546$

Not reported.

12. ^{9}Be(γ, p)^{8}Li $\quad Q_m = -16.885$

At $E_{\rm brems.} = 32$ MeV, transitions are observed to the ground and first excited states of ^{8}Li (1962CU05). See also (1958CH31, 1962NE14, 1963NE02, 1965AL02, 1965KO1B).

13. ^{9}Be(n, d)^{8}Li $\quad Q_m = -14.660$

Not reported.

14. ^{9}Be(p, 2p)^{8}Li $\quad Q_m = -16.885$

At $E_{\rm p}$ = 138 MeV, the cross section of production of 0.98 MeV γ-rays is 2.4 ± 0.4 mb (1961CL09). The summed proton spectrum shows two peaks, corresponding to pickup of protons with binding energies of $\approx 16.7 \pm 0.3$ MeV and 25.8 ± 0.4 MeV ($1p_{\frac{3}{2}}$ and $1s_{\frac{1}{2}}$, respectively) (1958MA1B, 1958TY49, 1962GA23, 1964TI02, 1966TY01). See also ^{9}Be.

15. ^{9}Be(d, ^{3}He)^{8}Li $Q_{\rm m} = -11.391$

See (1954WI25).

16. ^{9}Be(t, α)^{8}Li $Q_{\rm m} = 2.930$

At $E_{\rm t} = 12.98$ MeV, α-particle groups are observed to the ^{8}Li ground state, to the states at 0.98 and 2.26 MeV and to a state at 6.530 ± 0.020 MeV. The width of the 6.53 MeV state is < 40 keV (1965WA12).

17. ^{9}Be(^{7}Li, ^{8}Be)^{8}Li $Q_{\rm m} = 0.367$

See ^{9}Be.

18. ^{10}B(n, ^{3}He)^{8}Li $Q_{\rm m} = -15.754$

Not reported.

19. ^{10}B(p, 3p)^{8}Li $Q_{\rm m} = -23.472$

See (1965BE1P).

20. ^{11}B(γ, ^{3}He)^{8}Li $Q_{\rm m} = -27.210$

See (1963NE07).

21. ^{11}B(n, α)^{8}Li $Q_{\rm m} = -6.632$

See (1959SA04) and ^{12}B.

^{8}Be

(Figs. 12 and 14)

GENERAL: See (1956KU1A, 1957FR1B, 1958WI1E, 1959BA1F, 1959BA1D, 1959BR1E, 1959WI1B, 1960BI1E, 1960KU05, 1960PE11, 1960PH1A, 1960PH1C, 1960TA1C, 1961BA1E, 1961CL10, 1961VA17, 1962IN02, 1962IN1A, 1962IW1A, 1963BR1N, 1963BU1C, 1963DA1C, 1963FR1G, 1963KU03, 1963MA1E, 1963MO1H, 1963NA1E, 1963SH1G, 1964AM1D, 1964BA1Y, 1964BE1N, 1964BE1M, 1964BR1H, 1964DA1G, 1964DU1D, 1964GR1J, 1964MA1G, 1964VO1B, 1965BA2H, 1965BE1H, 1965MA2B, 1965MA1G, 1965NE1C, 1965TR1B, 1965YU1D).

Table 8.5: Energy levels of ^{8}Be

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	Decay	Tables	Reactions
g.s.	6.8 ± 0.6 eV	$0^+; 0$	α	6, 8	1, 4, 12, 13, 14, 15, 16, 23, 24, 25, 26, 28, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 42, 45, 46, 50, 51
2.90 ± 30	1450 ± 60	$2^+; 0$	α	6, 8, 9	4, 13, 14, 15, 16, 23, 24, 26, 28, 29, 30, 31, 32, 33, 34, 37, 39, 42, 44, 45, 50
11.4 ± 300	≈ 7000	$4^+; 0$	α	8	4, 13, 14, 23, 32, 34
16.628 ± 5	97 ± 11	2^+	α	6, 8, 11, 16	4, 13, 15, 23, 29, 30, 32, 34, 39, 45
16.923 ± 6	83 ± 10	2^+	α	6, 8, 11	4, 13, 15, 23, 34, 39, 45
17.638 ± 2	10.7 ± 0.5	1^+	p, γ	6, 11, 12, 14, 16	13, 15, 16, 18, 23, 24, 34, 45
18.153 ± 5	147	1^+	p, γ	6, 12, 14, 16	15, 16, 18, 19, 23
18.9	> 500	2^-	p, n	13	17, 32
19.05 ± 20	270 ± 20	(3)	p, γ	6, 12, 14	16, 18, 27
19.22	190	3^+	p, n	13, 14	17, 18
19.9	≈ 1000	2^+; (0)	p, α	15	22
(19.9)	> 1000	(1^+)	p, n	13	17
20.36	1160	(1^-)	p, n	13	17
20.9 ± 200	1570 ± 180	4^-	p	14	19
21.5	1000	(3^+)	p, n	13	17
21.6	≈ 5000	(1^-)	p, γ	6, 12	16
22.5	(800)	2^+; (0)	p, d, α, (n), (γ)	10, 12, 14, 15	6, 7, 11, 15, 16, 18, 22

Table 8.5: Energy levels of ^{8}Be (continued)

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$J^{\pi}; T$	Deacy	Tables	Reactions
23.		(4^+)	p, α	15	22, 32
23.6	≈ 5000	$(1^-, 2^-)$	p, γ	6, 12	16
(24.0)	(1360)	$(0^-; 0)$	d, α	10	11
25.2	(270)	2^+	d, α, p	10, 15	7, 11, 22
(28.5)	≈ 20 MeV	6^+; (0)	α	8	3
(57)	≈ 73 MeV	8^+; (0)	α	8	4

1. ^{8}Be → ^{4}He + ^{4}He $\qquad Q_m = 0.095$

The weighted mean of direct Q determinations to 1957 is $Q = 94.1 \pm 0.7$ keV (1957VA11). Reported widths are 4.5 ± 3 eV (1956RU41), 6.8 ± 0.6 eV (1962BA1C), ≤ 3.5 eV (1956HE57), > 0.1 eV (1955TR03): see Table 8.8. (1966BE05) find $Q = 92.12 \pm 0.05$ keV, $\Gamma = 6.8 \pm 1.7$ eV.

2. ^{4}He(α, n)^{7}Be $\qquad Q_m = -18.991 \qquad E_b = -0.095$

At $E_\alpha = 39$ MeV, $\sigma < 0.7$ mb (1952WA31).

3. ^{4}He(α, p)^{7}Li $\qquad Q_m = -17.347 \qquad E_b = -0.095$

See ^{7}Li.

4. ^{4}He(α, α)^{4}He $\qquad E_b = -0.095$

Reported differential cross section measurements are cited in Table 8.7. The course of the derived phase shifts with increasing energy from $E_\alpha = 0.15$ to 120 MeV is exhibited in (1956RU41, 1958NI05, 1960JO03, 1963TO02, 1965DA1A).

The s-wave phase shift, δ_0, decreases smoothly from $180°$ at 0.3 MeV. The absence of measurable effects in the range $E_\alpha = 0.15$ to 0.2 MeV yields an upper limit of 3.5 eV on the width of the ground state (1956HE57). Analysis of the $0 - 6$ MeV data leads to $\Gamma(\text{g.s.}) = 4.5 \pm 3$ eV (1956RU41), 6.8 ± 0.6 eV (1962BA1C): see Table 8.8.

Table 8.6: Electromagnetic transitions in ^{8}Be

Transition	Remarks	References
$16.6 \rightarrow 2.9$ $16.9 \rightarrow 2.9$	$\Gamma(\mathrm{M1}) = 1.9 \pm 0.6$ eV	(1962NO02: (^{8}Li, ^{8}B))
$17.6 \rightarrow$ g.s.	$\Gamma(\mathrm{M1}) = 16.7$ eV	(1949FO18, 1961ME10)
$17.6 \rightarrow 2.9$	$\Gamma(\mathrm{M1}) = 8.2$ eV, $\Gamma(\mathrm{E2}) = 0.15$ eV	(1961ME10)
$17.6 \rightarrow 16.6$	$\sigma(\mathrm{p}, \gamma) = 6.5\ \mu$b	(1965WI07, 1965WIZZ)
$17.6 \rightarrow 16.9$	$\sigma(\mathrm{p}, \gamma) = 0.4\ \mu$b	(1965WI07, 1965WIZZ)
$18.15 \rightarrow$ g.s.	$\Gamma \approx 1.8$ eV	(1954KR06, 1960MA23)
$18.15 \rightarrow 2.9$	$\Gamma \approx 3.6$ eV	(1954KR06, 1960MA23)
$19.05 \rightarrow 2.9$		(1957NE22, 1963PE15)
$21.6 \rightarrow$ g.s.	E1 giant res.: $\int \sigma \mathrm{d}E = 22$ MeV · mb	(1963MI08, 1963RE09)
$23.6 \rightarrow 2.9$	E1 giant res.	(1963MI08, 1963RE09)

Table 8.7: Measurements of $\mathrm{d}\sigma/\mathrm{d}\Omega$ in ^{4}He(α, α)^{4}He

E_α (MeV)	References	E_α (MeV)	References
$0.15 - 3.0$	(1956HE57)	$23 - 38$	(1959BR71)
$3.0 - 6.0$	(1956RU41)	$23 - 51$	(1964SH19)
$4.0 - 12.0$	(1963TO02)	30	(1951GR45, 1952GR1A)
$5.0 - 9.0$	(1960JO03)	33.5, 35.5	(1961CH09)
$6.4 - 7.8$	(1960BE05, 1961DU01)	38.5	(1957BU13)
$10 - 20$	(1964WE1C)	$37 - 47$	(1960CO04, 1964CO1D, 1964CO27)
$12.3 - 22.9$	(1956NI20)	51	(1964VA1J)
$12.9 - 21.6$	(1953ST52)	$53 - 120$	(1965DA1A)
20, 20.4	(1951BR92, 1951MA1B)		

The d-wave phase shift becomes appreciable for $E_\alpha > 2.5$ MeV and passes through resonance at $E_\alpha = 6$ MeV ($J = 2^+$, $E_x = 3.18$ MeV, $\Gamma = 1.5$ MeV). The g-wave shift rises from $E_\alpha \approx 11$ MeV and indicates a broad $J^\pi = 4^+$ level at $E_x = 11.4$ MeV. The $l = 6$ and $l = 8$ phase shifts become active above $E_\alpha \approx 30$ and 50 MeV respectively. Dispersion formula fits are somewhat unsatisfactory, but indicate $J^\pi = 6^+$ and 8^+ levels at $E_x \approx 28$ and ≈ 57 MeV respectively. Both the excitation energies and the reduced widths for all five levels are approximately proportional to $J(J + 1)$ (1965DA1A).

Sharp oscillations in the excitation functions at $15°$ and $45°$ are observed corresponding to ^{8}Be*(16.6) and (16.9). Since no oscillations were observed at $27.8°$, these states are assigned $J^\pi = 2^+$ (1964SH19).

Optical model analysis of α-α scattering is discussed by (1960IG02, 1965DA1A); analysis in terms of two-nucleon forces is given by (1959VA1F, 1961SC1B). See also (1959BU07, 1959WI1F, 1960BI1E, 1961GO1T, 1961SH1F, 1962IG1B, 1962SH1F, 1963WI1H, 1964EN1C, 1965OK1B).

5. ^{6}Li(d, γ)^{8}Be $\qquad Q_m = 22.280$

Not observed: (1953SA1A, 1954SI07).

6. (a) ^{6}Li(d, n)^{7}Be $\qquad Q_m = 3.384 \qquad E_b = 22.280$
   (b) ^{6}Li(d, n)^{4}He + ^{3}He $\qquad Q_m = 1.797$

The yield curve has been measured for $E_d = 0.06$ to 5.5 MeV (1952BA64, 1954HI34, 1956NE13, 1957SL01). A broad s-wave resonance is indicated at $E_d = 0.41$ MeV, $\Gamma = 0.45$ MeV (1952BA64, 1956NE13). The forward cross section rises from ≈ 22 mb/sr at $E_d = 1.1$ MeV to ≈ 57 mb/sr at 5.5 MeV without sharp resonances (1957SL01). Above $E_d = 0.6$ MeV, angular distributions indicate a strong admixture of stripping process (1956NE13).

Comparison of the yields n_0/n_1 (^{7}Be(0) and ^{7}Be*(0.43)) and p_0/p_1 (^{7}Li(0) and ^{7}Li*(0.48)) over the energy range $E_d = 0.4$ to 3.2 MeV shows that the angular distributions are closely similar for n and p. The yield ratios are also closely equal over this range, consistent with the assumption of charge symmetry. The ratio n_0/n_1 increases rapidly as E_d falls below 0.8 MeV, suggesting a change in the reaction mechanism there (1957WI24, 1963BI27, 1963CR08).

7. (a) ^{6}Li(d, p)^{7}Li $\qquad Q_m = 5.028 \qquad E_b = 22.280$
   (b) ^{6}Li(d, p)^{4}He + ^{3}H $\qquad Q_m = 2.561$

Cross sections and angular distributions have been measured for $E_d = 30$ keV to 5.4 MeV (1959AJ76, 1963BI27, 1963ME09, 1964PA06). A broad maximum near $E_d = 1.0$ MeV is interpreted as indicating a level at $E_d = 0.4$ MeV (1950WH02). In the range $E_d = 1$ to 5 MeV there

Table 8.8: ^{8}Be parameters from ^{4}He(α, α)^{4}He

E_x (MeV)	J^π	$\Gamma_{c.m.}$	R (fm)	θ^2	References
g.s.	0^+	4.5 ± 3 eV [a]	5.7	0.15	(1956RU41)
			4.4	[0.40]	(1958NI05)
		6.8 ± 0.6 eV	3.5	1.7	(1962BA1C)
		$\lesssim 3.5$ eV			(1956HE57)
		6.8 ± 1.7 eV			(1966BE05)
2.9	2^+	2 MeV	5.0	0.7	(1956RU41)
3.1			3.5	1.32	(1960JO03)
3.18		1.5 MeV	3.5	1.27	(1963TO02)
3.13		1.8 MeV	3.5	2.46	(1962BA1C)
11.8	4^+		4.4	1.3	(1958NI05)
11.4 ± 0.3					(1959BR71)
11.3 ± 0.4					(1962CE01) [b]
≈ 14					(1960IG02)
16.6	2^+				(1964SH19)
16.9	2^+				(1964SH19)
≈ 28.5	6^+	≈ 20 MeV	≈ 4.5	≈ 1.8	(1964DA12, 1965DA1A)
≈ 57	8^+	≈ 73 MeV	4.5	≈ 4.1	(1964DA12, 1965DA1A)

[a] See also (1962BA1C).
[b] From ^{6}Li(α, d)^{8}Be.

is evidence for both direct interaction and compound nucleus formation (1963BI27, 1963ME09, 1964PA06): at back angles the (d, p_1) data show evidence of the $E_d = 3.7$ MeV resonance (see ^{6}Li(d, α)^{4}He). See also ^{6}Li(d, n)^{7}Be and (1964FE01).

8. ^{6}Li(d, d)^{6}Li $E_b = 22.280$

Excitation functions have been measured for $E_d = 2$ to 4.8 MeV; they do not show any clear resonance behavior (1964PA06). See also ^{6}Li.

9. ^{6}Li(d, t)^{5}Li $Q_m = 0.595$ $E_b = 22.280$

Table 8.9: Parameters of ^{8}Be*(2.9) [a]

E_x (MeV)	$\Gamma_{c.m.}$ (MeV)	R (fm)	γ^2 (MeV)	θ^2 [b]	Reaction	Reference
(3.18)	1.5	3.5	3.36	1.27	^{4}He(α, α) [c]	(1963TO02)
		4.48	2.65	3.4	^{7}Li(p, $\gamma\alpha$)	(1960GE07)
2.6 ± 0.15	0.7 ± 0.1				^{7}Li(p, γ)	(1963BA58)
3.1 ± 0.1	1.75 ± 0.1				^{7}Li(d, n)	(1964JO04)
	1.6 ± 0.4				^{7}Be(d, p)	(1959SP1A)
2.90 ± 0.06	1.53 ± 0.04	5.75	0.60	0.64	^{7}Be(d, p)	(1960KA17)
2.8 ± 0.1	0.8				^{9}Be(d, t)	(1955CU16)
	1.35 ± 0.15	5		0.082	^{9}Be(d, t)	(1959VL24)
2.90 ± 0.04	1.35 ± 0.15				^{9}Be(^{3}He, α)	(1963DO08)
3.06		5.5	0.62	0.60	^{10}B(d, α)	(1963PU02)
2.88 ± 0.08		4.48	3.0	≈ 2	^{10}B(d, α)	(1953TR04)
2.895 ± 0.028	1.45 ± 0.06				mean	

[a] Spectra from several reactions – e.g. ^{8}Li(β^-, α), ^{8}B(β^+, α), ^{11}B(p, α), ^{9}Be(p, d) – are reported "consistent with phase shifts of ^{4}He(α, α) scattering" and so support the parameters of Table 8.8.

[b] Units of $\frac{3}{2}(\hbar^2/\mu R^2)$.

[c] See Table 8.8.

The cross section for tritium production rises rapidly to 190 mb at 1 MeV, then more slowly to 290 mb near 4 MeV. There is evidence of deviation from isotropy near 0.4 MeV (1955MA20). See also ^{5}Li.

10. ^{6}Li(d, ^{3}He)^{5}He $\qquad Q_m = 0.839 \qquad E_b = 22.280$

See ^{5}He.

11. ^{6}Li(d, α)^{4}He $\qquad Q_m = 22.375 \qquad E_b = 22.280$

Cross sections and angular distributions have been measured for $E_d = 0.03$ to 12 MeV (1948HE01, 1950WH02, 1962HA15, 1962JE02, 1963AN10, 1963ME09, 1964MA2D, 1964PA06, 1965MA13). Maxima are observed at $E_d = 0.8$ MeV, $\Gamma_{lab} \approx 0.8$ MeV, and $E_d = 3.75$ MeV,

Table 8.10: Levels of ^{8}Be from ^{6}Li(d, α)^{4}He [a]

E_{res} (MeV)	E_λ(c.m.) (MeV)	E_x (MeV)	$\Gamma_{c.m.}$ [b] (MeV)	J^π	θ_d^2	θ_α^2
0.8	0.26	22.54	0.80	2^+	0.23	0.003
	1.74	24.02	1.36	0^+	0.75	0.09
3.75	2.95	25.23	0.27	2^+	0.025	0.022

[a] (1965FR02).
[b] Partial width, $\Gamma_{\lambda\lambda}$.

$\Gamma_{lab} \approx 1.4$ MeV. Analysis of the angular distributions in terms of two-level interference favors $J^\pi = 2^+$ for the upper level, and $J^\pi = 0^+$ or 2^+ for the lower (1963ME09, 1964PA06). The upper level appears to have a large deuteron width, $\theta_d^2 \approx 0.2$, and small $\theta_\alpha^2 \approx 0.025$ and $\theta_p^2 < 0.005$ (1964PA06). A more elaborate analysis appears to require that both levels, $E_x = 22.54$ and 25.23 MeV, have $J^\pi = 2^+$ and that a third broad $J^\pi = 0^+$ level exist at $E_x = 24.02$ MeV (1965FR02): see Table 8.10. The same parameters give a good account of the data up to $E_d = 9.5$ MeV. There is no evidence of further resonances (1965MA13). See also (1959HA29, 1960HA14, 1963EL1D, 1963FR1G, 1964FE01).

12. ^{6}Li(t, n)^{8}Be $\qquad$ $Q_m = 16.023$

See (1959AJ77, 1962SE1A).

13. ^{6}Li(^{3}He, p)^{8}Be $\qquad$ $Q_m = 16.787$

At $E(^3\text{He}) = 1.2$ to 2 MeV, proton groups are reported corresponding to ^{8}Be(0), ^{8}Be*(2.9) and possibly ^{8}Be*(12.3) (1956MO19, 1956SC01). At $E(^3\text{He}) = 3.5$ to 4.2 MeV, groups with $Q = 0.163$, -0.143 and -0.854 MeV (± 10 keV) are observed, corresponding to the 16.6, 16.9 and 17.6 MeV states (1961ER01): see Table 8.11.

The differential cross sections for ground-state protons show backward peaking at $E(^3\text{He}) = 5$, 6 and 7 MeV, forward peaking at $E(^3\text{He}) = 13$ and 17 MeV, and both forwards and backward peaks in the intermediate region (1963MA02). Analysis of the angular distribution of protons leading to the $E_x = 16.6$ MeV level indicates stripping, with $L = 0$ and a large deuteron width (1963MO1K, 1964MO1L). See also (1963WE1B, 1965KA1F, 1965RO1R, 1965YO1D).

14. ^{6}Li(α, d)^{8}Be $\qquad$ $Q_m = -1.567$

Table 8.11: ^{8}Be levels near 16 MeV

E_x [a] (MeV $\pm$ keV)	Γ (keV)	Reaction	Reference
16.624 ± 10	95 ± 20	^{6}Li(^{3}He, p)^{8}Be	(1961ER01)
16.627 ± 15	105 ± 30	^{9}Be(^{3}He, α)^{8}Be	(1961ER01)
16.635 ± 15	96 ± 20	^{9}Be(^{3}He, α)^{8}Be	(1963DO08)
16.623 ± 10	95 ± 20	^{10}B(d, α)^{8}Be	(1961ER01)
16.64 ± 15		^{7}Li(d, n)^{8}Be	(1960DI02)
16.67	190	^{7}Li(d, n)^{8}Be	(1957SL01)
16.4 ± 200	< 400	^{12}C(γ, α)^{8}Be	(1955GO59)
16.628 ± 5	97 ± 11	mean	
16.930 ± 10	85 ± 20	^{6}Li(^{3}He, p)^{8}Be	(1961ER01)
16.914 ± 12	88 ± 25	^{9}Be(^{3}He, α)^{8}Be	(1961ER01)
16.930 ± 15	80 ± 15	^{9}Be(^{3}He, α)^{8}Be	(1963DO08)
16.919 ± 10	85 ± 20	^{10}B(d, α)^{8}Be	(1961ER01)
16.9 ± 50		^{7}Li(d, n)^{8}Be	(1960DI02)
16.8 ± 200	< 300	^{12}C(γ, α)^{8}Be	(1955GO59)
16.923 ± 6	83 ± 10	mean	
17.641 ± 10	< 20	^{6}Li(^{3}He, p)^{8}Be	(1961ER01)
17.636 ± 10	< 15	^{9}Be(^{3}He, α)^{8}Be	(1961ER01)
17.641 ± 10		^{9}Be(^{3}He, α)^{8}Be	(1963DO08)
17.61	< 20	^{7}Li(d, n)^{8}Be	(1957SL01)
17.639 ± 6		mean	

[a] Based on listed Q_{m}.

At $E_\alpha = 43$ MeV, deuteron groups corresponding to ^{8}Be(0) and ^{8}Be*(2.9) are reported (1959ZE1A); at $E_\alpha = 48$ MeV, an additional group ascribed to ^{8}Be*(11.3 ± 0.4) is observed (1962CE01). Angular distributions of d_0 and d_1 show forward peaking, with that of d_0 exhibiting pronounced oscillatory characteristics. Attempts to fit the observations with direct interaction theory are only moderately successful (1959ZE1A, 1962CE01). See also (1959ST30, 1962KO13, 1963BL20, 1963DE1G, 1963DE29, 1963WE1B, 1964DE1K).

15. ^{6}Li(^{6}Li, α)^{8}Be $\qquad Q_m = 20.808$

In addition to α-groups to the ground and 2.9 MeV states, there is evidence for a cluster reaction mechanism in which ^{6}Li combines with a deuteron cluster to produce a state of ^{8}Be at 20.95 ± 0.3 MeV, $\Gamma = 3.4$ MeV. At $E(^6\text{Li}) = 1.9$ MeV, the cross section is 1.3 mb, or 23 times that for ground-state alpha particles (1963KA20). On the other hand (1964QU01) find that the α-particle spectrum is consistent with the involvement of a ^{8}Be level near 22 MeV, with $\Gamma \approx 0.4$ MeV. See also (1962CO05). The ^{8}Be state decays by proton and α emission: $\Gamma_p/\Gamma_\alpha = 1.64$ (1962GA21). At $E(^6\text{Li}) = 3.2$ MeV, alpha groups corresponding to ^{8}Be* $= 16.6$, 16.9, (17.6), 18.15 MeV are reported (1964CA1G). See also (1960SH01, 1962CO21, 1963LE19, 1963TA1B, 1964GA1E, 1964SH05, 1965MA2A, 1965NO1A).

16. ^{7}Li(p, γ)^{8}Be $\qquad E_b = 17.252$

Cross sections and angular distributions have been reported from $E_p = 30$ keV to 14.5 MeV. Two γ-rays are observed, γ_0 to the ground state and γ_1 to the broad, 2^+, excited state at 2.9 MeV: $E_\gamma = (17.2,\ 14.3) + \frac{7}{8}E_p$. Resonances for both γ_0 and γ_1 occur at $E_p = 0.44$ and 1.03 MeV, and for γ_1 alone at 2 MeV (see, however, (1963PE15)): see Table 8.12. In the range $E_p = 2.5$ to 9 MeV, broad resonances are reported at $E_p \approx 5$ MeV (γ_0), $\Gamma \approx 5$ MeV (1959GE33, 1963MI08, 1963PE15 ($\Gamma = 5.5$ MeV)), at $E_p \approx 7.3$ MeV (γ_1), $\Gamma \approx 8$ MeV, and possibly at $E_p \approx 6$ MeV (γ_1). The $E_p \approx 5$ MeV resonance ($E_x \approx 21.6$ MeV) is presumed to represent the giant dipole resonance based on ^{8}Be(0), while the γ_1 resonance, 2.0 ± 0.5 (1963MI08), 3 ± 0.5 MeV (1963RE09) higher is similarly related to ^{8}Be*(2.9). Angular distributions from $E_p = 2.0$ to 7.5 MeV are approximately isotropic (except at 2.59 MeV), suggesting $l = 0$ capture (1963MI08, 1963PE15). The integrated (γ, p) cross section, determined by reciprocity is 22 ± 4 MeV · mb (1963RE09), 20 MeV · mb (1964TA05). See also (1965TA1E).

Angular distributions near the $E_p = 0.44$ MeV resonance show strong $\cos\theta$ interference terms which vanish at resonance. At resonance the radiation is nearly isotropic, consistent with p-wave formation, $J^\pi = 1^+$, with channel spin ratio $\sigma(J_c = 2)/\sigma(J_c = 1) = 5$. A detailed study of the angular distributions of γ_0 and γ_1 yields a small $\cos^2\theta$ term for γ_0: $A_2 = 0.067 \pm 0.025$ (1961ME10), $A_2 = 0.028 \pm 0.003$ (1958NE17, 1961BR02), while γ_1 is isotropic: $A_2 = -0.004 \pm 0.008$ (1961ME10); see, however, (1958NE17, 1961BR02). Analysis of these data together with γ-α correlations leads to Γ(E2)/Γ(M1) for $\gamma_1 = 0.018 \pm 0.009$ (1961ME10), 0.044 ± 0.014 (1960GR21).

Table 8.12: ^{8}Be levels from ^{7}Li(p, γ)^{8}Be

E_{res} (keV)	Γ_{lab} (keV)	^{8}Be*	l_p	J^π	σ_{max} (mb)	γ_0/γ_1	$w\Gamma_\gamma$ (eV)	References
441.4 ± 0.5 [a]	12.2 ± 0.5	17.64	1	1^+	6.0	1.9	9.4	(1949FO18, 1956BU27)
1030 ± 5	168	18.15	1	1^+		0.54	2	(1954KR06, 1960MA33, 1963RI09)
2060 ± 20	310 ± 20	19.05		(-) [d]	γ_1 only			(1957NE22, 1963PE15, 1963RI09)
5000	≈ 5000	21.6	(0)	(1^-)	0.05 [b]	0.5	[c]	(1959GE33, 1963MI08, 1963PE15)
(6000)		(22.5)			(γ_1)	0.3		(1963MI08)
7300	≈ 5500	23.6	(0)	$(1^-, 2^-)$	(γ_1)	0.2		(1963MI08, 1963PE15)

[a] See (1959AJ76).
[b] γ_0 only (1964TA05).
[c] $\int \sigma(\mathrm{p}\gamma_0) = 0.37 \pm 0.15$ MeV · mb (1963RE09).
[d] (1964SC19).

With $\Gamma_\gamma = 25$ eV, one obtains $\Gamma(\gamma_0) = 16.7$ eV, $\Gamma(\gamma_1$, M1$) = 8.15 \pm 0.07$ eV, $\Gamma(\gamma_1$, E2$) = 0.15 \pm 0.07$ eV. The observed E2 strength is about 15 times smaller than predicted by intermediate coupling shell model (1961ME10). See (1957KU58). The channel spin mixture $\sigma(2)/\sigma(1)$ is 3.2 ± 0.5 (1961ME10), 4.1 ± 0.1 (1958NE17).

The relative intensity of γ_0/γ_1 at resonance is 2.0 (1961ME10), 2.3 ± 0.04 (1960MA23: $\theta = 90°$), 1.8 ± 0.2 (1963BA58); the ratio falls rapidly above resonance and is approximately constant at 0.54 ± 0.08 for $E_p = 0.8$ to 1.0 MeV (1960MA23: see also (1961BR02)). There is evidence for an increase in the ratio at $E_p = 1.03$ MeV (1964SC19). At $E_p = 5.4$, 6.5, 7.5 and 8.6 MeV, the ratios are 0.5 ± 0.07, 0.3 ± 0.04, 0.2 ± 0.04 and 0.2 ± 0.04, respectively (1964TA05). Angular distributions in the range $E_p = 0.2$ to 1.1 MeV indicate interference with s-wave and d-wave non-resonant radiation (1960MA33: see also (1961BR02)); at $E_p = 1.03$ MeV the resonant radiation is isotropic, suggesting p-wave, $J = 1^+$, $\sigma(2)/\sigma(1) = 5$ (1960MA33).

Angular distributions from $E_p = 0.8$ to 1.7 MeV appear to require interference of the $E_p = 0.44$ and 1.03 (1^+) MeV levels with at least two odd-parity levels, possibly those at $E_p = 2.1$ and 5.8 MeV (1964SC19).

A pair-spectrometer measurement yields $E_\gamma = 17.647 \pm 0.015$ MeV for γ_0 at the $E_p = 440$ keV resonance: from the spectrum of γ_1 an excitation energy of $E_x = 2.6 \pm 0.15$, $\Gamma = 0.7 \pm 0.1$ MeV is obtained for the first excited state (1963BA58). See Table 8.9.

At $E_p = 440$ keV, α-particles from ^{8}Be*(16.63) are observed, indicating the existence of the γ-transition ^{8}Be*($17.64 \to 16.63$). The total resonant cross section is 6.45 ± 0.7 μb (1965WIZZ). The coincidence spectrum at resonance shows the 1.02 MeV γ-ray ($17.64 \to 16.63$), and a weak branch (5.9 ± 2)% (1965WI07), (7.5 ± 2)% (1965KO05), to the 16.92 MeV state. There is no indication of resonance in the yield of α-particles from ^{8}Be*(16.6) at $E_p = 1.03$ MeV (1965WI07). Evidence from this and other reactions involving ^{8}Be*(16.6) and (16.9) indicates that neither has a pure isospin character (1965KO05, 1965MA1G). See also (1964PA13).

A careful study of γ-α coincidence spectra at $E_{\rm p} = 441$ keV reveals only the 2.9 MeV level in the range $E_{\rm x} = 2$ to 7 MeV; the α-spectra can be matched with a single-level dispersion formula with $E_\lambda = 5.95$ MeV, $\gamma_\alpha^2 = 11.9$ MeV · fm, $\theta^2 = (1.7)$, $R = 4.48$ fm (1960GE07). A report of other γ-α groups by (1962CA13) is ascribed to contamination (1964MA25, 1964MI10, 1964PR04, 1964WE1C).

For a review of earlier work, see (1959AJ76). See also (1960SI10, 1960SI1D, 1963FE03, 1963SC1N, 1963TR08)

17. ^{7}Li(p, n)^{7}Be $\quad$ $Q_{\rm m} = -1.644$ $\quad$ $E_{\rm b} = 17.252$

This reaction is widely used as a source of monochromatic neutrons: see summary by (1960GI1A). The threshold is $E_{\rm p} = 1880.36 \pm 0.22$ keV (1963MA1R: see ^{7}Be); a second threshold, for neutrons leading to ^{7}Be*(0.43), occurs at $E_{\rm p} = 2376 \pm 2$ keV (1960MA1G), and above $E_{\rm p} = 7$ MeV, neutrons corresponding to ^{7}Be*(4.55) may be produced (1963BO06).

Reaction cross sections and angular distributions have been reported by (1948TA16: to 2.55 MeV), (1964BU08: 2.4 to 3.0 MeV; n_1), (1957NE22, 1958MA07: to 5.5 MeV), (1959GA08: to 3.25 MeV), (1961BE05: 2.6 to 4.2 MeV; n_0 and n_1 groups separately), (1961NI04: 2.7 to 3.5 MeV), (1963BO06: 3 to 13 MeV; n_0, n_1, n_2), (1964BA16: 4 to 14 MeV) and by (1960HI04: 8 to 14 MeV; n_0, n_1, n_2). See also (1959AJ81, 1960GI1A, 1962AU01, 1963PA1K). The yield of ground state neutrons (n_0) rises steeply from threshold and shows pronounced resonances at $E_{\rm p} = 2.25$ ($\sigma \approx 0.57$ b) and 4.9 MeV ($\sigma \approx 0.36$ b) (1963BO06). The yield of n_1 also rises steeply from threshold (1964BU08) and exhibits a broad maximum near $E_{\rm p} = 3.5$ MeV (1961BE05).

The behavior of the cross section near the n_0 threshold indicates a broad resonance with $J^\pi = 2^-$, $T = (0)$, $(l = 0)$ at $E_{\rm p} = 1.9$ MeV with $\gamma_{\rm n}^2/\gamma_{\rm p}^2 \approx 5.0$ (Table 8.13). The structure at $E_{\rm p} = 2.25$ MeV is ascribed to a 3^+, $T = (1)$, $l = 1$ resonance with $\Gamma_{\rm n} \sim \Gamma_{\rm p}$ and $\gamma_{\rm n}^2/\gamma_{\rm p}^2 = 3$ to 10 (1957NE22, 1958MA07, 1959WE1A, 1960GI1A, 1961BE05). The broad peak at 4.9 MeV can be fitted by $J^\pi = 3^{(+)}$ with $\Gamma = 1.1$ MeV, $\gamma_{\rm n}^2 \sim \gamma_{\rm p}^2$ (1963BO06). An additional resonance at $E_{\rm p} = 3.0$ MeV may be indicated (1957NE22, 1961BE05). The behavior of the n_1 cross section can be fitted in terms of a single level with $J^\pi = 1^-$ at $E_{\rm p} = 3.55$ MeV (1964BU08).

Polarization of the neutrons has been measured by (1961DA04, 1962EL01: 2.0 to 2.4 MeV), (1959CR84: 3.5 to 5 MeV), (1961AU02: 2 to 3 MeV), (1965MO1L: 3.1 to 3.3 MeV), (1965AN09: 3.0 to 4.0 MeV), (1959BA34, 1960BA27: 3 to 6 MeV), (1963MI01, 1963MI06, 1963MI20, 1964MI14: 4 to 5 MeV), (1962BE11: 4 to 10 MeV) and others (1959AJ76, 1963HA1G). Dominant effects are ascribed to the narrow 3^+ level at $E_{\rm p} = 2.25$ MeV and a broad 2^- background level. At least one level is needed near threshold, and at the higher energies ($E_{\rm p} > 2.6$ MeV) two additional levels are indicated (1961AU02).

Neutron spectra and polarizations have been measured at $E_{\rm p} = 143$ MeV by (1962BO33, 1963BO1N). Some contribution from quasi-free scattering is indicated: see (1963VA1C, 1965VA23).

18. ^{7}Li(p, p)^{7}Li $\quad$ $E_{\rm b} = 17.252$

Table 8.13: ^{8}Be levels from ^{7}Li(p, n)^{7}Be

E_p (keV)	Γ_{lab} (keV)	^{8}Be*	l_p	J^π	σ_{max} (b)	γ_n^2/γ_p^2	References
1900	> 500	18.91	0	2^-		≈ 5.0	(1957NE22, 1961BE05)
2250	220	19.22	1	3^+	0.57	5.2	(1957NE22, 1961BE05)
(3000)	> 1000	(19.9)	(1)	(1^+)	(n_0)	(5)	(1957NE22, 1961BE05)
3550	1300	20.36	(0)	(1^-)	(n_1)	5.2	(1961BE05, 1964BU08)
4900	1100	21.5		$3^{(+)}$	0.36	≈ 1	(1959GI47, 1963BO06)

Absolute differential cross sections are reported for $E_p = 0.4$ to 12 MeV (1953WA27, 1956MA12, 1965GL03) and for $E_p = 14.5$, 20.0 and 31.5 MeV by (1956KI54). Anomalies appear at $E_p = 0.44$, 1.03, 1.88, 2.1, 2.5, 4.2 and 6.0 MeV (see Table 8.14). Both the 0.44 and 1.03 MeV resonances are ascribed to p-waves, $J = 1^+$, with channel spins 1 and 2 in a ratio of 1 to 5 (1953CH1A, 1955LI1B: compare ^{7}Li(p, γ)^{8}Be). The structure at $E_p = 2.1$ MeV may indicate a state with $J^\pi \leq 3^+$ (1956MA12), 3^- (1957NE22). The $E_p = 4.2$ MeV resonance is ascribed to an almost pure single-particle level in ^{8}Be at 20.9 MeV (1965GL03).

The polarization of 14.5 and 40 MeV protons scattered from ^{7}Li has been studied by (1962RO20) and (1963HW01). See also (1961RO20).

See also (1961JO17, 1961JO18, 1965AN12) and (1959AJ76).

Table 8.14: ^{8}Be levels from ^{7}Li(p, p)^{7}Li and ^{7}Li(p, p′)^{7}Li*

E_p (keV)	Γ_{lab} (keV)	^{8}Be*	l_p	J^π	$\Gamma_{p'}$ (keV)	References
441	12.2 [b]	17.64	1	1^+		(1953CH1A, 1953WA27)
1030 ± 5	168	18.15	1	1^+	≈ 6	(1954MO04, 1955LI1B)
1880 [a]						(1956MA12, 1957NE22)
2100	≈ 0.4	19.0		(3) [c]	small	(1956MA12, 1957NE22)
2250		19.22		3^+	small	(1956MA12, 1957NE22)
4200 ± 200	1800 ± 200	20.9		4^-	(res)	(1965GL03)
5600		22.2				(1965GL03)

[a] (p, n) threshold.

[b] $\theta_p^2 = 0.064$.

[c] (1957NE22: 3^-), (1956MA12: ≤ 3).

19. ^{7}Li(p, p′)^{7}Li* $E_b = 17.252$

A pronounced resonance appears in the yield of inelastically scattered protons (1951BR10, 1954MO04) and 0.48 MeV γ-rays (1954KR06) at $E_p = 1.03$ MeV (see Table 8.14); it is an s- or p-wave resonance interfering with a non-resonant wave of opposite parity (1954MO04: see also (1955LI1B)). Excitation functions for the proton group to the 0.48 MeV state have been measured for $E_p = 2.3$ to 12 MeV: a peak is observed at 5.6 MeV (1965GL03). See also (1964FA08). The yield of 0.48 MeV γ-rays rises smoothly from $E_p = 1.5$ to 3.0 MeV except for a pronounced cusp at 1.881 MeV (1955HA34, 1957NE22). See also (1962CA13).

20. ^{7}Li(p, d)^{6}Li $Q_m = -5.028$ $E_b = 17.252$

See ^{6}Li.

21. ^{7}Li(p, t)^{5}Li $Q_m = -4.433$ $E_b = 17.252$

See ^{5}Li.

22. ^{7}Li(p, α)^{4}He $Q_m = 17.347$ $E_b = 17.252$

Excitation functions and angular distributions have been reported by (1962LU01: 0.4 to 3.3 MeV), (1948HE01: 0.5 to 3.8 MeV), (1958CO62: 0.1 to 0.6 MeV), (1963SA10: 3.0 to 5.5 MeV), (1962CA12: 1.5 to 4.8 MeV), (1960AL18: 12 MeV), (1961HA27: 2.8 to 12 MeV), (1962TE04, 1962TE07: 3.3 to 6.6 MeV), (1964MA51: 4 to 12 MeV), (1962MA40: 15, 18.6 MeV) and (1962CA13, 1963CA1K: 0.5 to 2.5 MeV; see, however, (1964MA25, 1964MI10)). Polarization effects have been studied by (1964AN08: 0.5 to 2.0 MeV), (1962BE14: 1 to 3.2 MeV), (1964AS04: 2 to 3.5 MeV), (1965BO07: 3.2 to 5.3 MeV).

A broad resonance occurs at $E_p = 3.0$ MeV, $\Gamma \approx 1$ MeV, $\sigma_{max} \approx 90$ mb (1948HE01): see Table 8.15. A second prominent peak appears at $E_p = 5.6$ MeV, $\Gamma \approx 1$ MeV (1961HA27, 1962TE04, 1964MA51). Some structure is reported near $E_p = 6.0$ to 6.5 MeV, and a further peak occurs at $E_p = 9.0$ MeV (1964MA51).

An earlier suggestion that a $J = 0$ resonance near $E_p \approx 0$ is involved appears to be contradicted by polarization data (1962BE14). The states at $E_x = 19.9$ MeV and 22.1 MeV ($E_p = 3.0$ and 5.5 MeV resonances) appear to have $J = 2^+$ (1959AJ76, 1961HA27, 1962TE04, 1962TE07, 1965FR02) and to have ^{6}Li + d parentage (1962TE01, 1965FR02). Levels at $E_x = 23$ MeV ($E_p = 6.5$ MeV) and 25.2 MeV ($E_p = 9.0$ MeV) are assigned $J^\pi = 4^+$ and 2^+, respectively (G. Temmer, private communication).

See also (1960BO13, 1962PE20, 1962WE13, 1963AN09, 1964MA2D).

Table 8.15: ^{8}Be levels from ^{7}Li(p, α)^{4}He

$E_{\rm res}$ (MeV)	Γ (MeV)	^{8}Be*	$J^{\pi}; T$	References
3.0	≈ 1	19.9	$2^{+}; 0$	(1948HE01)
5.6	≈ 1	22.1 [a]	(2^{+})	(1961HA27, 1962TE04, 1964MA51)
6.5		23	(4^{+})	(1961HA27, 1964MA51)
9.0		25.1	(2^{+})	(1964MA51)

[a] Possibly same as $E_{\rm x} = 22.5$ seen in ^{6}Li(d, α): see (1965FR02).

Table 8.16: Slow neutron thresholds in ^{7}Li(d, n)^{8}Be (1957SL01)

$E_{\rm d}$ (MeV)	$\Gamma_{\rm c.m.}$ (MeV)	^{8}Be* (MeV)
1.35	0.31	(16.08)
2.10	0.19	16.66
3.32	< 0.02	17.61
4.08	0.23	18.20

23. ^{7}Li(d, n)^{8}Be $\qquad Q_{\rm m} = 15.028$

For $E_{\rm d} = 3.6$ to 7.3 MeV, neutron time-of-flight spectra indicate states in ^{8}Be at 0, 2.9, 16.64 ± 0.015, 16.9 ± 0.05, 17.64 and 18.15 MeV. Angular distribution of neutrons corresponding to the 16.6, 17.6 and 18.15 MeV states are strongly forward; $l_{\rm n} = 1$ for the 16.6 MeV state, consistent with $J = 2^{+}$ (1960DI02). At $E_{\rm d} = 2$ MeV, recoil proton spectra show only the ground state and $E_{\rm x} = 2.9$ MeV groups; in the range $E_{\rm x} < 9$ MeV, no others appear with intensity > 10% of the ground-state group. The spectrum yields $E_{\rm x} = 3.1 \pm 0.1$, $\Gamma = 1.75 \pm 0.1$ MeV; comparison with the shape calculated from known α-α phase shifts suggest a considerable contribution of three-body processes (1964JO04). Reported slow neutron thresholds are listed in Table 8.16. See also (1964JO1D, 1964JO1F, 1965DI1F).

Alpha-particle spectra indicate groups corresponding to the break up of ^{8}Be*(16.6) and (16.9) (1963BI22, 1963PA04, 1964GL03). Alpha particles attributed to ^{8}Be*(11.4) are also reported (1963PA04). In the range $E_{\rm x} = 15.0$ to 18.5 MeV, no α-emitting states other than the 16.6 and 16.9 MeV levels are observed (1964GL03). See also (1965BI1F, 1965JO19, 1965MA1G, 1965MA1K).

A large number of additional states with $E_{\rm x} < 16.1$ MeV has been suggested in addition to ^{8}Be*(0, 2.9, 11.4): for a listing of early references, see (1959AJ76, 1964JO04). See also (1958CA1E, 1960AG03, 1960JU04, 1963MI1M, 1964MI1J).

24. ^{7}Li(^{3}He, d)^{8}Be $\quad Q_{\rm m} = 11.759$

At $E(^{3}{\rm He}) = 24.3$ MeV, angular distributions of deuterons corresponding to the ground and first excited states of ^{8}Be have been measured (1963WE1B). At $E(^{3}{\rm He}) = 9$ to 10 MeV, excitation of ^{8}Be*(17.6) is observed (1965GR08). See also (1964DU1E).

25. ^{7}Li(α, t)^{8}Be $\quad Q_{\rm m} = -2.562$

The angular distributions of the tritons to the ground state of ^{8}Be have been determined at a number of energies up to 48 MeV; the distributions indicate strong contribution of direct interaction (1959ST1B, 1960GO04, 1960MA15, 1960VL03, 1962MA59, 1963WE1B). At $E_{\alpha} = 40$ MeV, higher states are also observed (1960VL03).

26. ^{7}Li(^{7}Li, ^{6}He)^{8}Be $\quad Q_{\rm m} = 7.272$

See (1957NO17, 1964CA16).

27. (a) ^{7}Be(n, p)^{7}Li $\quad Q_{\rm m} = 1.644 \quad E_{\rm b} = 18.896$

(b) ^{7}Be(n, α)^{4}He $\quad Q_{\rm m} = 18.991$

(c) ^{7}Be(n, $\gamma\alpha$)^{4}He

At thermal energies, the (n, p) cross section is $(5.1 \pm 0.6) \times 10^{4}$ b (1955HA34), the (n, α) cross section is ≤ 0.1 mb (1962BA1B, 1963BA34) and the (n, $\gamma\alpha$) cross section is 155 mb (1963BA34). These observations are consistent with odd parity of ^{7}Be; the small value of σ(n, α) leads to an estimated $F^{2} < 4 \times 10^{-10}$ for the intensity of a positive parity admixture (1963BA34). Comparison of the thermal cross section for reaction (a) with the (p, n) cross section observed in the inverse reaction supports the assignment $J = \frac{3}{2}$ for ^{7}Be(0) (1957NE22). See also (1959AJ76).

28. ^{7}Be(d, p)^{8}Be $\quad Q_{\rm m} = 16.672$

For $E_{\rm d} = 0.8$ to 1.7 MeV, proton groups are observed corresponding to the ground state and the 2.9 MeV level: $\Gamma(2.9) = 1.6 \pm 0.4$ (1959SP1A), 1.53 ± 0.04 MeV (1960KA17). A dispersion formula fit yields parameters $E_{\rm x} = 2.90 \pm 0.06$ MeV, $\gamma^{2} = 0.60$ MeV, $\theta^{2} = 0.64$, $R = 5.75$ fm (1960KA17): see Table 8.9.

Table 8.17: α-β angular correlation coefficients [a] in ^{8}Li, ^{8}B

Nuclide	A/W_β	B/W_β	W_β (MeV)	Reference
^{8}Li		$(5.7^{+2.9}_{-1.9}) \times 10^{-3}$	7.0	(1960KR03)
^{8}Li	$(-8.7 \pm 0.7) \times 10^{-3}$	$(+3.16 \pm 0.6) \times 10^{-3}$	11	(1962NO02)
^{8}Li	$(-8.3 \pm 1.1) \times 10^{-3}$	$(+3.7 \pm 1.0) \times 10^{-3}$	7.5	(1963GR11)
^{8}B	$(-8.7 \pm 0.9) \times 10^{-3}$	$(-3.86 \pm 1.0) \times 10^{-3}$	11	(1962NO02)

[a] $W(\theta) = 1 + A\cos\theta + B\cos^2\theta$.

29. ^{8}Li(β^-)^{8}Be $\qquad Q_m = 16.002$

^{8}Li decays mainly to the broad 2.9 MeV, 2^+ level of ^{8}Be, which decays into two α-particles. The β-spectrum, which extends to $\gtrsim$ 14 MeV, has been studied by (1950HO01), (1960FA02) and others, while the α-spectrum, extending to $\approx$ 10 MeV, has been reported by (1938RU01, 1948BO20, 1955FR29, 1960BI10, 1960BI06, 1960FA04, 1961DE1E) and others: see (1955AJ61). The two spectra correspond well, except perhaps for low β-energies (1960GR10). For $E_\alpha \lesssim 5$ MeV, the spectrum is closely matched by a density-of-states derived from the experimental d-wave phase shift of α-α scattering; at higher energies, an increasing excess of α-particles appears which may reflect transition into the tail of the $J^\pi = 2^+$ level at $E_x = 16.67$ MeV (1960GR10, 1963AL19, 1963DA05). See also ^{8}B(β^+).

Studies of the distribution of recoil momenta and neutrino-recoil correlation indicate that the decay is at least 90% GT, and that the GT portion is at least 90% axial vector. The observations indicate $J = 2^+$ for ^{8}Li (1958BA1E, 1958LA08, 1959LA11, 1959LA05).

The angular correlations $W(\theta_{\beta\alpha})$ have been measured for the decays of ^{8}Li and ^{8}B as a test of the conserved vector current theory of β-decay. The observed correlation is of the form $W(\theta) = 1 + A\cos\theta + B\cos^2\theta$; reported values of A and B are listed in Table 8.17. With shell model calculations of the matrix element Γ_γ(M1) for ^{8}Be*($T = 1$) $\rightarrow$ ^{8}Be*(2.9 MeV), the CVC theory predicts $\delta \equiv B(^8\text{Li}) - B(^8\text{B}) = (7 \pm 2) \times 10^{-3}\ W_\beta$ (1960KU05, 1960WE1A); conversely, if CVC is assumed correct, the experiment yields Γ(M1) $= 1.9 \pm 0.6$ eV (1962NO02). See also (1963IS04).

See also (1958KE1B, 1959JA1B, 1960NO01, 1960NO05, 1960ST23, 1961FO1C, 1963DA05, 1963HU1G, 1963LE1K, 1964TO1D).

30. ^{8}B(β^+)^{8}Be $\qquad Q_m = 17.979$

The decay proceeds mainly to ^{8}Be*(2.9). The α and β spectra correspond closely to those of ^{8}Li, when account is taken of the different Q-values (1960FA04). The ratio $ft(^8\text{B})/ft(^8\text{Li}) = 1.096$

(1964TO1D). Detailed study of the high energy portion of the α-spectrum reveals a maximum near $E_\alpha = 8.3$ MeV, corresponding to transitions to ^{8}Be*(16.62). The observed shape is reproduced with a Breit-Wigner density-of-states function with parameters $E_x = 16.67$ MeV, $\Gamma = 150$ to 190 keV; parameters $E_x = 16.62$, $\Gamma = 95$ keV are less good, but acceptable. With the former set, $\log ft = 2.9$ (using $\tau_{1/2} = 0.774 \pm 0.005$ sec); with the latter, $\log ft = 3.03$. In either case, the low ft-value supports the identification $T = 1$, $J = 2^+$ for ^{8}Be*(16.63) (1964MA35). See, however, (1965MA1G).

See also (1960FA02, 1960GR10, 1963DI17) and see ^{8}Li(β^-)^{8}Be for a discussion of the work on β-α angular correlations.

31. (a) ^{9}Be(γ, n)^{8}Be $\qquad Q_m = -1.665$
(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_m = -1.665$
(c) ^{9}Be(α, αn)^{8}Be $\qquad Q_m = -1.665$

For reaction (a), see ^{9}Be. The (n, 2n) reaction appears to proceed largely via excited states of ^{9}Be, with subsequent decay to ^{8}Be, mainly ^{8}Be*(2.9) (1959CH1E, 1961MY01, 1963JE05, 1964BO31): see ^{9}Be and ^{10}Be. For reaction (c), see (1962ST12) and ^{9}Be. See also (1959WI41, 1960KO1G, 1961JE01, 1962CU05, 1965LO1K).

32. ^{9}Be(p, d)^{8}Be $\qquad Q_m = 0.559$

At $E_p = 5.2$ MeV, the α-spectrum shows a sharp ground-state group α_0, and a broad group, α_1, corresponding to ^{8}Be*(2.9). A pronounced anomaly appears at $E_x \approx 0.75$ MeV, on the side of the α_1 group, which is apparently a "ghost" of α_0. A quantitative account is given with a density-of-states function derived from α-α scattering phase shifts (1961BE1E: see also (1962BA1C, 1962HA23, 1963AL19)).

At $E_p = 95$ to 155 MeV, ^{8}Be states at 0, 2.9, 11.4, 16.6, 18.8 and (23) MeV are excited (1956SE1A, 1963BA1R, 1963RA01). See also (1959AJ76, 1959FI1B, 1960PH1B, 1964SH07, 1964TO1D, 1964YA1A), ^{9}Be and ^{10}B.

33. (a) ^{9}Be(d, t)^{8}Be $\qquad Q_m = 4.592$
(b) ^{9}Be(d, t)^{4}He + ^{4}He $\qquad Q_m = 4.687$

Angular distributions of ground-state tritons have been measured at a number of energies up to 20 MeV: see (1959AJ76) and (1959VL24, 1960NE09, 1960NE11, 1961RE03, 1962BI11, 1965JA07). The width of the 2.9 MeV state is 0.8 MeV (1955CU16), 1.35 ± 0.15 MeV (1959VL24).

See also (1959FI1B, 1959KU1C, 1959ZA01, 1962HA23, 1963OG1A).

34. ^{9}Be(^{3}He, α)^{8}Be $\qquad Q_{\rm m} = 18.913$

At $E(^{3}{\rm He}) = 3.0$ and 4.0 MeV, angular distributions of the α-particles to the ground-state of ^{8}Be and to the levels at 2.9, 16.6, 16.9 and 17.6 MeV have been measured. The excitation energy and width of the first excited state are found to be 2.90 ± 0.04 MeV and 1.35 ± 0.15 MeV (1963DO08): see Table 8.9. The parameters of the higher states (from (1961ER01) and (1963DO08)) are given in Table 8.11. The angular distributions are amenable to analysis by direct interaction except in the case of the 16.6 MeV state which appears to involve compound nucleus formation (1963DO08) (compare ^{7}Li(d, n)^{8}Be). For angular distribution data at lower energies, see (1955AJ61) and (1963WE08).

The α-particles corresponding to the 2.9 MeV excited state are superposed on a broad, intense continuum extending to $E_{\rm x} > 16$ MeV. Some part of this spectrum may be ascribed to a broad level at $E_{\rm x} = 12.5$ MeV, with $\Gamma \approx 5$ MeV, but the main contribution appears to be due to a direct 3α breakup (1963DO11: see also (1963WE08)). (1964MO19) find, on the other hand, that the sequential decay, via ^{8}Be*(2.9) and (16.93) dominates the reaction. See, however, (1965MO1M). Angular correlation studies confirm $J^{\pi} = 2^{+}$ for ^{8}Be*(16.9) (1964MO19, 1965MO1N).

See also (1962WE1C, 1964BL12, 1965MA1G).

35. (a) ^{9}Be(^{6}Li, ^{7}Li)^{8}Be $\qquad Q_{\rm m} = 5.587$

(b) ^{9}Be(^{7}Li, ^{8}Li)^{8}Be $\qquad Q_{\rm m} = 0.367$

For reaction (a) see (1960MA1H, 1961LE1K). For reaction (b) see ^{9}Be.

36. ^{10}B(γ, d)^{8}Be $\qquad Q_{\rm m} = -6.028$

See ^{10}B and (1955AJ61).

37. ^{10}B(n, t)^{8}Be $\qquad Q_{\rm m} = 0.229$

Angular distributions of the tritons to the ground and 2.9 MeV states of ^{8}Be have been measured at $E_{\rm n} = 14.4$ MeV (1964VA14). See also (1959AJ76, 1964VA1E) and ^{11}B.

38. (a) ^{10}B(p, ^{3}He)^{8}Be $\qquad Q_{\rm m} = -0.534$

(b) ^{10}B(p, pd)^{8}Be $\qquad Q_{\rm m} = -6.028$

See ^{11}C and (1964BA1C).

39. (a) ^{10}B(d, α)^{8}Be $\quad Q_{\rm m} = 17.819$
(b) ^{10}B(d, α)^{4}He + ^{4}He $\quad Q_{\rm m} = 17.914$

Alpha groups are reported corresponding to ^{8}Be states at 0, 2.9 (1960BE15, 1960BI11, 1961CI02, 1961LE10, 1963PU02, 1964YA1A; and see (1959AJ76)), 16.6 and 16.8 MeV (1961ER01: see Table 8.11). A coincidence study of the α_1 group yields the following parameters for the level shape: $E_{\rm res} = 3.15$ MeV, $\Gamma = 2.04$ MeV, $E_\lambda = 4.00$ MeV, $\gamma^2 = 3.4$ MeV · fm, $\theta^2 = 0.60$, $R = 5.5$ fm (1963PU02: E relative to $E(2\alpha)$). (1953TR04) reports $E_\lambda = 5.29$ MeV (relative to 2α), $\gamma^2 = 13.4$ MeV · fm, $\theta^2 \approx 2$, $R = 4.48$ fm: see Table 8.9.

Arguments are presented for the assignments $J = 2^+$, $T = 1$ for $E_{\rm x} = 16.63$ and $J^\pi = 0^+$ or 2^+, $T = 0$ for $E_{\rm x} = 16.93$ MeV. Comparison of yields with ^{6}Li(^{3}He, p)^{8}Be* indicates gross violation of the isospin selection rule, possibly to be ascribed to intermixture in the compound nucleus stage (1961ER01). See, however, (1965MA1G). There is no evidence for an earlier reported level at $E_{\rm x} = 16.08$ MeV (1961ER01). See also (1961TE02, 1962TE02, 1965LE09).

40. ^{10}B(^{3}He, pα)^{8}Be $\quad Q_{\rm m} = 12.326$

See (1964ET02, 1965AL1B, 1965ET1A, 1965WA1M) and ^{12}C.

41. (a) ^{11}B(γ, t)^{8}Be $\quad Q_{\rm m} = -11.226$
(b) ^{11}B(γ, t)^{4}He + ^{4}He $\quad Q_{\rm m} = -11.132$

See ^{11}B.

42. ^{11}B(p, α)^{8}Be $\quad Q_{\rm m} = 8.588$

Alpha groups are reported corresponding to the ground and 2.9 MeV state: see (1959AJ76) and (1962AL20). At $E_{\rm p} = 3$ to 5 MeV, the α-spectrum shows an anomaly at $E_{\rm x} \approx 0.75$ MeV, ascribed to successive two-body decays with a final density-of-states related to α-α scattering phase shifts (1961BE1E: see ^{9}Be(p, d)^{8}Be and (1963BR03, 1964BR05, 1964DE1H)). See also ^{12}C and (1959KA12, 1959KA13, 1961KO08, 1962BE21, 1963PH1A, 1964BA1C, 1964YA1A, 1965DU1C, 1965LE09, 1965PH1A, 1965SW1B).

43. ^{11}B(d, nα)^{8}Be $Q_{\rm m} = 6.363$

See (1965OL01).

44. ^{11}B(^{3}He, ^{6}Li)^{8}Be $Q_{\rm m} = 4.566$

At $E(^{3}\text{He}) = 3.0$ MeV, ^{8}Be*(2.9) is produced with an intensity 20 times that of the ground state (1964YO06).

45. (a) ^{12}C(γ, α)^{8}Be $Q_{\rm m} = -7.369$

(b) ^{12}C(α, 2α)^{8}Be

(c) ^{12}C(p, pα)^{8}Be

(d) ^{12}C(n, nα)^{8}Be

Reaction (a) involves states of ^{8}Be at 0, 2.9, 16.6, 16.9 and (17.6) MeV: see (1955GO59, 1959AJ76, 1964TO1A). See also (1961SE13, 1963SH04, 1964LE1C).

At $E_{\alpha} = 25.4$ MeV, the four-body breakup ($^{12}\text{C} + \alpha \rightarrow 4\alpha$) is greatly favored over reaction (b) (1962BR14: see also (1961VA38, 1962VA25)). See also (1961GO1T, 1962IG1B, 1963LA02).

Reaction (c) at $E_{\rm p} = 15$ to 29 MeV proceeds predominantly through the ground state and the 2.9 MeV level. It is not clear whether higher levels of ^{8}Be are involved (1955NE18, 1960VA10, 1962VA1A, 1963VA04). See also (1963JA07, 1964BA1C, 1964KE1F, 1964SY02, 1965YU1C, 1965YU1D).

For reaction (d) see (1955FR35, 1960VA10, 1964BR25).

See also ^{12}C.

46. ^{12}C(d, ^{6}Li)^{8}Be $Q_{\rm m} = -5.897$

See (1963DR1B, 1964BL1C, 1964DA1B, 1965BE1W, 1965DE1V, 1965SL1C).

47. ^{12}C(^{3}He, ^{7}Be)^{8}Be $Q_{\rm m} = -5.782$

See (1964PA1K, 1965MA1V).

48. ^{12}C(^{12}C, 6^{4}He) $Q_{\rm m} = -14.549$

See (1962BE43, 1963BE1U).

49. ^{12}C(^{14}N, ^{18}F)^{8}Be $Q_{\rm m} = -2.953$

See (1965WI1A).

50. (a) ^{16}O(γ, α)^{12}C* $\rightarrow$ ^{8}Be + ^{4}He $Q_{\rm m} = -14.530$
(b) ^{16}O(α, ^{8}Be)^{12}C $Q_{\rm m} = -7.256$

For reaction (a) see (1955AJ61, 1959AJ76, 1964TO1E) and ^{12}C.
For reaction (b) see (1964BR1U) and ^{12}C.

51. ^{16}O(p, p′)^{4}He^{4}He^{4}He^{4}He $Q_{\rm m} = -14.436$

See (1962VA1A) and ^{16}O.

52. ^{20}Ne(α, ^{16}O)^{8}Be $Q_{\rm m} = -4.824$

This reaction has not been observed: see (1962LA15).

Table 8.18: Energy levels of ^{8}B

E_x (MeV ± keV)	$J^\pi; T$	Γ (keV)	Decay	Reactions
g.s.	$(2^+); 1$	$\tau_{1/2} = 774 \pm 4$ msec	β^+	1, 2
0.778 ± 7		42 ± 10		2
2.17 ± 50				2

^{8}B
(Figs. 13 and 14)

GENERAL: See (1958FO1C, 1960TA1C, 1962IN02, 1963NA1E, 1964BA1X, 1964BA2A, 1964GR1J, 1964ST1B).

1. ^{8}B(β^+)^{8}Be $\qquad Q_m = 17.979$

The beta decay leads mainly to ^{8}Be*(2.9). Reported half lives are listed in Table 8.19; taking $\tau_{1/2} = 0.774$ sec and $Q = 17.979 - 2.90$, $ft = 4.41 \times 10^5$ (1966BA1A). There is also observed a branch to a ^{8}Be state at ≈ 16.6 MeV; $\log ft = 2.9$ (1964MA35). See also (1964BA1X) and ^{8}Be.

2. ^{6}Li(^{3}He, n)^{8}B $\qquad Q_m = -1.975$

Thresholds for production of slow neutrons are reported at $E(^{3}\mathrm{He}) = 2.9661 \pm 0.0017$ MeV (1958DU78), 2.974 ± 0.010 MeV (1959FA02), corresponding to the ground state of ^{8}B, and at $E(^{3}\mathrm{He}) = 4.16 \pm 0.05$ (1958DU78), 4.159 ± 0.030 MeV (1959FA02), corresponding to an excited state at $E_x = 0.789 \pm 0.030$ MeV with $\Gamma_{\mathrm{c.m.}} = 70 \pm 40$ keV. A threshold at 3.9 MeV reported by (1958DU78) is not confirmed by (1959FA02).

Neutron time-of-flight spectra at $E(^{3}\mathrm{He}) = 4$ to 9 MeV show groups corresponding to ^{8}B(0) and ^{8}B*(0.8), with forward-peaked angular distributions, and to a new state at $E_x = 2.17 \pm 0.05$ MeV (1963DI02). At $E(^{3}\mathrm{He}) = 4.5$ to 5.3 MeV, time-of-flight spectra locate the first excited state at 0.767 ± 0.012 (1965FA03), 0.783 ± 0.010 MeV (1965MC06: $\Gamma = 40 \pm 10$ keV). See also (1963MO1J).

3. ^{7}Be(p, γ)^{8}B $\qquad Q_m = 0.135$

Table 8.19: Half life of ^{8}B

$\tau_{1/2}$ (sec)	Reference
0.65 ± 0.1	(1950AL57)
0.61 ± 0.11	(1952SH44)
0.78 ± 0.01	(1958DU78)
0.75 ± 0.02	(1958VE20)
0.79 ± 0.02	(1959FA02)
0.774 ± 0.005	(1964MA35)
0.774 ± 0.004	mean

The cross section for proton capture is 0.48 ± 0.18 μb at $E_{\rm p} = 0.80$ MeV and 0.50 ± 0.20 μb at $E_{\rm p} = 1.40$ MeV (1960KA05). The relevance of this reaction in stellar energy production is discussed by (1958FO1C, 1960KA05, 1963BA2D, 1964BA2A, 1964PA1A). See also (1961CH1C).

4. (a) ^{10}B(p, t)^{8}B $\quad Q_{\rm m} = -18.532$
   (b) ^{9}Be(p, 2n)^{8}B $\quad Q_{\rm m} = -20.426$
   (c) ^{12}C(p, nα)^{8}B $\quad Q_{\rm m} = -26.130$

See (1950AL57).

5. (a) ^{10}B(γ, 2n)^{8}B $\quad Q_{\rm m} = -27.014$
   (b) ^{11}B(γ, 3n)^{8}B $\quad Q_{\rm m} = -38.470$
   (c) ^{12}C(γ, p3n)^{8}B $\quad Q_{\rm m} = -54.426$

See (1952SH44).

References

(Closed July 01, 1965)

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.

1938RU01 L.H. Rumbaugh, R.B. Roberts and L.R. Hafstad, Phys. Rev. 54 (1938) 657

1947HU06 D.J. Hughes, D. Hall, C. Eggler and E. Goldfarb, Phys. Rev. 72 (1947) 646

1948BO20 T.W. Bonner, J.E. Evans, C.W. Malich and J.R. Risser, Phys. Rev. 73 (1948) 885

1948HE01 N.P. Heydenburg, C.M. Hudson, D.R .Inglis, W.D. Whitehead, Jr., Phys. Rev. 74 (1948) 405

1948TA16 R. Taschek and A. Hemmendinger, Phys. Rev. 74 (1948) 373

1949FO18 W.A. Fowler and C.C. Lauritsen, Phys. Rev. 76 (1949) 314

1950AL57 L.W. Alvarez, Phys. Rev. 80 (1950) 519

1950HO01 W.F. Hornyak and T. Lauritsen, Phys. Rev. 77 (1950) 160

1950WH02 W. Whaling and T.W. Bonner, Phys. Rev. 79 (1950) 258

1951BR10 A.B. Brown, C.W. Snyder, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 82 (1951) 159

1951BR92 C.H. Braden, S.M. Carter and A.G. Ford, Phys. Rev. 84 (1951) 837

1951GR45 E. Graves, Phys. Rev. 84 (1951) 1250

1951MA1B Mather, Phys. Rev. 82 (1951) 126

1951RA12 W. Rall and K.G. McNeill, Phys. Rev. 83 (1951) 1244

1952BA64 L.M. Baggett and S.J. Bame, Jr., Phys. Rev. 85 (1952) 434

1952GR1A Graves, Phys. Rev. 85 (1952) 703A

1952MO19 C.D. Moak, W.M. Good and W.E. Kunz, Phys. Rev. 85 (1952) 928

1952PE02 T.P. Pepper, K.W. Allen, E. Almqvist and J.T. Dewan, Phys. Rev. 85 (1952) 155

1952SH44 R.K. Sheline, Phys. Rev. 87 (1952) 557

1952WA31 D. Walker, W.T. Link and W.I.B. Smith, Proc. Phys. Soc. (London) A65 (1952) 861

1953BA04 M.E. Battat and F.L. Ribe, Phys. Rev. 89 (1953) 80

1953BR1B Bretonneau, Compt. Rend. 236 (1953) 913

1953BU35 D.S. Bunbury, Phys. Rev. 90 (1953) 1121; Erratum Phys. Rev. 91 (1953) 1580

1953CH1A Christy, Phys. Rev. 89 (1953) 839

1953SA1A Sawyer and Phillips, Los Alamos Rept.1578 (1953)

1953ST52 F.E. Steigert and M.B. Sampson, Phys. Rev. 92 (1953) 660

1953TR04 P.B. Treacy, Phil. Mag. 44 (1953) 325

1953WA27 W.D. Warters, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 91 (1953) 917

1954AL35 K.W. Allen, E. Almqvist, J.T. Dewan and T. Pepper, Phys. Rev. 96 (1954) 684

1954HI34 F. Hirst, I. Johnstone and M.J. Poole, Phil. Mag. 45 (1954) 762

1954KL36 R.M. Kline and D.J. Zaffarano, Phys. Rev. 96 (1954) 1620

1954KR06 A.A. Kraus Jr., Phys. Rev. 93 (1954) 1308

1954MO04 F. Mozer, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 93 (1954) 829

1954SI07 R.M. Sinclair, Phys. Rev. 93 (1954) 1082

1954WI25 M.M. Winn, Proc. Phys. Soc. (London) A67 (1954) 946

1955AJ61 F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys. 27 (1955) 77

1955CU16 P. Cuer and J. Jung, J. Phys. Rad. 16 (1955) 385

1955CU17 P. Cuer, D. Magnac-Valette and G. Baumann, Compt. Rend. 240 (1955) 1880

1955FR10 J.M. Freeman, A.M. Lanem and B. Rose, Phil. Mag. 46 (1955) 17

1955FR29 R.T. Frost and S.S. Hanna, Phys. Rev. 99 (1955) 8

1955FR35 G.M. Frye Jr., L. Rosen and L. Stewart, Phys. Rev. 99 (1955) 1375

1955GO59 F.K. Goward and J.J. Wilkins, Proc. Roy. Soc. 228 (1955) 376

1955HA34 R.C. Hanna, Phil. Mag. 46 (1955) 381

1955KH35 L.M. Khromchenko, Izv. Akad. Nauk SSSR Ser. Fiz. 19 (1955) 277; Columbia Tech. Transl. 19 (1956) 252

1955LA1D Lane, Proc. Phys. Soc. (London) A68 (1955) 189

1955LE24 S.H. Levine, R.S. Bender and J.N. McGruer, Phys. Rev. 97 (1955) 1249

1955LI1B Liberman, Thesis, CalTech (1955)

1955MA20 R.L. Macklin and H.E. Banta, Phys. Rev. 97 (1955) 753

1955NE18 J.L. Need, Phys. Rev. 99 (1955) 1356

1955TR03 P.B. Treacy, Proc. Phys. Soc. (London) A68 (1955) 204

1956BU27 F. Bumiller, H.H. Staub and H.E. Weaver, Helv. Phys. Acta 29 (1956) 83

1956GO62 G.V. Gorlov, B.M. Gokhberg, V.M. Morozov and G.A. Otroschenko, Dokl. Akad. Nauk SSSR 110 (1956) 963; Sov. Phys. Dokl. 1 (1956) 598

1956HE57 N.P. Heydenburg and G.M. Temmer, Phys. Rev. 104 (1956) 123

1956KI54 B.B. Kinsey and T. Stone, Phys. Rev. 103 (1956) 975

1956KU1A Kurath, Phys. Rev. 101 (1956) 216

1956MA12 P.R. Malmberg, Phys. Rev. 101 (1956) 114

1956MO19 C.D. Moak and W.R. Wisseman, Phys. Rev. 101 (1956) 1326

1956NE13 G.C. Neilson and J.B. Warren, Phys. Rev. 103 (1956) 1758

1956NI20 R. Nilson, R.O. Kerman, G.R. Briggs and W. Jentschke, Phys. Rev. 104 (1956) 1673

1956RU41 J.L. Russell Jr., G.C. Phillips and C.W. Reich, Phys. Rev. 104 (1956) 135

1956SC01 J.P. Schiffer, T.W. Bonner, R.H. Davis and F.W. Prosser Jr., Phys. Rev. 104 (1956) 1064

1956SE1A Selove, Phys. Rev. 101 (1956) 231

1956TH06 R.G. Thomas, M. Walt, R.B. Walton and R.C. Allen, Phys. Rev. 101 (1956) 759

1956WI04 H.B. Willard, J.K. Bair, J.D. Kington and H.O. Cohn, Phys. Rev. 101 (1956) 765

1957BU13 W.E. Burcham, W.M. Gibson, D.J. Prowse and J. Rotblat, Nucl. Phys. 3 (1957) 217

1957FR1B French and Fujii, Phys. Rev. 105 (1957) 652

1957KU58 D. Kurath, Phys. Rev. 106 (1957) 975

1957NE22 H.W. Newson, R.M. Williamson, K.W. Jones, J.H. Gibbons and H. Marshak, Phys. Rev. 108 (1957) 1294

1957NO17 E. Norbeck Jr. and C.S. Littlejohn, Phys. Rev. 108 (1957) 754

1957SL01 J.C. Slattery, R.A. Chapman and T.W. Bonner, Phys. Rev. 108 (1957) 809

1957VA11 D.M. Van Patter and W. Whaling, Rev. Mod. Phys. 29 (1957) 757

1957WI24 D.H. Wilkinson, Phil. Mag. 2 (1957) 83

1958BA1E Barnes, Fowler, Greenstein, Lauritsen and Nordberg, Bull. Amer. Phys. Soc. 3 (1958) 328

1958CA1E Catala, Font, Senent, Aguilar and de La Cuadra, Nuovo Cim. 9, Suppl. 2 (1958) 377

1958CH31 I.V. Chuvilo and V.G. Shevchenko, Zh. Eksp. Teor. Fiz. 34 (1958) 593; JETP (Sov. Phys.) 7 (1958) 410

1958CO62 B. Conrad, V. Konig and U. Timm, Naturwiss. 45 (1958) 204

1958DU78 K.L. Dunning, J.W. Butler and R.O. Bondelid, Phys. Rev. 110 (1958) 1076

1958FO1C Fowler, Mem. Soc. Roy. Sc. Liege III (1958) 207

1958KE1B Keszthelyi and Zimanyi, Nuovo Cim. 10 (1958) 909; Repts. Central Research Inst. Phys. Hung. Acad. Sci. 6 (1958) 353

1958LA08 T. Lauritsen, C.A. Barnes, W.A. Fowler and C.C. Lauritsen, Phys. Rev. Lett. 1 (1958) 326

1958MA07 R.L. Macklin and J.H. Gibbons, Phys. Rev. 109 (1958) 105

1958MA1B Th.A.J. Maris, P. Hillman and H. Tyren, Nucl. Phys. 7 (1958) 1

1958NE17 H. Neuert and T. Retz-Schmidt, Z. Naturforsch. A13 (1958) 829

1958NI05 R. Nilson, W.K. Jentschke, G.R. Briggs, R.O. Kerman and J.N. Snyder, Phys. Rev. 109 (1958) 850

1958TY49 H. Tyren, P. Hillman and T.A.J. Marris, Nucl. Phys. 7 (1958) 10

1958VE20 J.F. Vedder, Thesis, Univ. of California (1958); UCRL-8324 (1958)

1958WI1E Wildermuth and Kanellopoulos, Nucl. Phys. 7 (1958) 150

1959AJ76 F. Ajzenberg and T. Lauritsen, Nucl. Phys. 11 (1959) 1

1959AJ77 F. Ajzenberg-Selove, N. Jarmie and E. Haddad, Bull. Amer. Phys. Soc. 4 (1959) 258, NA9

1959AJ81 F. Ajzenberg-Selove, C.F. Osgood and C.P. Baker, Phys. Rev. 116 (1959) 1521

1959BA1D Baz, Adv. Phys. 8 (1959) 349

1959BA1F Balashov and Tulinov, Zh. Eksp. Teor. Fiz. 36 (1959) 615; JETP (Sov. Phys.) 9 (1959) 426

1959BA34 J.A. Baicker, Thesis, Columbia Univ. (1959); CU-183 (1959)

1959BI19 E.G. Bilpuch, L.W. Weston, C.D. Bowman and H.W. Newson, Bull. Amer. Phys. Soc. 4 (1959) 42, R4

1959BO1C Bockelman, Nucl. Phys. 13 (1959) 205

1959BR1E Brink and Kerman, Nucl. Phys. 12 (1959) 314

1959BR71 D.J. Bredin, W.E. Burcham, D. Evans, W.M. Gibson, M.S.C. McKee, D.J. Prowse, J. Rotblat and J.N. Snyder, Proc. Roy. Soc. 251 (1959) 143

1959BU07 A.C. Butcher and J.M. McNamee, Proc. Phys. Soc. (London) 74 (1959) 529

1959CH1E Chuan, J. Phys. Rad. 20 (1959) 621

1959CO68 D. Connor, Phys. Rev. Lett. 3 (1959) 429

1959CR84 L. Cranberg, Phys. Rev. 114 (1959) 174

1959FA02 B.J. Farmer and C.M. Class, Bull. Amer. Phys. Soc. 4 (1959) 95, C3

1959FI1B Filho, An. Acad. Brasil. Cienc. 31 (1959) 1

1959GA08 F. Gabbard, R.H. Davis and T.W. Bonner, Phys. Rev. 114 (1959) 201

1959GE33 D.S. Gemmell, A.H. Morton and E.W. Titterton, Nucl. Phys. 10 (1959) 33

1959GI47 J.H. Gibbons and R.L. Macklin, Phys. Rev. 114 (1959) 571

1959HA29 E.W. Hamburger, Thesis, Univ. of Pittsburgh (1959)

1959IM04 W.L. Imhof, R.G. Johnson, F.J. Vaughn and M. Walt, Phys. Rev. 114 (1959) 1037

1959JA1B Jancovici, Ann. Phys. 4 (1959) 689

1959KA12 D. Kamke, Z. Phys. 156 (1959) 603

1959KA13 D. Kamke, Z. Phys. 156 (1959) 621

1959KU1C Kurepin and Neudachin, Zh. Eksp. Teor. Fiz. 36 (1959) 1725; JETP (Sov. Phys.) 9 (1959) 1229

1959KU1E Kurath, Phys. Rev. Lett. 3 (1959) 431

1959LA05 K.H. Lauterjung, B. Schimmer, U. Schmidt-Rohr and H. Maier-Leibnitz, Z. Phys. 155 (1959) 547

1959LA11 K.H. Lauterjung, B. Schimmer, U. Schmidt-Rohr and H. Maier-Leibnitz, Z. Phys. 155 (1959) 560

1959SA04 M. Sakisaka, J. Phys. Soc. Jpn. 14 (1959) 554

1959SE1A Sellschop, Phys. Rev. Lett. 3 (1959) 346

1959SP1A Spear, Aust. J. Phys. 12 (1959) 99

1959ST1B Starodubtsev and makaryunas, Zh. Eksp. Teor. Fiz. 36 (1959) 1594; JETP (Sov. Phys.) 9 (1959) 1133

1959ST30 S.V. Starodubtsev and K.V. Makaryunas, Dokl. Akad. Nauk SSSR 129 (1959) 547; Sov. Phys. Dokl. 4 (1960) 1292

1959VA1F Van der Spuy, Nucl. Phys. 11 (1959) 615

1959VL24 N.A. Vlasov and A.A. Ogloblin, Zh. Eksp. Teor. Fiz. 37 (1959) 54; JETP (Sov. Phys.) 10 (1960) 39

1959WE1A Weston, Bilpuch and Newson, Bull. Amer. Phys. Soc. 4 (1959) 42

1959WI1B Wildermuth and Kanellopoulous, Congres. Int. de Phys. Nucl., 1958(Dunod, Paris, 1959) 793

1959WI1F Wittern, Naturwiss. 46 (1959) 443

1959WI41 K. Winter, B. Torki and E. Remy, Nuovo Cim. 11 (1959) 1

1959ZA01 N.I. Zaika and O.F. Nemets, Izv. Akad. Nauk SSSR Ser. Fiz. 23 (1950) 1460

1959ZE1A Zeidman and Yntema, Nucl. Phys. 12 (1959) 298

1960AG03 J. Aguilar, M. De la Cuadra and R. Font, An. Real Soc. Espan. Fis. Y Quim. (Madrid) 56 (1960) 71; Phys. Abs. 16796 (1961)

1960AL18 J. Alster and J. Gonzalez-Vidal, Bull. Amer. Phys. Soc. 5 (1960) 493, C5

1960BA27 J.A. Baicker and K.W. Jones, Nucl. Phys. 17 (1960) 424

1960BE05 N. Berk, F.E. Steigert and G.L. Salinger, Phys. Rev. 117 (1960) 531

1960BE15 R.L. Becker, Phys. Rev. 119 (1960) 1076

1960BI06 R. Bilwes, R. Seltz, M. Suffert, C. Gerardin, J. Linck, D. Magnac-Valette and P. Cuer, J. Phys. Rad. 21 (1960) 376

1960BI10 R. Bilwes, R. Seltz, C. Gerardin and D. Magnac-Valette, Compt. Rend. 251 (1960) 1771

1960BI11 R. Bilwes, C. Gerardin and D. Magnac-Valette, Compt. Rend. 251 (1960) 2157

1960BI1E Bifl, Butcher and McNamee, Nucl. Forces and the Few Nucleon Problem (Pergamon, 1960) 641

1960BO13 R. Bouchez, C. Delome, J. Fleury, J. Krafft, P. Perrin, L. Goldman, M. Boge and B. Dudek, J. Phys. Rad. 21 (1960) 346

1960CO04 H.E. Conzett, G. Igo, H.C. Shaw and R.J. Slobodrian, Phys. Rev. 117 (1960) 1075

1960DI02 F.S. Dietrich and L. Cranberg, Bull. Amer. Phys. Soc. 5 (1960) 493, C1

1960FA02 B.J. Farmer, J.G. Cramer Jr. and C.M. Class, Bull. Amer. Phys. Soc. 5 (1960) 101, C1

1960FA04 B.J. Farmer and C.M. Class, Nucl. Phys. 15 (1960) 626

1960GE07 D.S. Gemmell, Aust. J. Phys. 13 (1960) 116

1960GI1A Gibbons and Newson, Fast Neutron Phys.; Eds. J.B. Marion and J.L. Fowler (Academic Press, 1960) 133

1960GO04 J. Gonzalez-Vidal, H.C. Conzett and W.H. Wade, Bull. Amer. Phys. Soc. 5 (1960) 230, C9

1960GO1B Goldansky, Nucl. Phys. 19 (1960) 482

1960GO36 V.I. Goldansky, Zh. Eksp. Teor. Fiz. 38 (1960) 1637; JETP (Sov. Phys.) 11 (1960) 1179

1960GR10 T.A. Griffy and L.C. Biedenharn, Nucl. Phys. 15 (1960) 636

1960GR21 I.S. Grant, Proc. Phys. Soc. (London) 76 (1960) 737

1960HA14 E.W. Hamburger and J.R. Cameron, Phys. Rev. 117 (1960) 781

1960HI04 K. Hisatake, Y. Ishizaki, A. Isoya, T. Nakamura, Y. Nakano, B. Saheki, Y. Saji and K. Yuasa, J. Phys. Soc. Jpn. 15 (1960) 741

1960HO14 P.E. Hodgson, Nucl. Phys. 21 (1960) 21

1960HU08 D.J. Hughes, B.A. Magurno and M.K. Brussel, BNL-325, 2nd Ed., Suppl. 1 (1960)

1960IG02 G. Igo, Phys. Rev. 117 (1960) 1079

1960JO03 C.M. Jones, G.C. Phillips and P.D. Miller, Phys. Rev. 117 (1960) 525

1960JU04 J. Juna, P. Horvath and K. Konecny, Czech. J. Phys. 10 (1960) 715

1960KA05 R.W. Kavanagh, Nucl. Phys. 15 (1960) 411

1960KA17 R.W. Kavanagh, Nucl. Phys. 18 (1960) 492

1960KO1G Komarov, Kurepin and Popova, Zh. Eksp. Teor. Fiz. 38 (1960) 1824; JETP (Sov. Phys.) 11 (1960) 1312; Izv. Akad. Nauk SSSR 24 (1960) 1145; Bul. Acad. Sci. USSR Phys. 24 (1960) 1147

1960KR03 K. Krebs, H. Rieseberg and V. Soergel, Z. Phys. 159 (1960) 232

1960KU05 D. Kurath, Phys. Rev. Lett. 4 (1960) 180

1960LA1C Lane, Rev. Mod. Phys. 32 (1960) 519

1960MA15 K.V. Makariunas and S.V. Starodubtsev, Zh. Eksp. Teor. Fiz. 38 (1960) 372; JETP (Sov. Phys.) 11 (1960) 271

1960MA1G Marion, Levesque, Ludemann and Detenbeck, Nucl. Instrum. Meth. 8 (1960) 297

1960MA1H Marquez and Redon, Proc. Int. on Nucl. Struct., Kingston (1960)

1960MA23 B. Mainsbridge, Aust. J. Phys. 13 (1960) 204

1960MA32 R.D. Macfarlane and J.B. French, Rev. Mod. Phys. 32 (1960) 567

1960MA33 B. Mainsbridge, Nucl. Phys. 21 (1960) 1

1960NE09 O.F. Nemets, L.S. Saltykov, M.K. Sokolov and Y.V. Tsekhmistrenko, Izv. Akad. Nauk SSSR Ser. Fiz. 24 (1960) 858; Bull. Acad. Sci. USSR (Phys.) 24 (1960) 861

1960NE11 O.F. Nemets, L.S. Saltykov and M.V. Sokolov, Zh. Eksp. Teor. Fiz. 38 (1960) 1663; JETP (Sov. Phys.) 11 (1960) 1199

1960NO01 M.E. Nordberg, B. Povh and C.A. Barnes, Phys. Rev. Lett. 4 (1960) 23

1960NO05 M.E. Nordberg, F.B. Morinigo and C.A. Barnes, Phys. Rev. Lett. 5 (1960) 321

1960PE02 F.G.J. Perey and P. Lorrain, Bull. Amer. Phys. Soc. 5 (1960) 18, E6

1960PE11 L.D. Pearlstein, Y.C. Tang and K. Wildermuth, Nucl. Phys. 18 (1960) 23

1960PE25 J.M. Peterson, A. Bratenahl and J.P. Stoering, Phys. Rev. 120 (1960) 521

1960PH1A Phillips and Tombrello, Nucl. Phys. 19 (1960) 555

1960PH1B Phillips and Biedenharn, Bull. Amer. Phys. Soc. 5 (1960) 44

1960PH1C Phillips, Griffy and Biedenharn, Nucl. Phys. 21 (1960) 327

1960PR1D Price, Hamburger and Cohen, Bull. Amer. Phys. Soc. 5 (1960) 270

1960SA25 G.L. Salmon, Nucl. Phys. 21 (1960) 15

1960SE08 J.P.F. Sellschop, Phys. Rev. 119 (1960) 251

1960SE13 J.P.F. Sellschop and D.W. Mingay, Proc. Int. Conf. on Nucl. Struct., Kingston (1960) 396

1960SH01 S.M. Shafroth, Bull. Amer. Phys. Soc. 5 (1960) 55, RA1

1960SI10 L. Simons, Soc. Sci. Fenn. Comm. Phys. Math 24 (1960) 13

1960SI1D Simons, Proc. Int. on Nucl. Struct., Kingston (1960)

1960ST23 R. Stein, H. Braun and P. Cuer, J. Phys. Rad. 21 (1960) 374

1960TA1C Talmi and Unna, Ann. Rev. Nucl. Sci. 10 (1960) 353

1960VA10 S.S. Vasilev, V.V. Komarov and A.M. Popova, Izv. Akad. Nauk SSSR Ser. Fiz. 24 (1960) 1149; Bull. Acad. Sci. Phys. 24 (1960) 1151

1960VL03 N.A. Vlasov, S.P. Kalinin, A.A. Ogloblin and V.I. Chuev, Zh. Eksp. Teor. Fiz. 39 (1960) 1468; JETP (Sov. Phys.) 12 (1961) 1020

1960WA1G Warburton and Chase, Phys. Rev. 120 (1960) 2095

1960WE1A Weidenmuller, Phys. Rev. Lett. 4 (1960) 299

1960ZE03 Ya.B. Zeldovich, Zh. Eksp. Teor. Fiz. 38 (1960) 1123; JETP (Sov. Phys.) 11 (1960) 812

1961AU02 S.M. Austin, S.E. Darden, A. Okazaki and Z. Wilhelmi, Nucl. Phys. 22 (1961) 451

1961BA1C Baz, Goldanskii and Zeldovich, Sov. Phys. Uspekhi 3 (1961) 729

1961BA1E Balashov, Neudachin and Smirnov, Izv. Akad. Nauk SSSR Ser. Fiz. 25 (1961) 170; Bull. Acad. Sci. USSR Phys. 25 (1961) 165

1961BE05 P.R. Bevington, W.W. Rolland and H.W. Lewis, Phys. Rev. 121 (1961) 871

1961BE1E Beckner, Jones and Philips, Phys. Rev. 123 (1961) 255

1961BR02 G. Breuer, V. Riech, E. Thormann and H. Neuert, Z. Phys. 161 (1961) 500

1961CH09 R. Chiba, H.E. Conzett, H. Morinaga, N. Mutsuro, K. Shoda and M. Kimura, J. Phys. Soc. Jpn. 16 (1961) 1077

1961CH1C R.F. Christy and I. Duck, Nucl. Phys. 24 (1961) 89

1961CI02 N. Cindro, M. Cerineo and A. Strzalkowski, Nucl. Phys. 24 (1961) 107

1961CL09 A.B. Clegg, K.J. Foley, G.L. Salmon and R.E. Segel, Proc. Phys. Soc. (London) 78 (1961) 681

1961CL10 A.B. Clegg, Phil. Mag. 6 (1961) 1207

1961DA04 S.E. Darden, T.R. Donoghue and C.A. Kelsey, Nucl. Phys. 22 (1961) 439

1961DE1E Deka, Evans, Prowse and Baldo-Ceolin, Nucl. Phys. 23 (1961) 657

1961DU01 J.R. Dunning, A.M. Smith and F.E. Steigert, Phys. Rev. 121 (1961) 580

1961ER01 J.R. Erskine and C.P. Browne, Phys. Rev. 123 (1961) 958

1961FO1C Fowler and Preist, Nucl. Phys. 23 (1961) 667

1961GO1T Gooding and Igo, Phys. Rev. Lett. 7 (1961) 28

1961HA1G Halton and Hodgson, Proc. Rutherford Jub. Int. Conf. (1961) 593

1961HA27 I.G. Han and N.P. Heydenburg, Bull. Amer. Phys. Soc. 6 (1961) 415, B1, and Private Communication (1961)

1961JA19 von L. Jarczyk, J. Lang, R. Muller and W. Wolfli, Helv. Phys. Acta 34 (1961) 483

1961JE01 H. Jeremie, Compt. Rend. 252 (1961) 403

1961JO17 A. Johansson, U. Svanberg and O. Sundberg, Ark. Fys. 19 (1961) 527

1961JO18 A. Johansson, U. Svanberg and P.E. Hodgson, Ark. Fys. 19 (1961) 541

1961KO08 J. Kokame, J. Phys. Soc. Jpn. 16 (1961) 2101

1961LA1A Lane, Langsdorf, Monahan and Elwyn, Ann. Phys. 12 (1961) 135

1961LE10 G.J.F. Legge, Nucl. Phys. 26 (1961) 608

1961LE1K Lemeille, Saunier and Marquez, Centro Brasileiro de Pesquisas Fisicas 8:5 (1961)

1961LO07 O.V. Lozhkin and A.A. Rimskii-Korsakov, Zh. Eksp. Teor. Fiz. 40 (1961) 1519; JETP (Sov. Phys.) 13 (1961) 1064

1961ME02 J.W. Meadows and J.F. Whalen, Nucl. Sci. Eng. 9 (1961) 132

1961ME10 V. Meyer, H. Muller, H.H. Staub and R. Zurmuhle, Nucl. Phys. 27 (1961) 284

1961MY01 S.A. Myachkova and V.P. Perelygin, Zh. Eksp. Teor. Fiz. 40 (1961) 1244; JETP (Sov. Phys.) 13 (1961) 876

1961NI04 A. Nilsson, Ark. Fys. 19 (1961) 289

1961RE03 F.H. Read and J.M. Calvert, Proc. Phys. Soc. (London) 77 (1961) 65

1961RO20 J.R. Rook, Nucl. Phys. 27 (1961) 606

1961SC1B Schmid and Wildermuth, Nucl. Phys. 26 (1961) 463

1961SE13 W. Sebaoun and H. Gauvin, J. Phys. Rad. 22 (1961) 771

1961SH1F Shimodaya, Tamagaki and Tanaka, Prog. Theor. Phys. 25 (1961) 853

1961TE02 A. Tejera, M. Mazari, A. Jaidar and G. Lopez, Rev. Mex. Fis. 10 (1961) 229

1961VA17 S.S. Vasilev, V.M. Komarov and A.M. Popova, Izv. Akad. Nauk SSSR Ser. Fiz. 25 (1961) 1117; Bull. Acad. Sci. Phys. 25 (1960) 1124

1961VA38 S.S. Vasilev, V.V. Komarov and A.M. Popova, Zh. Skep. Teor. Fiz. 41 (1961) 1757; JETP (Sov. Phys.) 14 (1962) 1249

1961WA03 A.H. Wapstra and D.W. Connor, Nucl. Phys. 22 (1961) 336

1961YA04 M. Yamada and Z. Matumoto, J. Phys. Soc. Jpn. 16 (1961) 1497

1962AB01 Y.G. Abov, O.N. Yermakov, A.D. Gulko, P.A. Krupchitsky and S.S. Trostin, Nucl. Phys. 34 (1962) 505

1962AL20 R.G. Allas, S.S. Hanna and R.E. Segel, Bull. Amer. Phys. Soc. 7 (1962) 453, GA3

1962AU01 S.M. Austin, Bull. Amer. Phys. Soc. 7 (1962) 269, CB6

1962BA1B Bassi et al., Nuovo Cim. 24 (1962) 560

1962BA1C Barker and Treacy, Nucl. Phys. 38 (1962) 33

1962BA1W Batchelor and Towle, Phys. Lett. 2 (1962) 312

1962BE11 W. Benenson, T.H. May and R.L. Walter, Nucl. Phys. 32 (1962) 510

1962BE14 K. Bearpark, I.Hall, R.E. Segel, S.M. Shafroth and N.W. Tanner, Nucl. Phys. 33 (1962) 648

1962BE21 H. Beaumevieille, N. Longequeue and J.P. Longequeue, Compt. Rend. 255 (1962) 1340

1962BE35 J. Benveniste, A.C. Mitchell, C.D. Schrader and J.H. Zenger, Nucl. Phys. 38 (1962) 300

1962BE43 Y.A. Berezhnoi, A.P. Klyucharev, Y.N. Ranyuk and N.Y. Rutkevich, Zh. Skep. Teor. Fiz. 43 (1962) 1248; JETP (Sov. Phys.) 16 (1963) 883

1962BI11 J.A. Biggerstaff, R.F. Hood, H. Scott and M.T. McEllistrem, Nucl. Phys. 36 (1962) 631

1962BO33 P.H. Bowen, G.C. Cox, G.B. Huxtable, J.P. Scanlon, J.J. Thresher and A. Langsford, Nucl. Phys. 30 (1962) 475

1962BR14 L.B. Brown and H.B. Knowles, Phys. Rev. 125 (1962) 1339

1962CA12 Y. Cassagnou, J.M.F. Jeronymo, G.S. Mani, A. Sadeghi and P.D. Forsyth, Nucl. Phys. 33 (1962) 449

1962CA13 S. Cavallaro, R. Potenza and A. Rubbino, Nucl. Phys. 36 (1962) 597

1962CE01 J. Cerny, B.G. Harvey and R.H. Pehl, Nucl. Phys. 29 (1962) 120

1962CH14 L.F. Chase Jr., R.G. Johnson, F.J. Vaughn and E.K. Warburton, Phys. Rev. 127 (1962) 859

1962CO05 M. Coste and L. Marquez, Compt. Rend 254 (1962) 1768

1962CO08 D. Connor and T. Tsang, Phys. Rev. 126 (1962) 1506

1962CO21 M. Coste, Compt. Rend. 255 (1962) 2750

1962CU05 B. Cujec, Nucl. Phys. 37 (1962) 396

1962EL01 A.J. Elwyn and R.O. Lane, Nucl. Phys. 31 (1962) 78

1962FO1E Foster and Glasgow, Bull. Amer. Phys. Soc. 7 (1962) 334

1962GA21 A. Garin and L. Marquez, J. Phys. Rad. 23 (1962) 970

1962GA23 J.P. Garron, Ann. Phys. (Paris) 7 (1962) 301

1962HA15 I.G. Han and N.P. Heydenburg, Bull. Amer. Phys. Soc. 7 (1962) 570, D10

1962HA23 S.S. Hanna, Bull. Amer. Phys. Soc. 7 (1962) 470, LA4

1962IG1B Igo, Hansen and Gooding, UCRL 10574 (1962)

1962IN02 D.R. Inglis, Nucl. Phys. 30 (1962) 1

1962IN1A Inglis, Rev. Mod. Phys. 34 (1962) 165

1962IW1A Iwao and Viano, Phys. Lett. 3 (1962) 9

1962JE02 J.M.F. Jeronymo, G.S. Mani, F. Picard and A. Sadeghi, Nucl. Phys. 38 (1962) 11

1962KO13 M.P. Konstantinova, E.V. Myakinin, A.M. Petrov and A.N. Ronsnov, Zh. Eksp. Teor. Fiz. 43 (1962) 388; JETP (Sov. Phys.) 16 (1963) 278

1962LA15 N.O. Lassen, Nucl. Phys. 38 (1962) 442

1962LU01 R.A. Lux, R.A. Blue and W. Haeberli, Bull. Amer. Phys. Soc. 7 (1962) 268, CB5

1962MA40 D.R. Maxson, Phys. Rev. 128 (1962) 1321

1962MA59 K.V. Makariunas, E.K. Makariuniene and V.J. Dienys, Litov. FIz. Sbornik (USSR) 2 (1962) 351; ; Nucl. Sci. Abstr. 18, 2032, Abs.15242 (1964); Phys. Abs. 3703 (1964)

1962NE14 B.M.K. Nefkens, Bull. Amer. Phys. Soc. 7 (1962) 550, T6

1962NO02 M.E. Nordberg Jr., F.B. Morinigo and C.A. Barnes, Phys. Rev. 125 (1962) 321

1962OT01 P.S. Otstavnov and V.I. Popov, Zh. Eksp. Teor. Fiz. 43 (1962) 385; JETP (Sov. Phys.) 16 (1963) 276

1962PE20 A.M. Petrov, Zh. Eksp. Teor. Fiz. 43 (1962) 66; JETP (Sov. Phys.) 16 (1963) 47

1962RO12 L. Rosen and L. Stewart, Phys. Rev. 126 (1962) 1150

1962RO20 L. Rosen and W.T. Leland, Phys. Rev. Lett. 8 (1962) 379

1962SE1A Serov and Guzhovskii, Atomn. Energ. (USSR) 12 (1962) 5

1962SH1F Shimodaya, Tamagaki and Tanaka, Prog. Theor. Phys. 27 (1962) 793

1962ST12 F.A. St. Romain, T.W. Bonner, R.L. Bramblett and J. Hanna, Phys. Rev. 126 (1962) 1794

1962TE01 G.M. Temmer, Bull. Amer. Phys. Soc. 7 (1962) 59, R4

1962TE02 A.R. Tejera, Bull. Amer. Phys. Soc. 7 (1962) 570, D6

1962TE04 I.B. Teplov, I.S. Dmitriev, Y.A. Teplova and O.P. Shevchenko, Zh. Eksp. Teor. Fiz. 42 (1962) 353; JETP (Sov. Phys.) 15 (1962) 243

1962TE07 I.B. Teplov, I.S. Dmitriev, Y.A. Teplova and O.P. Shevchenko, Izv. Akad. Nauk SSSR Ser. Fiz. 26 (1962) 1150; Bull. Acad. Sci. USSR Phys. Ser. 26 (1962) 1162

1962VA1A Vasilyev, Komarcv and Popova, Zh. Skep. Teor. Fiz. 43 (1962) 737; JETP (Sov. Phys.) 16 (1963) 521

1962VA25 S.S. Vasilyev, V.V. Komarov and A.M. Popova, Nucl. Phys. 38 (1962) 344

1962WE13 C. Weddigen, Z. Phys. 170 (1962) 448

1962WE1C Wegner, Rev. Sci. Instrum. 33 (1962) 271

1963AL19 D.E. Alburger, P.F. Donovan and D.H. Wilkinson, Phys. Rev. 132 (1963) 334

1963AL1J Alter and Lorenzi, NAA-SR-MEMO-9028 (1963)

1963AN09 Y. Antoufiev, I. Bondouk, A. Fikri, F. Machali and P.V. Sorokin, Nucl. Phys. 47 (1963) 426

1963AN10 Y.P. Antoufiev, M.M. El-Shesheni, H.R. Saad, Z.A. Saleh and P.V. Sorokin, Nucl. Phys. 48 (1963) 299; Izv. Akad. Nauk SSSR Ser. Fiz. 27 (1963) 1451

1963AS01 V.J. Ashby, H.C. Catron, M.D. Goldberg, R.W. Hill, J.M. Le Blanc, L.L. Newkirk, J.P. Stoering, C.J. Taylor and M.A. Williamson, Phys. Rev. 129 (1963) 1771

1963BA1R Bachelier et al., Padua (1963) 1141

1963BA2D Bahcall, Fowler, Iben and Sears, Astrophys. J. 137 (1963) 344

1963BA34 P. Bassi, B. Ferretti, G. Venturini, G.C. Bertolini, F. Cappellani, V. Mandl, G.B. Restelli and A. Rota, Nuovo Cim. 28 (1963) 1049

1963BA50 R. Batchelor and J.H. Towle, Nucl. Phys. 47 (1963) 385

1963BA56 J.F. Barry, J. Nucl. Energy 17 (1963) 273

1963BA58 R. Balzer, D. Bharucha, F. Heinrich and A. Hofmann, Helv. Phys. Acta 36 (1963) 495

1963BE1U Y.A. Berezhnoi, A.P. Klyucharev, Y.N. Ranyuk and N.Y. Rutkevich, Zh. Skep. Teor. Fiz. 45 (1962) 1030; JETP (Sov. Phys.) 18 (1963) 713

1963BI22 R. Bilwes, B. Bourotte and D. Magnac-Valette, J. Phys. 24 (1963) 948

1963BI27 M. Birk, G. Goldring, P. Hillman and R. Moreh, Nucl. Phys. 41 (1963) 58

1963BL20 H.R. Blieden, G.M. Temmer and K.L. Warsh, Nucl. Phys. 49 (1963) 209

1963BO06 R.R. Borchers and C.H. Poppe, Phys. Rev. 129 (1963) 2679

1963BO1N Bowen, Cox, Huxtable, Scanlon, Thrresher, Langsford and Appel, Nucl. Phys. 41 (1963) 177

1963BR03 J.D. Bronson, W.D. Simpson and G.C. Phillips, Bull. Amer. Phys. Soc. 8 (1963) 125, U8

1963BR1N Brandus, Iosifescu, Sandulescu and Stihi, Rev. Phys. (Rumania) 8 (1963) 431

1963BR28 F. Brown, R.H. James, J.L. Perkin and J. Barry, J. Nucl. Energy (Reactor Sci. Tech.) A17 (1963) 137

1963BU1C Bunakov, Phys. Lett. 7 (1963) 14

1963CA1K Calvi, Cavallaro, Potenza and Rubbino, Padua (1963) 1068

1963CR08 L. Cranberg, A. Jacquot and H. Liskien, Nucl. Phys. 42 (1963) 608

1963DA05 J. Darvas, Z. Naturforsch. A18 (1963) 569

1963DA1C Davis, Bull. Amer. Phys. Soc. 8 (1963) 26

1963DE1G Demortier, Dossin, Savariraj and Deconninck, Ann. Soc. Sci. Bruxelles 77 (1963) 81

1963DE29 G. Deconninck and G. Demortier, Phys. Lett. 7 (1963) 260

1963DI02 F.S. Dietrich, J.L. Honsaker and J.W. Davies, Bull. Amer. Phys. Soc. 8 (1963) 120, M5

1963DI17 L. Dick, L. Feuvrais and M. Spighel, Phys. Lett. 7 (1963) 150

1963DO08 W.E. Dorenbusch and C.P. Browne, Phys. Rev. 131 (1963) 1212

1963DO11 W.E. Dorenbusch and C.P. Browne, Phys. Rev. 132 (1963) 1759

1963DR1B Drisko, Satchler and Dassel, 3rd Conf. on Reactions between Complex Nuclei (1963) 85

1963EL1D El-Nadi, Rabie and Sherif, Nucl. Phys. 48 (1963) 569

1963FE03 L. Feldman, B.B. Baliga and M. Nessin, Bull. Amer. Phys. Soc. 8 (1963) 290, A6

1963FR1G Freeman and Mani, J. Phys. 24 (1963) 951

1963GL1C Glendenning, Ann. Rev. Nucl. Sci. 13 (1963) 191

1963GL1E Glasgow and Burge, Nucl. Phys. 50 (1963) 327

1963GO1M Goldberg, May and Stehn, BNL-400, 2nd Ed., Vol. 1 (1963)

1963GR11 W. Gruhle, K.H. Lauterjung, B. Schimmer, U. Schimmer and U. Schmidt-Rohr, Nucl. Phys. 42 (1963) 321

1963HA1G Haeberli, in Fast Neutron Phys., Eds. Marion and Fowler (Academic Press, 1963) 1379

1963HU1G Huffaker and Greuling, Bull. Amer. Phys. Soc. 8 (1963) 315

1963HW01 C.F. Hwang, G. Clausnitzer, D.H. Nordby, S. Suwa and J.H. Williams, Phys. Rev. 131 (1963) 2602

1963IS04 G. Ischenko, D. Seyboth and H. Wegener, Z. Phy. 175 (1963) 422

1963JA07 A.N. James and H.G. Pugh, Nucl. Phys. 42 (1963) 441

1963JE05 H. Jeremie, Nucl. Phys. 47 (1963) 225

1963KA20 M. Kamegai, Phys. Rev. 131 (1963) 1701

1963KU03 D. Kurath, Phys. Rev. 130 (1963) 1525

1963LA02 R.A. Lasalle, R.D. Benta and J.G. Cramer Jr., Bull. Amer. Phys. Soc. 8 (1963) 303, D8

1963LE19 C. Lemeille, D. Manesse, L. Marquez, N. Saunier and J.L. Quebert, J. Phys. 24 (1963) 908

1963LE1K Levintov and Pavlovskii, Zh. Eksp. Teor. Fiz. 44 (1963) 1442; JETP (Sov. Phys.) 17 (1963) 969

1963LO1E Lozhkin, Perfilov and Iakovlev, Dokl. Akad. Nauk SSSR 151 (1963) 826; Sov. Phys. Dokl. 8 (1964) 791

1963LU10 H.F. Lutz, J.B. Mason and M.D. Karvelis, Nucl. Phys. 47 (1963) 521

1963MA02 J.D. Marshall, N.R. Fletcher and R.H. Davis, Bull. Amer. Phys. Soc. 8 (1963) 10, BA1

1963MA1E Mattkhiz, Neudachin and Smirnov, Izv. Akad. Nauk. SSSR Ser. Fiz. 27 (1963) 1273

1963MA1R Marion, Univ. of Maryland TR 320 (1963)

1963MA61 M.H. MacGregor, R. Booth and W.P. Ball, Phys. Rev. 130 (1963) 1471

1963ME09 V. Meyer, W. Pfeifer and H.H. Staub, Helv. Phys. Acta 36 (1963) 465

1963MI01 I. Minzatu, N. Martalogu, A. Calboreanu, I. Vilcov and T. Magda, Nucl. Phys. 40 (1963) 347

1963MI06 I. Minzatu, A. Calboreanu, N. Martalogu, R. Dumitrescu and M. Molea, Phys. Lett. 4 (1963) 357

1963MI08 I.V. Mitchell and R.B. Taylor, Nucl. Phys. 44 (1963) 664

1963MI1M Milone, Padua (1963) 536

1963MI20 I. Minzatu, A. Calboreanu, N. Martalogu, R. Dumitrescu and M. Molea, Rev. Roum. Phys. 8 (1963) 417

1963MO1H Mottelson, Nucl. Spectroscopy; Ed. Racah (Academis Press, 1962)

1963MO1J Morinigo, Private Communication (1963)

1963MO1K Morinigo, Unpublished Thesis, CalTech (1963)

1963NA1E Nash, Nuovo Cim. 30 (1963) 1064

1963NE02 B.M.K. Nefkens, Phys. Rev. Lett. 10 (1963) 55

1963NE07 B.M.K. Nefkens, Phys. Rev. Lett. 10 (1963) 243

1963OG1A Ogloblin, Nucl. Phys. 47 (1963) 408

1963PA04 P. Paul and D. Kohler, Phys. Rev. 129 (1963) 2698

1963PA1K Palmer, Skofronick and Herb, Bull. Amer. Phys. Soc. 8 (1963) 320

1963PE15 R.R. Perry, B. Mainsbridge and J. Rickards, Nucl. Phys. 45 (1963) 586

1963PH1A Phillips, Bronson, Pitts, Barnard, Weil and Belote, Padua (1963) 1070

1963PU02 K.H. Purser and B.H. Wildenthal, Nucl. Phys. 44 (1963) 22; Erratum Nucl. Phys. 50 (1964) 694

1963RA01 P. Radvanyi, D. Bachelier, M. Bernas, C. Detraz, J. Genin and J.N. Haag, Bull. Amer. Phys. Soc. 8 (1963) 10, BA2

1963RE09 N.W. Reay, N.M. Hintz and L.L. Lee Jr., Nucl. Phys. 44 (1963) 338

1963RI09 V. Riech, Phys. Lett. 6 (1963) 267

1963SA10 N. Sarma, K.S. Jayaraman and C.K. Kumar, Nucl. Phys. 44 (1963) 205

1963SC1N Schlueter, Univ. of Kansas Rept. (1963)

1963SE1F Sellschop and Mingay, Padua (1963) 425

1963SE1G Sellschop and Mingay, Padua (1963) 545

1963SH04 N.K. Sherman, Phys. Lett. 4 (1963) 113

1963SH1G Shumilov, Zh. Eksp. Teor. Fiz. 44 (1963) 1199; JETP (Sov. Phys.) 17 (1963) 812

1963TA1B Takeda and Nakasima, 3rd Conf. on Reactions between Complex Nuclei (1963) 159

1963TO02 T.A. Tombrello and L.S. Senhouse, Phys. Rev. 129 (1963) 2252

1963TR08 P. Truol and V. Meyer, Helv. Phys. Acta 36 (1963) 494

1963VA04 S.S. Vasilyev, V.V. Komarov and A.M. Popova, Nucl. Phys. 40 (1963) 443

1963VA1C Valentin, Albouy, Cohen and Gusakow, Phys. Lett. 7 (1963) 163

1963WE08 J.A. Weinman and R.K. Smither, Nucl. Phys. 45 (1963) 260

1963WE1B Wegner, Hall and Miller, Padua (1963) 1104

1963WE20 J.T. Wells, A.B. Tucker and W.E. Meyerhof, Phys. Rev. 131 (1963) 1644

1963WI1H Wittern, Z. Naturforsch. A18 (1963) 1254

1964AM1D Amit and Latz, Nucl. Phys. 58 (1964) 297

1964AN08 Y.P. Antufev, T. Bunduk, A. Fikri, F. Machali and N.V. Sorokin, Zh. Eksp. Teor. Fiz. 46 (1964) 409; JETP (Sov. Phys.) 19 (1964) 276

1964AR25 A.H. Armstrong, J. Gammel, L. Rosen and G.M. Frye, Jr., Nucl. Phys. 52 (1964) 505

1964AS04 F. Asfour, I. Bondouk, V.J. Gontchar, V.A. Lutsik, F. Machali and I.I. Zaloubovsky, Nucl. Phys. 58 (1964) 453

1964BA16 J.K. Bair, C.M. Jones and H.B. Willard, Nucl. Phys. 53 (1964) 209

1964BA1C Balashov, Boyarkina and Rotter, Nucl. Phys. 59 (1964) 417

1964BA1X Bahcall, Phys. Rev. 135 (1964) B137

1964BA1Y Barker, Proc. Phys. Soc. (London) 84 (1964) 681

1964BA2A Bahcall, Phys. Rev. Lett. 12 (1964) 300

1964BE1M Berkowitz, Nucl. Phys. 60 (1964) 555

1964BE1N Beregi, Selenskaja, Neudatchin and Smirnov, Congres Int. de Phys. Nucl., Paris (1964)

1964BL12 J.L. Black, G.A. Jones and P.B. Treacy, Nucl. Phys. 54 (1964) 689

1964BL1C Blieden, Phys. Lett. 9 (1964) 176

1964BO31 R. Bouchez, J.-C. Gondrand, P. Perrin, C. Perrin, A. Giorni, R. Quivy and M. Dubus, Compt. Rend. 259 (1964) 3501

1964BR05 J.D. Bronson, W.D. Simpson, W.R. Jackson and G.C. Phillips, Bull. Amer. Phys. Soc. 9 (1964) 406, CA4

1964BR1H Brown, Paris (1964) 129

1964BR1U Brown, Blair, Bodansky, Cue and Kavaloski, Bull. Amer. Phys. Soc. 9 (1964) 545

1964BR25 T.A. Brinkley, B.A. Robson and E.W. Titterton, Proc. Phys. Soc. (London) 84 (1964) 201

1964BU08 S.G. Buccino, C.E. Hollandsworth and P.R. Bevington, Nucl. Phys. 53 (1964) 375

1964CA16 R.R. Carlson, R.L. McGrath and E. Norbeck, Phys. Rev. 136 (1964) B1687

1964CA1G Carlson and Kibler, SUI 64-21 (1964)

1964CO1D Conzett, Slobodrian, Yamabe and Shield, Congres Int. de Phys. Nucl., Paris (1964)

1964CO27 H.E. Conzett, E. Shield, R.J. Slobodrian and S. Yamabe, Bull. Amer. Phys. Soc. 9 (1964) 704, B5

1964DA12 P. Darriulat, G. Igo, H.G. Pugh and H.D. Holmgren, Phys. Lett. 11 (1964) 326

1964DA1B W.W. Daehnick and L.J. Denes, Phys. Rev. 136 (1964) B1325.

1964DA1G Davis and Mayer-Boricke, Congres Int. de Phys. Nucl., Paris (1964)

1964DE1H Dehnhard, Kamke and Kramer, Phys. Lett. 12 (1964) 113

1964DE1K Demortier and Deconninck, Congres. Int. de Phys. Nucl., Paris (1964)

1964DU1D Duck, Nucl. Phys. 57 (1964) 643

1964DU1E Duncan, Duggan and Purrington, Phys. Rev. 134 (1964) B164

1964EN1C Endo, Shimodaya and Miura, Prog. Theor. Phys. 31 (1964) 1157

1964ET02 J.E. Etter, M.A. Waggoner, H.D. Holmgren, C. Moazed and A.A. Jaffe, Phys. Lett. 12 (1964) 42

1964FA08 U. Fasoli, D. Toniolo and G. Zago, Nuovo Cim. 34 (1964) 542

1964FE01 P. Fessenden and D.R. Maxson, Phys. Rev. 133 (1964) B71

1964GA1E Garin et al., J. Phys. 25 (1964) 768

1964GL03 R. Gleyvod, I.M. Naqib and N.P. Heydenburg, Bull. Amer. Phys. Soc. 9 (1964) 349, E11

1964GO25 V.I. Goldansky, Phys. Lett. 9 (1964) 184

1964GR1J Green, Nucl. Phys. 54 (1964) 505

1964HI04 C.T. Hibdon, Phys. Rev. 133 (1964) B353

1964JO04 C.H. Johnson and C.C. Trail, Phys. Rev. 133 (1964) B1183

1964JO1D Jones, Bair, Johnson and Willard, Congres Int. de Phys. Nucl., Paris (1964)

1964JO1F Jones, Bair, Johnson and Willard, Bull. Amer. Phys. Soc. 9 (1964) 390

1964KE1F Kermode, Proc. Phys. Soc. (London) 84 (1964) 557

1964LA19 R.O. Lane, A.J. Elwyn and A. Langsdorf Jr., Phys. Rev. 136 (1964) B1710

1964LE1C Letessier, Phys. Lett. 10 (1964) 102

1964LO1F Lozhkin and Yakovlev, Zh. Eksp. Teor. Fiz. 47 (1964) 7; JETP (Sov. Phys.) 20 (1965) 4

1964MA1G Mamasakhlisov, Izv. Akad. Nauk SSSR Ser. Fiz. 28 (1964) 1550

1964MA25 B.S. Madsen and M. Vedelsby, Nucl. Phys. 55 (1964) 477

1964MA2D Mani, Freeman, Redon, Sadeghi and Picard, Congres Int. de Phys. Nucl., Paris (1964)

1964MA35 E. Matt, H. Pfander, H. Rieseberg and V. Soergel, Phys. Lett. 9 (1964) 174

1964MA51 G.S. Mani, R. Freeman, F. Picard, A. Sadeghi and D. Redon, Nucl. Phys. 60 (1964) 588

1964MI10 P.D. Miller, J.L. Duggan and M.M. Duncan, Nucl. Phys. 54 (1964) 155

1964MI14 I. Minzatu, A. Calboreanu, N. Martalogu, M. Molea and R. Dumitrescu, Rev. Roum. Phys. 9 (1964) 763

1964MI1J Milone and Potenza, Congres Int. de Phys. Nucl., Paris (1964)

1964MO19 C. Moazed, J.E. Etter, H.D. Holmgren and M.A. Waggoner, Phys. Lett. 12 (1964) 45

1964MO1L Morinigo, Nucl. Phys. 50 (1964) 136

1964PA06 P. Paul and K.P. Lieb, Nucl. Phys. 53 (1964) 465

1964PA13 P. Paul, S.L. Blatt and D. Kohler, Phys. Lett. 10 (1964) 201

1964PA1A Parker, Bahcall and Fowler, Astrophys. J. 139 (1964) 602

1964PA1K Pape, UCRL 11598 (1964)

1964PR04 F.W. Prosser Jr. and F.L. Wilson, Nucl. Phys. 54 (1964) 148

1964QU01 J.L. Quebert, M. Coste and L. Marquez, Nucl. Phys. 54 (1964) 257

1964SC19 D.J. Schlueter, R.W. Krone and F.W. Prosser Jr., Nucl. Phys. 58 (1964) 254

1964SH05 J.H. Shafer, Phys. Rev. 133 (1964) B920

1964SH07 T.H. Short and N.M. Hintz, Bull. Amer. Phys. Soc. 9 (1964) 391, BA16

1964SH19 E. Shield, H.E. Conzett, P. Darriulat, H. Pugh and R.J. Slobodrian, Bull. Amer. Phys. Soc. 9 (1964) 703, B4

1964ST1B Stovall, Phys. Rev. 133 (1964) B268

1964ST25 J.R. Stehn, M.D. Goldberg, B.N. Magurno and R. Wiener-Chasman, BNL-325, 2nd Ed., Suppl. 2, Vol. 1 (1964)

1964SY02 G.D. Symons, Phys. Lett. 10 (1964) 89

1964TA05 N.W. Tanner, G.C. Thomas and E.D. Earle, Nucl. Phys. 52 (1964) 29

1964TI02 G. Tibell, O. Sundberg and P.U. Renberg, Ark. Fys. 25 (1964) 433

1964TO1A M.E. Toms, Nucl. Phys. 50 (1964) 561

1964TO1D Tombrello, Bull. Amer. Phys. Soc. 9 (1964) 704

1964TO1E Toms, Congre Int. de Phys. Nucl., Paris (1964)

1964VA14 V. Valkovic, Nucl. Phys. 54 (1964) 465

1964VA19 V. Valkovic, Nucl. Phys. 60 (1964) 581

1964VA1E Valkovic and Tomas, Congres Int. de Phys. Nucl., Paris (1964)

1964VA1J Van Niftrik, Brockman and Van Oers, Congres Int. de Phys. Nucl., Paris (1964)

1964VO1B Volkov, Phys. Lett. 12 (1964) 118

1964WE1C Werner and Zimmerer, Congres. Int. de Phys. Nucl., Paris (1964)

1964YA1A Yanabu et al., J. Phys. Soc. Jpn. 19 (1964) 1818

1964YO06 F.C. Young, P.D. Forsyth, M.L. Roush, W.F. Hornyak and J.B. Marion, Phys. Lett. 13 (1964) 50

1965AJ01 F. Ajzenberg-Selove, J.W. Watson and R. Middleton, Phys. Rev. 139 (1965) B592

1965AL02 W.J. Alston III, J.E. Draper and R.H. Hilberg, Bull. Amer. Phys. Soc. 10 (1965) 94, HD3

1965AL1B D.E. Alburger and P.F. Donovan, Rev. Mod. Phys. 37 (1965) 448

1965AN09 W.D. Andress Jr., F.O. Purser, J.R. Sawers Jr. and R.L. Walter, Nucl. Phys. 70 (1965) 313

1965AN12 G.B. Andreev, A.S. Deineko and I.Y. Malakhov, Izv. Akad. Nauk SSSR Ser. Fiz. 29 (1965) 210; Bull. Acad. Sci. USSR Phys. Ser. 29 (1966) 211

1965BA1A A.I. Baz, V.I. Goldanskii and Ya.B. Zeldovich, Usp. Fiz. Nauk 85 (1965) 445; Sov. Phys. Usp. 8 (1965) 177

1965BA2H Barker, Bull. Amer. Phys. Soc. 10 (1965) 439

1965BE1H Beregi, Zelenskaja, Neudatchin and Smirnov, Nucl. Phys. 66 (1965) 513

1965BE1P Bernstein, Ginaven, Chubinsky and Kossler, Unknown Source

1965BE1W Bender and Newman, Bull. Amer. Phys. Soc. 10 (1965) 602

1965BI1F Bilwes and Bourotte, Rev. Mod. Phys. 37 (1965) 458

1965BO07 I. Boca, M. Borsaru, M. Cenja and E. Iliescu, Nucl. Phys. 62 (1965) 75

1965DA1A Darriulat, Igo, Pugh and Holmgren, Phys. Rev. 137 (1965) B315

1965DE08 C. Detraz, J. Cerny and R.H. Pehl, Phys. Rev. Lett. 14 (1965) 708

1965DE1V Dehnhard, Gemmel and Vager, Bull. Amer. Phys. Soc. 10 (1965) 462

1965DI1F Dietrich and Zafiratos, Bull. Amer. Phys. Soc. 10 (1965) 439

1965DU1C Duck, Rev. Mod. Phys. 37 (1965) 418

1965ET1A Etter, Waggoner, Moazed, Holmgren and Han, Rev. Mod. Phys. 37 (1965) 444

1965FA03 U. Fasoli, D. Toniolo and G. Zago, Nuovo Cim. 37 (1965) 349

1965FR02 R.M. Freeman and G.S. Mani, Proc. Phys. Soc. (London) 85 (1965) 267

1965FU1G Fuller and Cohen, Appendix I, Nucl. Data Sheets 6-5 (1965)

1965GL03 R. Gleyvod, N.P. Heydenburg and I.M. Naqib, Nucl. Phys. 63 (1965) 650

1965GR08 G.M. Griffiths, Nucl. Phys. 65 (1965) 647

1965JA07 R. Jahr and R. Santo, Nucl. Phys. 67 (1965) 401

1965JO19 C.M. Jones, J.K. Bair, C.H. Johnson, H.B. Willard and M. Reeves III, Rev. Mod. Phys. 37 (1965) 437

1965KA1F Kacser and Aitchison, Rev. Mod. Phys. 37 (1965) 350

1965KO05 D. Kohler and P. Paul, Phys. Lett. 15 (1965) 157

1965KO1B Komar and Makhnovskii, Dokl. Akad. Nauk SSSR 160 (1965) 1300; Sov. Phys. Dokl. 10 (1965) 150

1965LE09 C. Lemeille, D. Manesse, L. Marquez, N. Saunier and J. Steyaert, J. Phys. (Paris) 26 (1965) 1

1965LO1K Lomakin and Nechaev, Atomnaya Energ. 18 (1965) 33

1965MA13 G.S. Mani, R.M. Freeman, F. Picard, D. Redon and A. Sadeghi, Proc. Phys. Soc. (London) 85 (1965) 281

1965MA1G Marion, Phys. Lett. 14 (1965) 315

1965MA1K Marion, Nucl. Phys. 68 (1965) 463

1965MA1V Markowitz and Pape, Bull. Amer. Phys. Soc. 10 (1965) 602

1965MA2A Mancusi et al., Bull. Amer. Phys. Soc. 10 (1965) 628

1965MA2B Marion, Bull. Amer. Phys. Soc. 10 (1965) 9

1965MC06 W.R. McMurray, P. Van Der Merwe and I.J. Van Heerden, Phys. Lett. 18 (1965) 319

1965MO1L Morgan, Hollandsworth and Walter, Bull. Amer. Phys. Soc. 10 (1965) 440

1965MO1M Moazed, Etter, Holmgren and Waggoner, Rev. Mod. Phys. 37 (1965) 354

1965MO1N Moazed, Etter, Holmgren and Waggoner, Rev. Mod. Phys. 37 (1965) 441

1965MO1P Morrison, Evans, Gale, Ollerhead and Warburton, Private Communication (1965)

1965NE1C Neudatchin and Smirnov, Nucl. Phys. 66 (1965) 25

1965NO1A Norbeck, Mancusi, Carlson and Berkowitz, Rev. Mod. Phys. 37 (1965) 455

1965OK1B Okai and Park, Bull. Amer. Phys. Soc. 10 (1965) 469

1965OL01 W.C. Olsen, W.K. Dawson, G.C. Neilson and J.T. Sample, Nucl. Phys. 61 (1965) 625

1965PH1A Phillips, Rev. Mod. Phys. 37 (1965) 409

1965PO03 A.M. Poskanzer, P.L. Reeder and I. Dostrovsky, Phys. Rev. 138 (1965) B18

1965RO1R Rogers, Bull. Amer. Phys. Soc. 10 (1965) 500

1965SL1C Slee, Bull. Amer. Phys. Soc. 10 (1965) 461

1965SW1B Swan, Rev. Mod. Phys. 37 (1965) 336

1965TA1E Tanner, Nucl. Phys. 63 (1965) 383

1965TR1B Treacy, Phys. Lett. 14 (1965) 125

1965VA23 L. Valentin, Nucl. Phys. 62 (1965) 81

1965WA12 J.W. Watson, F. Ajzenberg-Selove and R. Middleton, Phys. Lett. 18 (1965) 302

1965WA1M Waggoner, Etter, Holmgren and Moazed, Rev. Mod. Phys. 37 (1965) 358

1965WI07 M. Wilson and J.B. Marion, Phys. Lett. 14 (1965) 313

1965WI1A Williams, Gaedke and Toth, Bull. Amer. Phys. Soc. 10 (1965) 443

1965WIZZ M.A.D. Wilson, Unpublished Thesis, Univ. of Maryland (1965)

1965YO1D Young, Jayaramna, Etter, Holmgren and Waggoner, Rev. Mod. Phys. 37 (1965) 362

1965YU1C Yuasa and Hourani, Rev. Mod. Phys. 37 (1965) 399

1965YU1D Yuasa and Hourani, Compt. Rend. 260 (1965) 3609

1966BA1A J.N. Bahcall, Nucl. Phys. 75 (1966) 10

1966BE05 J. Benn, E.B. Dally, H.H. Muller, R.E. Pixley, H.H. Staub and H. Winkler, Phys. Lett. 20 (1966) 43

1966TY01 H. Tyren, S. Kullander, O. Sundberg, R. Ramachandran, P. Isacsson and T. Berggren, Nucl. Phys. 79 (1966) 321; Erratum Nucl. Phys. A119 (1968) 692