Energy Levels of Light Nuclei
$A = 8$

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

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

Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), 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 introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the TUNL/NNDC format.

(References closed December 01, 1958)

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

Table of Contents for $A = 8$

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

A. Nuclides: ^{8}Li, ^{8}Be, ^{8}B

B. Tables of Recommended Level Energies:

Table 8.1: Energy levels of ^{8}Li

Table 8.3: Energy levels of ^{8}Be

Table 8.10: Energy levels of ^{8}B

C. References

D. Figures: ^{8}Li, ^{8}Be, ^{8}B

E. Erratum to the Publication: PS or PDF

^{8}Li

(Fig. 7)

GENERAL:

Theory: See (1955LA1D, 1956KU1A, 1957FR1B, 1957KU1B).

1. ^{8}Li(β^-)^{8}Be $\qquad Q_m = 16.001$

The weighted mean of half-lives reported in (1955AJ61) is 0.848 ± 0.004 sec. A value of 0.873 ± 0.013 sec is given by (1958VE20). See also (1958IM1A). The decay is complex: see ^{8}Be.

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

$Q_0 = 0.790 \pm 0.011$ (1954AL35).

The ground state reaction has been observed by (1952MO19, 1952PE02, 1954AL35, 1955CU17). (1955CU17) also reports one event corresponding to the transition to an excited state at 0.7 ± 0.2 MeV.

3. ^{7}Li(n, γ)^{8}Li $\qquad Q_m = 2.035$

The thermal capture cross section is 33 ± 5 mb (1947HU06), 42 ± 10 mb (1956KO1C). At $E_n = 275$ keV, neutron capture is not observed: $\sigma < 0.25$ mb (1956KO1C). Polarization of ^{8}Li produced by polarized thermal neutrons has been detected by (1957BU44). See also (1957KU1B, 1958IM1A, 1958SH1A).

4. ^{7}Li(n, n)^{7}Li $\qquad E_b = 2.035$

Cross sections for Li metal and for ^{7}Li are reported in (1958HU18: see also (1956GO62, 1957KA1B, 1958BR16)). The thermal cross section is 1.07 ± 0.04 b (C. Hibdon: see (1955HU1B, 1956TH06)).

A pronounced resonance occurs at $E_n = 258$ keV (see Table 8.2). Total cross sections and angular distributions establish that the state has $J = 3^+$, formed by p-waves (1956WI04). A further, broad peak centering at $E_n \approx 5$ MeV may indicate a broad level of ^{8}Li at ≈ 6.5 MeV (1958HU18: see also (1956GO62)).

Table 8.1: Energy levels of ^{8}Li

E_x in ^{8}Li (MeV)	J^π	$\tau_{1/2}$ or Γ (keV)	Decay	Reactions
0	2^+	$\tau_{1/2} = 0.848 \pm 0.004$ sec	β^-	1, 2, 3, 9, 12, 14, 18
0.975 ± 0.012	$\leq 3^+$		(γ)	2, 9, 18
2.260 ± 0.005	3^+	28	n	4, 9
3.22	$1^{(+)}$	≈ 1000	n	5

Table 8.2: ^{7}Li(n, n)^{7}Li resonance parameters [a]

	(1956WI04)	(1956TH06, 1958HU18)
E_{res} (keV)	256	258 ± 3 [b]
Γ (keV)	32	32 [c]
$\Gamma_n(E_r)$ (keV)	35.8	
γ_n^2 (keV)	351	307
E_λ (keV)	-49	-43
radius (10^{-13} cm)	4.08	4.0
σ_{max} (b)		12.0

[a] Energies in the laboratory system.
[b] $E_{res} = 275$ keV, $\sigma_{max} = 7.0 \pm 0.2$ b (1956GO62).
[c] 35 ± 5 keV (1958HU18).

Data on coherent scattering and total cross section for zero-energy neutrons permit two solutions for the two s-wave scattering lengths corresponding to anti-parallel ($J = 1^-$) and parallel ($J = 2^-$) interactions; for the first solution, the interaction is essentially pure $J = 1^-$, for the other, pure $J = 2^-$. Measurement of the interference between the s-wave background and the p-wave (channel spin 2) resonance indicate that the second solution is the correct one, and it is concluded that the splitting between parallel and anti-parallel interactions is about 1.5 MeV (1956TH06). (1956WI04) find, on the other hand, that the observed asymmetries in the angular distributions indicate a nearly statistical ($\frac{5}{3}$) mixture of $J = 1^-$ and 2^- background. Use of scattering in ^{7}Li as a polarization analyzer is discussed by (1956WI1E).

See also (1956BE98, 1957KH1A).

5. ^{7}Li(n, n′)^{7}Li* $\qquad$ $E_b = 2.035$

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 $E_{\rm n} = 1.35$ 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). On the other hand, the latter resonance appears to be better described as a $J = 1^+$ level, formed by p-waves. Under this assumption, $E_{\rm r}$(lab) $= 1.45$ MeV, $\Gamma = 1.14$ MeV, with the sum of reduced widths $\theta^2_{\rm in} + \theta^2_{\rm out} \approx 0.5 \times (3\hbar^2/2MR^2)$. The ratio $\theta^2_{\rm in}/\theta^2_{\rm out} = 0.1$ to 0.4 or 1.0 to 3.0 (1955FR10).

6. ^{7}Li(n, p)^{7}He $\qquad Q_{\rm m} = -14 \qquad E_{\rm b} = 2.035$

Not observed: see ^{7}He.

7. ^{7}Li(n, d)^{6}He $\qquad Q_{\rm m} = -7.779 \qquad E_{\rm b} = 2.035$

At $E_{\rm n} = 14$ MeV, the cross section is 9.8 ± 1.1 mb (1953BA04). See also (1954FR03).

8. (a) ^{7}Li(n, t)^{5}He $\qquad Q_{\rm m} = -3.423 \qquad E_{\rm b} = 2.035$

(b) ^{7}Li(n, t)^{4}He + n $\qquad Q_{\rm m} = -2.466$

The cross section for reaction (a) is 55 ± 8 mb at $E_{\rm n} = 14$ MeV (1954FR03). See also (1954MA1E) and (1954BA1B).

9. ^{7}Li(d, p)^{8}Li $\qquad Q_{\rm m} = -0.192$

$Q_0 = -0.183 \pm 0.02$ (1955KH31).

Three proton groups are observed, corresponding to the ground state and to levels at 0.974 ± 0.015 (1955LE24), 0.977 ± 0.02 MeV (1955KH31, 1955KH35) and 2.28 MeV (1955LE24). A search for further levels in the range $E_{\rm x} = 2.28$ to 8 MeV revealed no levels with $\Gamma < 80$ keV (1958HA10, 1958HA1G). At $E_{\rm d} = 14$ MeV, the angular distributions of the protons, analyzed by stripping theory, indicate $l_{\rm n} = 1$ and therefore even parity, $J \leq 3$, for the ground state and the 0.98-MeV level (1955LE24). On the assumption that $J = 2^+$ and 1^+ for the ground state and 0.98-MeV level, respectively, (1957FR1B) calculate $\theta^2 = 0.054$ and 0.028 from the data of (1955LE24). These two levels are presumed to arise from a ^{33}P term, with a third component of $J = 0^+$ expected at higher energy (1957FR1B). See also (1955GI1A).

10. ^{7}Li(t, d)^{8}Li $\quad Q_{\rm m} = -4.224$

Not observed.

11. ^{7}Li(α, ^{3}He)^{8}Li $\quad Q_{\rm m} = -18.543$

Not observed.

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

See ^{9}Be and (1958CH31).

13. ^{9}Be(n, d)^{8}Li $\quad Q_{\rm m} = -14.658$

Not observed.

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

Production of ^{8}Li at $E_{\rm p} = 20$ MeV is reported by (1956LE46). At $E_{\rm p} = 185$ MeV, the summed proton spectrum shows two peaks, corresponding to pickup of protons with binding energies of ≈ 18 and ≈ 26 MeV, respectively. There is some indication of α-particle structure (1958MA1B, 1958TY49).

15. ^{9}Be(d, ^{3}He)^{8}Li $\quad Q_{\rm m} = -11.409$

See (1954WI25).

16. ^{9}Be(t, α)^{8}Li $\quad Q_{\rm m} = 2.928$

Not observed.

17. ^{10}B(n, ^{3}He)^{8}Li $\quad Q_{\rm m} = -15.771$

Not observed.

18. ^{11}B(n, α)^{8}Li $\quad Q_{\rm m} = -6.636$

See ^{12}B.

^{8}Be

(Fig. 8)

GENERAL:

Theory: See (1955HE1E, 1956KU1A, 1956PE1A, 1957BI1C, 1957FR1B, 1958WI1E).

1. ^{8}Be $\rightarrow$ ^{4}He + ^{4}He $\quad Q_{\mathrm{m}} = 0.094$

Recent Q-values are 93.7 ± 0.9 keV (1957CO59: ^{9}Be(p, d)^{8}Be), 90 ± 5 keV (1955TR03: ^{11}B(p, α)^{8}Be): the weighted mean of all measurements is 94.1 ± 0.7 keV (1957VA11). The width of the ground state is 4.5 ± 3 eV (1956RU41: 15% of Wigner limit), ≤ 3.5 eV (1956HE57). The second value leads to $\tau_{\mathrm{m}} \geq 2 \times 10^{-16}$ sec. (Combination of these values places the mean life in the range $\tau_{\mathrm{m}} = 2$ to 4.5×10^{-16} sec.) An upper limit to the mean life is 6×10^{-15} sec (1955TR03). See also (1955AJ61).

2. ^{4}He(α, p)^{7}Li $\quad Q_{\mathrm{m}} = -17.347 \quad E_{\mathrm{b}} = -0.094$

See ^{7}Li.

3. ^{4}He(α, α)^{4}He $\quad E_{\mathrm{b}} = -0.094$

Absolute differential cross sections are reported for $E_{\alpha} = 0.15$ to 3.0 MeV (1956HE57), $E_{\alpha} = 3.0$ to 5.9 MeV (1956RU41), $E_{\alpha} = 12.9$ to 21.6 MeV (1953ST52), $E_{\alpha} = 12.3$ to 22.9 MeV (1956NI20), $E_{\alpha} = 20$ and 20.4 MeV (1951BR92, 1951MA1B), $E_{\alpha} = 30$ MeV (1951GR45, 1952GR1A), $E_{\alpha} = 38.5$ MeV (1957BU13), and $E_{\alpha} = 44.7$ MeV (1957CO63). See also (1958CH35).

Phase shifts summarizing the work of (1956HE57), (1956RU41) and (1956NI20) are presented in (1956RU41) and (1958NI05). These three sets of data appear to join smoothly, but do not appear to fit well with the data of (1953ST52). For $E_{\alpha} < 3$ MeV, only the s-wave phase shift is important. A careful survey in the range $146 - 202$ keV reveals no effect of the ground state and places an upper limit of $\Gamma \leq 3.5$ eV on this state (1956HE57): see Table 8.5. Analysis of the 0 to 6 MeV data by effective range theory leads to a value $\Gamma = 4.5 \pm 3$ eV for the ground-state width; $\theta^{2} \approx 0.15$ of the Wigner limit (with $R = 5.7 \times 10^{-13}$ cm). Some evidence of shape-dependence is found in this analysis (1956RU41). According to (1958NI05) a good account of the s-wave phase shift below 6 MeV is given by hard-sphere scattering plus resonance scattering from the ground state with a width $\theta^{2} = 0.75$ ($R = 4.44 \times 10^{-13}$ cm). There is no indication of other S-states below $E_{\mathrm{x}} = 11.5$ MeV (1958NI05).

Table 8.3: Energy levels of ^{8}Be

E_x in ^{8}Be (MeV)	$J^\pi; T$	Γ (MeV)	Deacy	Reactions
0	$0^+; 0$	2.5 ± 1 eV	α	1, 3, 12, 13, 14, 21, 22, 24, 26, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42
2.90 [a]	$2^+; 0$	1.2 ± 0.3 [b]	α	3, 12, 14, 21, 26, 27, 28, 29, 30, 31, 32, 33, 35, 36, 37, 38, 39, 40
11.7	$4^+; 0$	≈ 6.7	α	3, 12, 21, 27, 28
16.08		0.31	(α)	21, 39, 41
16.67	$(2^+; 1)$	0.19	α	21, 39, 41
(17.6)	$(2^+; 1)$	(< 0.3)	(α)	39
17.64	$1^+; (1)$	10.7 ± 0.5 keV	γ, p	14, 16, 21
18.15	$1^+; (0)$	147 keV	γ, p	14, 16, 17, 21
18.9	$(2^-; 0)$	> 0.5	n, p	15, 16, 17, 25
19.1	(3^-)	0.4	γ, p	14, 15, 16
19.22	$3^+; (1)$	0.19	n, p	15, 16
19.9	(2^+)	≈ 0.9	(n), α, p	15, 20
21.6		≈ 0.8	n, p	15
22.6	$(^+)$	≈ 0.35	d, n, α, p, γ	5, 6, 10, 14

[a] A number of additional states from $E_x = 2$ to 15 MeV have been reported by various observers: see, e.g. ^{7}Li(d, n)^{8}Be, ^{10}B(d, α)^{8}Be, ^{11}B(p, α)^{8}Be, ^{12}C(γ, α)^{8}Be and (1954TI1C).

[b] See Table 8.4.

Table 8.4: Energy and width of first excited state of ^{8}Be

E_x (MeV)	Γ (MeV)	Reaction	Reference
2.9	2.0	^{4}He(α, α)^{4}He	(1956RU41)
	1.9	^{7}Li(p, γ)^{8}Be	(1958ME78)
2.95	1.6 ± 0.4	^{7}Be(d, p)^{8}Be	(1958SP1A)
3.0 ± 0.1	1.0 ± 0.2	^{8}Li(β^-)^{8}Be	(1955AJ61) [a]
2.8 ± 0.1	0.8	^{9}Be(d, t)^{8}Be	(1955CU16)
2.87 ± 0.06	0.9 ± 0.2 [b]	^{10}B(d, α)^{8}Be	(1955AJ61) [a]
2.94 ± 0.06	0.84	^{11}B(p, α)^{8}Be	(1955AJ61) [a]
3.06	0.9	^{12}C(γ, α)^{8}Be	(1955GO59)

[a] See also text in reaction 3 in ^{8}Be.
[b] $\theta^2 \approx 2$ (1953TR04).

The d-wave phase shift first becomes appreciable near $E_\alpha = 2.5$ MeV (1956HE57) and appears to pass through resonance at 6.0 MeV (1956RU41). The g-wave shift rises continuously from $E_\alpha = 11$ to 23 MeV; a broad ^{8}Be level is indicated at $E_x = 11.7$ MeV (1956NI20, 1958NI05). The course of the phase shifts appears to be consistent with a simple two-body interaction with an attractive potential near $R \approx 5 \times 10^{-13}$ cm and a repulsive core at a smaller radius; some dependence of the well shape on l is required (1951HA1B, 1956HE1B, 1956RU41, 1958NI05, 1958VA1B). A detailed comparison with the model of (1951HA1B) is made by (1958NI05). At 38.5 MeV, the s and d phase shifts are large, while the δ_4, δ_6 and δ_8 phase shifts are small. These results are consistent with 0^+ and 2^+ states near 19 MeV (see ^{7}Li(p, α)^{4}He) and are not inconsistent with a 4^+ state at ≈ 11 MeV (1957BU13). See also (1955AJ61), (1956HA1C, 1958MC1C; theor.) and (1954SN1A).

4. ^{6}Li(d, γ)^{8}Be $\qquad Q_m = 22.279$

Not observed: see (1953SA1A, 1954SI07).

5. (a) ^{6}Li(d, n)^{7}Be $\qquad Q_m = 3.380 \qquad E_b = 22.279$
(b) ^{6}Li(d, n)^{4}He + ^{3}He $\qquad Q_m = 1.796$

The excitation 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

Table 8.5: Levels of ^{8}Be from ^{4}He(α, α)^{4}He [a]

E_x (MeV)	J^π	$\Gamma_{c.m.}$	R (10^{-13} cm)	θ^2 ($3\hbar^2/2MR^2$)
0	0^+	2.5 ± 1 eV	5.7	0.15
			4.44	0.75
2.9	2^+	2.0 MeV	5.0	0.7
			3.5	0.4
11.8	4^+	6.7 MeV	4.44	1.3

[a] From (1956HE57, 1956RU41, 1958NI05). Double entries indicate alternative solutions.

(1952BA64, 1956NE13). At this energy the neutron yield to the 0.43-MeV state of ^{7}Be is isotropic, while at $E_d = 600$ keV and above, the angular distributions indicate a strong admixture of stripping process (1956NE13). A sharp resonance at $E_d = 2.12$ MeV is reported by (1952BA64). However, (1957SL01) find that 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. This is confirmed by (1954BU1B) who reports no appreciable change in slope at $E_d \approx 1.8$ MeV and suggests that the increase in neutron yield observed by (1952BA64) might have been due to oxygen contamination.

The ratio of 430-keV γ-radiation from this reaction and 477-keV γ-radiation from the mirror reaction, ^{6}Li(d, p)^{7}Li, has been measured for $E_d = 0.2$ to 1.8 MeV. This ratio, which measures Γ_n/Γ_p, rises from 1.1 to about 1.13 at $E_d = 0.45$ MeV, falling to 0.98 at $E_d = 1.8$ MeV. The theoretical ratio, assuming charge symmetry, rises from 0.96 at low energy to 0.98 at $E_d = 1.8$ MeV. It is concluded that the predictions of charge independence are borne out within 15%, and that the slight deviation observed may be connected with the resonance near $E_d = 0.45$ MeV (1957WI24). See also (1954HI34).

6. (a) ^{6}Li(d, p)^{7}Li $\qquad Q_m = 5.027 \qquad E_b = 22.279$

(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 3 MeV by (1950KR1A, 1953SA1A: see (1950WH02, 1954NI10, 1957JA37)). A broad maximum near $E_d = 1.0$ MeV is interpreted by (1950WH02) as indicating a level at $E_d = 0.4$ MeV, $\Gamma \approx 0.5$ MeV. The angular distributions at $E_d > 1$ MeV indicate stripping effects, with $l_n = 1$ (1954NI10). See also the discussion of the work of (1957WI24) in the preceding section. See also (1955AJ61).

7. ^{6}Li(d, d)^{6}Li $\qquad E_b = 22.279$

See ^{6}Li.

8. ^{6}Li(d, t)^{5}Li $Q_m = 0.765$ $E_b = 22.279$

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.

9. ^{6}Li(d, ^{3}He)^{5}He $Q_m = 0.839$ $E_b = 22.279$

See ^{5}He.

10. ^{6}Li(d, α)^{4}He $Q_m = 22.373$ $E_b = 22.279$

Cross sections have been measured for $E_d = 30$ keV to 1.6 MeV (1953SA1A: see (1950WH02, 1954HI34, 1957JA37)). A broad maximum is observed at $E_d = 0.6$ MeV which is interpreted in terms of a resonance at $E_d = 0.35$ MeV, $\Gamma \approx 0.5$ MeV (1950WH02: see, however, (1954HI34)). See also (1956PO1A), (1956SA1B; theor.) and (1952AJ38).

11. ^{6}Li(t, n)^{4}He + ^{4}He $Q_m = 16.115$

See (1952CU1B).

12. ^{6}Li(^{3}He, p)^{8}Be $Q_m = 16.786$

At $E(^3\mathrm{He}) = 1.25$ MeV, proton groups are observed to the ground state, the 2.9-MeV state and possibly to a state at ≈ 12.3 MeV ($\Gamma \approx 2$ MeV, intensity $\approx 6\%$ of 2.9-MeV transition). It is suggested that the 12.3-MeV state may be that observed in ^{4}He(α, α)^{4}He. No other states are observed with $E_x \lesssim 14$ MeV. The upper limits on the intensities of groups leading to such states are 1% (of 2.9-MeV transition) for sharp states and 3% for levels 1 MeV wide (1956MO19). These results are confirmed by (1956SC01) at $E(^3\mathrm{He}) = 1.5$ and 2 MeV: no group of width $\lesssim 1$ MeV appears for $E_x < 14$ MeV with an intensity as much as 2% of the ^{8}Be*(2.9) group. See also (1953KU24, 1955AL57).

13. ^{6}Li(α, d)^{8}Be $\qquad Q_{\mathrm{m}} = -1.565$

This reaction has been observed at $E_{\alpha} = 31.5$ MeV (1956WA29).

14. ^{7}Li(p, γ)^{8}Be $\qquad E_{\mathrm{b}} = 17.253$

The cross section has been studied from $E_{\mathrm{p}} = 30$ keV (1957JA37) to 7.7 MeV. Resonances are observed at $E_{\mathrm{p}} = 0.44$, 1.03 and 2.1 MeV: see Table 8.6. There is no further structure up to 5 MeV (1952BA1B). The radiation comprises two components, one from the ground-state transition, with $E_{\gamma} = 17.2 + \frac{7}{8}\,E_{\mathrm{p}}$ and the other from the transition to the 2.9-MeV broad excited state, with $E_{\gamma} \approx 14.3 + \frac{7}{8}\,E_{\mathrm{p}}$. Both are resonant at the 0.44-MeV resonance, but only the lower energy transition shows the 2.1-MeV resonance (1957NE22). The intensity ratio of the higher to the lower-energy radiation increases from 0.5 at $E_{\mathrm{p}} = 0.2$ MeV to 1.7 at $E_{\mathrm{p}} = 0.44$ MeV and falls to 1.0 at $E_{\mathrm{p}} = 0.6$ MeV (1956CA1A: $\theta = 90°$). Between $E_{\mathrm{p}} = 1.0$ and 3.5 MeV the ratio is constant within 30% at $\frac{2}{3}$ (1955WI1D, 1957NE22). Evidence for a component at ≈ 12 MeV is discussed by (1953TI1C: see also (1955CA19)). A broad resonance appears near $E_{\mathrm{p}} = 5.8$ MeV probably corresponding to the “giant” (γ, p) resonance, $E_{\mathrm{x}} = 22.3$ MeV (1959GE33).

The angular distributions of both γ-rays show small deviations from isotropy at the $E_{\mathrm{p}} = 0.44$ MeV resonance and exhibit strong interference effects nearby. The observed distribution of the 17.6-MeV radiation at resonance is consistent with p-wave formation if the channel spin ratio $\chi \equiv \sigma(1)/\sigma(2) = \frac{1}{4}$: this ratio implies an intermediate coupling with $a/K = 2$ to 3 (1958NE17: see also (1950DE1A, 1957FR1B)). Angular distributions in the range $E_{\mathrm{p}} = 0.9$ to 1.2 MeV are reported by (1954KR06) an $0°/90°$ cross sections for $E_{\mathrm{p}} = 1.5$ to 3.5 MeV by (1957NE22). The latter observations indicate that some process other than direct s-wave capture is responsible for the background between resonances (1954WI1A, 1957NE22).

A study of (γ-α) coincidences at $E_{\mathrm{p}} = 0.45$ MeV yields an angular correlation which rules out the assignment $J = 0^{+}$ to the 2.9-MeV ^{8}Be level and indicates that the 14.7-MeV γ-radiation contains a mixture of E2 and M1 radiation (1956BO1H: see also (1954DE1D)). The alpha spectra, taken singly (1956LA1A) and in coincidence with γ-rays (1958ME78) show no evidence of weakly excited levels reported by (1954IN1A: see also (1955TI1B)). In the work of (1958ME78), the 2.9-MeV level appears to have a width of 1.9 MeV; compare (1950BU1B). There is some evidence for a broad level near $E_{\mathrm{x}} = 10$ MeV (1956LA1A).

See also (1955RI1A, 1956PO1A) and (1957FR1B, 1957KU58; theor.).

15. ^{7}Li(p, n)^{7}Be $\qquad Q_{\mathrm{m}} = -1.646 \qquad E_{\mathrm{b}} = 17.253$

The cross section has been studied from the threshold at $E_{\mathrm{p}} = 1.8811$ MeV (see ^{7}Be) to 10 MeV (1957BO1F, 1957JA37, 1957KA1C: see also (1958TA03)). Resonances are indicated at $E_{\mathrm{p}} = 1.93$, 2.25, (3.0) and 5.0 MeV (see Table 8.7). Absolute cross sections are given by

Table 8.6: Resonances in ^{7}Li(p, γ)^{8}Be [a]

E_r (keV)	Γ_{lab} (keV)	^{8}Be* (MeV)	References
441.4 ± 0.5	12	17.64	(1948BO21, 1949FO18)
441.5 ± 0.5	12.2 ± 0.5		(1952HU1C)
441.2 ± 0.6	12 ± 1		(1955BU1A, 1956BU27)
1030 ± 5 [b]	168 [b]	18.15	(1954KR06)
2000			(1954PR1A)
2100	400		(1955SW1A)
2130	400	19.1	(1957NE22)

[a] See also Table 8.7.

[b] From ^{7}Li(p, p)^{7}Li (1949FO18).

(1948TA16) and (1958MA07): see also (1959MA20: footnote 14). Angular distributions in the range $E_p = 2.0$ to 2.5 MeV show strong ($\cos\theta$) terms, suggesting interference of states of opposite parity (1948BR1A, 1948TA16). (1954AD1A) has shown that the behavior in this region can be accounted for by ascribing the 2.25-MeV resonance to p-wave formation, with $J = 3^+$ and $\gamma_p^2 = \gamma_n^2 = 0.8 \times 10^{-13}$ MeV-cm (presumably the $T = 1$ analogue of ^{8}Li*(2.28)), and assuming a background due to s-wave, $J = 1^-$ and 2^-, levels of undetermined location. According to (1957NE22), a better account of the cross section below 2.4 MeV is obtained with the $J = 3^+$ level assumed to have $\gamma_n^2/\gamma_p^2 = 5.5$ and a single s-wave $J = 2^-$ level at $E_p = 1.9$ MeV, with $\gamma_n^2/\gamma_p^2 = 5.5$. With this large ratio the low energy cross section can be accounted for in detail and can be made to agree with that derived from the inverse reaction ^{7}Be(n, p)^{7}Li (1957NE22, 1958MA07: see also (1955HA34)). [It is of interest to note that a similar apparent deviation from charge independence occurs in ^{10}B(α, n)^{13}N and ^{10}B(α, p)^{13}C (see ^{14}N). On the other hand, see ^{6}Li(d, p)^{7}Li and ^{6}Li(d, n)^{7}Be.] Using the stacked-foil method, (1957KA1C) report structure in the excitation function corresponding to ^{8}Be levels at 21.5, 22.5, 23.85, (24.9) and (25.6) MeV. At $E_p = 10$ MeV, the cross section for production of ^{7}Be is 120 ± 20 mb (1957KA1C), 100 ± 20 mb (1957BO1F).

The relative intensity of the low-energy neutrons (to ^{7}Be*(0.43)) to the high-energy (ground state) neutrons varies with energy: see Table 8.8. In the range $E_p = 2.5$ to 2.9 MeV, the low-energy neutrons are practically isotropic (c.m. system). From the shape of the excitation function, (1955BA1L) conclude that the reaction to ^{7}Be* proceeds by s-wave protons in and s-wave neutrons out.

It is pointed out by (1954AD1A) that the existence of the $J = 3^+$ level, apparently well separated from the other components $J = 1^+$ and 2^+ which can be formed with channel spin 2, indicates a strong spin-orbit interaction, which should lead to polarization of the neutrons and scattered protons. Polarization measurements are reported by (1954AD1A, 1954WI42, 1955OK01, 1956WI1E, 1958CL98, 1958CR85, 1958ST28). See also (1957RO1C, 1958GI15).

16. ^{7}Li(p, p)^{7}Li $E_b = 17.253$

Absolute differential scattering cross sections are reported for $E_p = 0.4$ to 1.4 MeV (1953WA27), $E_p = 1.4$ to 3.0 MeV (1956MA12), and $E_p = 14.5$, 20.0 and 31.5 MeV (1956KI54). Anomalies appear at $E_p = 0.44$, 1.03, 1.88, 2.1 and 2.5 MeV (see Table 8.7). Both the 0.44- and the 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, 1953LI1A, 1955LI1B: compare ^{7}Li(p, γ)^{8}Be).

The anomaly at $E_p = 1.88$ MeV coincides with the ^{7}Li(p, n)^{7}Be threshold and is ascribed to the abrupt change in total width of a broad (2^- ?) resonance when neutron emission becomes possible (1956MA12, 1957NE22). The observed structure at $2.0 - 2.25$ MeV may reflect interference of the p-wave 2.25-MeV ($J = 3^+$) resonance with one at $E_p = 2.1$ MeV, also formed by p-waves (1956MA12). Preliminary results of a phase shift analysis suggest, on the other hand, interference between a $J = 3^-$ level at $E_p = 2.1$ MeV with a 2^- level at $E_p = 1.9$ MeV, and interference of the 3^+ level at $E_p = 2.25$ MeV with a broad 1^+ level near 3 MeV (J. Olness quoted in (1957NE22)).

17. (a) ^{7}Li(p, p$'$)^{7}Li* $E_b = 17.253$
(b) ^{7}Li(p, p$'\gamma$)^{7}Li

A pronounced resonance appears in the yield of inelastically scattered protons (1951BR10, 1954MO04) and 0.48-MeV γ-rays (1954KR06) at $E_p = 1.030 \pm 0.005$ MeV, $\Gamma = 168$ keV. The angular distribution of the protons is approximately isotropic at resonance, $\sigma = 42$ mb, and asymmetric above it, consistent with an s- or p-wave resonance interfering with a non-resonant wave of opposite parity (1954MO04: see also (1955LI1B)).

The yield of 480-keV radiation rises smoothly from $E_p = 1.5$ to 3.0 MeV except for a pronounced cusp at 1.881 MeV (1955HA34, 1957NE22). Analysis of the excitation function suggests that the inelastic process is enhanced by the $J = 2^-$ level at 1930 keV and that the cusp results from the sudden increase in the total width when neutron emission becomes possible (1957NE22). See also (1951BA79).

18. ^{7}Li(p, d)^{6}Li $Q_m = -5.026$ $E_b = 17.253$

See ^{6}Li.

19. ^{7}Li(p, t)^{5}Li $Q_m = -4.261$ $E_b = 17.253$

See ^{5}Li.

Table 8.7: Levels in ^{8}Be from ^{7}Li + p

$E_{\rm res}$ (keV)	^{8}Be* (MeV)	$\Gamma_{\rm lab}$ (keV)	$l_{\rm p}$	$J^{\pi}; T$	$\theta^2_{\rm p}$	^{7}Li(p, γ)^{8}Be		^{7}Li(p, n)^{7}Be			^{7}Li(p, p′)^{7}Li*	References
						$\sigma_{\rm res}$ (mb)	$\omega\Gamma_{\gamma}$ (eV)	$l_{\rm n}$	$\gamma^2_{\rm n}/\gamma^2_{\rm p}$	$\theta^2_{\rm n}$	$\Gamma_{\rm p'}$ (keV)	
441.5	17.64	12.2	1	$1^+; 1$	0.064	6.0	9.4				0	(1949FO18, 1952HU1C)
1030	18.15	168	1	$1^+; (0)$		res.	2				≈ 6	(1949FO18, 1951BR10, 1954KR06, 1954MO04)
1900	18.94	> 500	0	2^-		non res.						(1957NE22, 1958MA07)
2100	19.1	400	2(1)	(3^-)		res.		0	4.5 [b]	> 0.3	res.	(1957NE22, 1958MA07)
2250	19.22	220	1	$3^+; (1)$	0.04	(non res.)				small	small	(1957NE22)
(≈ 3000)	(19.9)	> 1000	(1)	(1^+)				1	5.5 [c]	[0.2]	small	(1957NE22) [d]
≈ 3000	19.9 [a]	≈ 1000	(1)	(2^+)						(res.)		(1957NE22, 1958MA07) [d]
5000	21.6	≈ 900								res. [e]		(1951BL1A, 1952BA1B, 1959GI47)

[a] ^{7}Li(p, α)^{4}He.
[b] 5.2 ± 0.3 (1958MA07); $\Gamma_{\rm n} = \Gamma_{\rm p}$ at $E_{\rm p} = 1.93$ to 1.97 MeV.
[c] 5.2; $\gamma^2_{\rm n} = 2.9 \times 10^{-13}$ MeV-cm (1958MA07), $\Gamma_{\rm n} = \Gamma_{\rm p}$.
[d] See also (1955MA84).
[e] (1959GI47) find $E_{\rm res} \approx 5.0 \pm 0.5$ MeV, $\Gamma \approx 0.9$ MeV, $\sigma \approx 140$ mb, $J \geq 3$ (if single resonance).

Table 8.8: Relative yield of neutrons to ^{7}Be*(0.43) and ^{7}Be(0)

$E_{\rm p}$ (MeV)	θ(lab)	$I_{0.43}/I_0$ (%)	References
2.40	all	0.18 ± 0.06	(1955MA84)
2.5	all	2.5 [a]	(1955BA1K, 1955BA1L)
2.75	30°	9 ± 1.5	(1950JO57)
2.89	30°	10.5 ± 1	(1950JO57)
3.0		8 [a]	(1955BA1K, 1955BA1L)
3.66	30°	12 ± 1	(1950JO57)
$3.9 - 5.4$		≈ 10	(1954CR1A)
5.0	$20° - 90°$	52.5	(1950GR1A)

[a] See curve in (1955BA1K).

20. ^{7}Li(p, α)^{4}He $\qquad Q_{\rm m} = 17.347 \qquad E_{\rm b} = 17.253$

The cross section, which has been measured to 3.8 MeV, exhibits a broad maximum at $E_{\rm p} = 3$ MeV which is interpreted in terms of a level ≈ 1 MeV wide, with $J = 2^+$, at $E_{\rm p} \approx 3$ MeV, and a several-MeV broad level of $J = 0^+$, underlying the region: see (1948HE01, 1948HE1B, 1948IN1A, 1953SA1A, 1957JA37). Absolute differential cross sections are reported by (1958FR03) for $E_{\rm p} = 1.0$ to 1.5 MeV: at 1.01 MeV, dσ/dω (lab, 90°) = 0.67 mb/sr, see also (1956MA12). Differential cross sections have also been measured at $E_{\rm p} = 15.0$ and 18.5 MeV; there are indications of a triton pickup process at these energies (1957MA1F). See also ^{4}He(α, p)^{7}Li, (1955AJ61, 1955RI1A, 1956BA1E, 1956CR47, 1958BU38).

Table 8.9: Slow neutron thresholds in ^{7}Li(d, n)^{8}Be (1957SL01)

E_d (MeV)	$\Gamma_{c.m.}$ (MeV)	^{8}Be* (MeV)
1.35	0.31	16.08
2.10	0.19	16.67
3.32	< 0.02	17.61
4.08	0.23	18.20

21. ^{7}Li(d, n)^{8}Be $\qquad Q_m = 15.026$

A careful study of the neutron spectrum at $E_d = 2$ MeV at several angles reveals only two distinct groups, corresponding to ^{8}Be(0) and ^{8}Be*(2.9). No other levels below $E_x = 10$ MeV appear in this work: upper limits for groups leading to levels near $E_x = 4$ to 5 MeV and $E_x = 7.5$ MeV are 10% and 20%, respectively, of the ground state group. Angular distributions of the ground state and 3-MeV state neutrons exhibit $l_p = 1$ stripping patterns at forward angles (1954TR1A, 1955TR1B). Other workers have reported neutron groups corresponding to levels at 2.2, 2.9, 4.1, 5.1 and 7.6 MeV: see for instance, (1953TR1B, 1954RE1A, 1955BE1D, 1955GI1B, 1955IH1A, 1955IH1B), as well as states at 10 MeV (1941RI1A), 11.1 and 14.7 MeV (1950WH1B).

Thresholds for slow neutron production indicate ^{8}Be levels at 16.08, 16.67, 17.61 and 18.20 MeV (1954BO79, 1957SL01) (see Table 8.9). It is suggested that the 16.67-MeV level is the lowest $T = 1$ level of ^{8}Be, and that the levels at 17.61 and 18.20 MeV correspond to those seen in (^{7}Li + p) at $E_p = 0.44$ and 1.03 MeV (1954BO79). A search for nuclear pairs from possible pair-emitting states of ^{8}Be yielded an upper limit of 2×10^{-5} mb at $E_d = 0.33$ MeV for excitation of such states in the range $E_x = 5.0$ to 8.5 MeV (1955BE62). See also (1955CA1A, 1955CA1C, 1955PE1C, 1956BO1F, 1956BO43, 1956CA1B, 1956RI37, 1957CA14).

22. ^{7}Li(^{3}He, d)^{8}Be $\qquad Q_m = 11.759$

See (1954MO92) and (1955AL57).

23. ^{7}Li(α, t)^{8}Be $\qquad Q_m = -2.560$

Not observed.

24. ^{7}Li(^{7}Li, ^{6}He)^{8}Be $\qquad Q_m = 7.247$

See (1957NO17).

25. (a) ^{7}Be(n, p)^{7}Li $\quad Q_m = 1.646 \quad E_b = 18.899$
(b) ^{7}Be(n, α)^{4}He $\quad Q_m = 18.993$

At thermal energies, the (n, p) cross section is $(5.1 \pm 0.6) \times 10^4$ b (1955HA34) while the (n, α) cross section is < 25 mb (1958SE08). These observations are consistent with the odd parity of ^{7}Be. Less than 10% of transitions involve ^{7}Li*(0.48). Comparison of the (n, p) cross section with the cross section for ^{7}Li(p, n)^{7}Be gives evidence for an $l = 0$ level in ^{8}Be within 20 keV below the neutron threshold, with $\Gamma < 30$ keV (1955HA34). See, however, (1957NE22, 1958MA07), and see also (1954AD1A). Comparison of the thermal cross section with the (p, n) cross section observed in the inverse reaction supports the assignment $J = \frac{3}{2}$ for ^{7}Be$_{\text{g.s.}}$ (1957NE22).

26. ^{7}Be(d, p)^{8}Be $\quad Q_m = 16.672$

At $E_d = 0.85$ MeV, $\theta = 30°$, $90°$ and $270°$, proton groups are observed corresponding to ^{8}Be$_{\text{g.s.}}$ and the broad level, $E_x = 2.95$ MeV, $\Gamma = 1.6 \pm 0.4$ MeV. No other prominent groups appear for $E_x < 5.8$ MeV (1958SP1A).

27. ^{8}Li(β^-)^{8}Be $\quad Q_m = 16.001$
$Q_0 = 15.94 \pm 0.08$ (1958VE20).

The observed β-spectrum closely matches the mean of reported α-spectra (1955FR29) for $E_\beta > 3$ MeV and is consistent with 89% branching via ^{8}Be*(2.9), with $\log ft = 5.67$ and 11% to higher states, possibly ^{8}Be*(11.7), $\log ft = 4.6$. Less than 1% of transitions involve ^{8}Be$_{\text{g.s.}}$: $\log ft > 8$ (1958VE20: see also (1955AJ61)). Upper limits to transitions to sharp states in ^{8}Be with $E_x = 2$, 4 and 6 MeV are, respectively, 2.5, 1 and 0.5% (1955FR29: see also (1956AR21)).

The α-β angular correlation is isotropic within a few per cent for all β-energies: see (1955AJ61). It is pointed out by (1955MO1A) that a small, $\approx 0.5\%$, anisotropy may be expected at high β-energies because of the increased importance of $l = 1$ and 2 emission, even in an allowed transition. Anisotropy in the β-decay from partially oriented ^{8}Li nuclei is reported by (1957BU44: see also (1958SH1A)). The distribution of recoil momenta and the neutrino-recoil correlation establish that the decay is at least 90% Gamow-Teller and that the Gamow-Teller portion is at least 90% axial vector in character. The observations also require $J = 2^+$ for the ^{8}Li ground state (1958BA1E, 1958LA07, 1958LA08: see also (1958MO1D)). An upper limit of 0.2 ± 0.1 % is reported by (1956TA07) on the number of disintegrations leading to 4.9-MeV γ-radiation: see also (1953BU35). See also (1955GI1A) and (1955JA1C, 1955LA1D; theor.).

28. ^{8}B(β^{+})^{8}Be $\quad Q_{\rm m} = 17.978$

The observed positron spectrum matches the ^{8}Li-^{8}B α-spectra for $E_{\beta^+} > 6$ MeV. About 80% of transitions involve ^{8}Be*(2.9), $\log ft = 5.72$, with $\approx$ 19% to higher states, possibly ^{8}Be*(11.7), $\log ft = 4.6$. Less than 5% go to ^{8}Be$_{\rm g.s.}$, $\log ft > 7.3$ (1958VE20). See (1950AL57, 1952KI1A, 1954GI1A). See also (1955GI1A).

29. (a) ^{9}Be(γ, n)^{8}Be $\quad Q_{\rm m} = -1.667$

(b) ^{9}Be(n, 2n)^{8}Be $\quad Q_{\rm m} = -1.667$

$Q_0 = -1.664 \pm 0.004$ (1956CO56).

At $E_\gamma = 6$ MeV, most of the transitions are to the 2.9-MeV state (1954CA1A). See also ^{9}Be and (1956CO56). For reaction (b), see ^{9}Be and ^{10}Be.

30. ^{9}Be(p, d)^{8}Be $\quad Q_{\rm m} = 0.560$

Angular distributions of ground-state deuterons are remarkably similar for $E_{\rm p} = 5$, 10, 16.5 and 22 MeV and show strong contributions from the pickup process (1951HA1A, 1953CO1C, 1955SU1A, 1956RA32, 1956RE04, 1956SU1A, 1958SU14). The significance of this result, which is not consistent with the simple Butler theory, is discussed by (1955DA1D, 1956GL25: see also (1955DA1E, 1955SA1D, 1956DA1D, 1956KO1B, 1957GR1C). At $E_{\rm p} = 16.5$ MeV, the distribution is consistent with $l_{\rm n} = 1$, $R_0 = 3.0 \times 10^{-13}$ cm, and $\theta^2 = 0.024$ for ^{8}Be(0)$+$n (1956RE04). At higher energies, the distributions appear to be affected by pickup from within the nuclear volume (1956BE14, 1956SE1A). For $E_{\rm p} = 31$ and 95 MeV, unresolved ^{8}Be states near 17 MeV appear, possibly representing pickup of a 1s neutron in ^{9}Be (1956BE14, 1956SE1A: see ^{9}Be).

At $E_{\rm p} = 7.4$ MeV, a search for ^{8}Be levels revealed only the ground-state and the 2.9-MeV state in the range $E_{\rm x} = 0$ to 6.5 MeV (1956CA1C). See also (1954FI35, 1955GI1A, 1956ST30, 1957BE49) and (1955LA1C; theor.).

31. (a) ^{9}Be(d, t)^{8}Be $\quad Q_{\rm m} = 4.592$

(b) ^{9}Be(d, t)^{4}He^{4}He $\quad Q_{\rm m} = 4.686$

At $E_{\rm d} \approx 1.2$ and 3.5 MeV, the ground and first excited states are observed: see (1952CU1A, 1953CU1B, 1953GE01, 1956GE1A, 1956JU1D). For the first excited state, (1955CU16) finds $E_{\rm x} = 2.8 \pm 0.1$ MeV, $\Gamma = 0.8$ MeV. At $E_{\rm d} = 0.5$ MeV ($\theta = 60^\circ$ and 90°), there is no evidence for excited states of ^{8}Be with $E_{\rm x} = 3.4$ to 4.8 MeV: the upper limit to the intensity of the corresponding groups is 2% of the 2.9-MeV group (1956GE1A). At $E_\mathrm{d} = 14.8$ MeV ($\theta = 15°$), there is no evidence for states with $E_\mathrm{x} = 7.1$ to 15.4 MeV (1956CA1C).

Recent studies of the angular distribution of ground-state tritons for $E_\mathrm{d} = 0.1$ to 15 MeV have been reported by (1955JU10, 1955JU1B, 1956HA90, 1957SM78: see also (1955AJ61)). Below $E_\mathrm{d} \approx 0.5$ MeV, the tritons show strong backward peaking, suggestive of interference of compound nucleus states of opposite parity (1957SM78: see ^{11}B). At high energies, the reaction proceeds mainly by pickup, with $l_\mathrm{n} = 1$ (1956HA90). See also (1955DA1E; theor.), (1957HA1F) and ^{9}Be.

32. ^{9}Be(^{3}He, α)^{8}Be $\qquad Q_\mathrm{m} = 18.911$

At $E(^{3}\mathrm{He}) = 0.90$ MeV, the ground (weak) and 2.9-MeV (strong) states are observed: see (1955AJ61).

33. ^{10}B(γ, d)^{8}Be $\qquad Q_\mathrm{m} = -6.025$

^{8}Be states up to $E_\mathrm{x} = 10$ MeV are reported to be involved in this reaction: see (1954TI1C, 1955AJ61, 1955TI1A).

34. ^{10}B(n, t)^{8}Be $\qquad Q_\mathrm{m} = 0.234$

See (1951PE1B, 1954RI15, 1955JA18, 1956FR18, 1957TI1A) and ^{11}B.

35. ^{10}B(p, ^{3}He)^{8}Be $\qquad Q_\mathrm{m} = -0.532$

See (1952CR30, 1955RE16).

36. (a) ^{10}B(d, α)^{8}Be $\qquad Q_\mathrm{m} = 17.819$
(b) ^{10}B(d, α)^{4}He^{4}He $\qquad Q_\mathrm{m} = 17.913$

All observers agree that transitions occur to the ground state and a state at $E_\mathrm{x} \approx 2.87 \pm 0.06$ MeV, $\Gamma = 0.93 \pm 0.15$ MeV, (weighted mean of (1951WH1A, 1953CU1C, 1953TR04)). However, there is conflicting evidence on whether other states with $E_\mathrm{x} < 15$ MeV are involved in this reaction. (1954CU1A) report additional states at (4), 5.1 and 7.5 MeV (see also (1955AJ61)). However, (1953TR04: $E_\mathrm{d} = 0.6$ to 1.07 MeV) report no other low lying states; (1956BO1J: $E_\mathrm{d} = 5$ MeV,

$\theta = 50°$ and $90°$) have not observed any other states below $E_x = 9$ MeV; (1955HO48: $E_d = 1.4$ to 3.2 MeV, several angles) find no evidence for excited states other than the 2.9-MeV level below $E_x \approx 10$ MeV; and (1956KA1A, 1958KA31: $E_d = 1.7$ MeV) find no groups corresponding to ^{8}Be states with $E_x = 9.8$ to 14.8 MeV above the continuum attributed to ^{10}B(d, α)^{4}He^{4}He.

The observed α-spectrum corresponding to the 2.9-MeV level may be reasonably well accounted for by the Breit-Wigner formula with $l_\alpha = 2$, $E_\lambda = 5.29$ MeV, $\gamma_\alpha^2 = 13.4 \times 10^{-13}$ MeV-cm, $R = 4.48 \times 10^{-13}$ cm [$\theta^2 \approx 2$] (1953TR04).

37. (a) ^{11}B(γ, t)^{8}Be $\qquad Q_m = -11.230$

(b) ^{11}B(γ, t)^{4}He^{4}He $\qquad Q_m = -11.136$

These reactions have been observed in boron-loaded photoplates. Six states of ^{8}Be below $E_x = 5$ MeV are reported to be involved in reaction (a) (1953ER1A). See also (1955TI1A).

38. ^{11}B(p, α)^{8}Be $\qquad Q_m = 8.582$

Alpha-particle groups corresponding to the ground state and to the 2.9-MeV state are reported; $E_x = 2.94 \pm 0.06$ MeV, $\Gamma = 0.84$ MeV (1951LI1B, 1953BE61: see (1955AJ61)). Excitation of several additional levels is reported by (1953GL1A); however, a careful search by (1955HO48) reveals no evidence for any levels with $E_x < 7$ MeV except the ground state and that at 2.9 MeV.

The alpha particles leading to the ground state are strongly anisotropic at the $E_p = 163$-keV resonance (^{12}C* $= 16.11$, $J = 2^+$; $T = 1$); it is thus unlikely that $J = 2$ (1952TH1B). The directional correlation of successively emitted α-particles at $E_p = 163$ keV indicates isotropic breakup of ^{8}Be(0) and hence $J = 0$, with $J = 2$ excluded. From the angle between the α-particles resulting from the breakup, $Q = 90 \pm 5$ keV is obtained; the half-life is $< 4 \times 10^{-15}$ sec (1955TR03). The angular correlation of alpha particles leading to the 2.9-MeV state with those resulting from the subsequent breakup is consistent with $J = 2^+$ for the 2.9-MeV state (1955GE1A). Certain peculiarities in the relative yields of ground state and 2.9-MeV excited state α-particles suggest that the latter level may have a significant $T = 1$ admixture: see (1953BE61, 1955HO48).

Nuclear pairs have been reported with $E(\pi) = 7$ MeV (1951PH1B); see, however, (1955BE62). See also (1955TI1B).

39. ^{12}C(γ, α)^{8}Be $\qquad Q_m = -7.375$

For $E_\gamma < 40$ MeV, the reaction involves mainly states of ^{8}Be at 0, 2.9, (4.1) (16.5 $\pm$ 0.2; $\Gamma < 0.4$), 16.8 ± 0.2 ($\Gamma < 0.3$), 17.6 ± 0.2 ($\Gamma < 0.3$) MeV, with indications of further states near 6, 10 and 15 MeV. There is no evidence for three-body reactions in this work (1955GO59). Evidence for levels at 3.2, 4.0, (7.5) and 9.0 MeV is reported by (1955GL1A: see also (1954TI1C)). The ground state decay energy is given as 87 ± 8 keV; for the first excited state, $E_x = 3.06$ MeV, $\Gamma = 0.9$ MeV (1955GO59). The excitation function is characterized by a number of resonances, suggesting that the process takes place via definite energy levels of ^{12}C (see ^{12}C); the principal types of levels involved being $J = 1^-$; $T = 1$, (E1 absorption) and $J = 2^+$; $T = 0, 1$ (E2) (1955GO59: see also (1953GE1B, 1955TI1A, 1957MU1C)). For $E_\gamma < 25$ MeV, the reaction proceeds mainly to ^{8}Be(0) and ^{8}Be*(2.9); angular correlations indicate $J = 0$ and $J = 2$, respectively for these states. Wide variations in the branching ratio with energy are attributed to differences in isobaric spin impurities, estimated as 0.05×10^{-3} for the ground state, and $\geq 10^{-3}$ for ^{8}Be*(2.9).

For $E_\gamma > 26$ MeV the reaction changes radically, now involving the 17 to 18 MeV states of ^{8}Be, with E1 absorption. The fact that these levels are so strongly excited in this manner suggests that they have $T = 1$. Angular distributions indicate $J = 2$ for ^{8}Be*(16.8) and $J = 2$ (or possibly 0) for ^{8}Be*(17.6). It is noted that the latter level cannot be identified with the well-known 17.63-MeV, $J = 1^+$ level (see ^{7}Li+p) (1955GO59: see, however, (1953WA27)). Excitation of proton-emitting levels near $E_x = 18$ and 22 MeV is reported by (1956LI05). See also (1953GU1A, 1955HA1D, 1955TI1A).

40. (a) ^{12}C(n, n$'$)^{4}He^{4}He^{4}He $\quad Q_m = -7.281$

(b) ^{12}C(p, p$'$)^{4}He^{4}He^{4}He $\quad Q_m = -7.281$

Reaction (a) has been studied for $E_n = 12.3$ to 20.1 MeV by (1955FR35) who find evidence for transitions through the ground state and the 2.9-MeV level. See also (1955AJ61) and ^{12}C.

Reaction (b) at $E_p = 29$ MeV appears to proceed predominantly through the ground state and the 2.9-MeV level. It is not clear whether higher levels in ^{8}Be are involved (1955NE18). See also (1955CU1C, 1956SA1C, 1956SA1D, 1957JA1B).

41. ^{16}O(γ, α)^{12}C* $\rightarrow$ ^{8}Be + ^{4}He $\quad Q_m = -14.524$

At $E_\gamma \approx 22$ MeV, the reaction appears to proceed mainly via the 9.6 and 10.8-MeV states of ^{12}C to the ground state of ^{8}Be. For $E_\gamma > 24$ MeV, transitions through the 15(?) and 16-MeV $T = 1$ state(s) of ^{12}C, to the 2.9-MeV state of ^{8}Be appear to dominate: see (1955AJ61) and (1955HA1D, 1955TI1A, 1956DA1C).

42. ^{16}O(p, p$'$)^{4}He^{4}He^{4}He^{4}He $\quad Q_m = -10.822$

At $E_p = 29$ MeV, more than half the transitions are through the ground state of ^{8}Be; there is no evidence for participation of any excited states of ^{8}Be (1955KO1A). See also (1957JA1B).

Table 8.10: Energy levels of ^{8}B

E_x in ^{8}B (MeV)	J^π	$\tau_{1/2}$ or Γ (MeV)	Decay	Reactions
0	$(2^+, 3^+)$	$\tau_{1/2} = 0.77 \pm 0.01$ sec	β^+	1, 2, 3, 4
(0.6 ± 0.1) [a]		0.15 ± 0.1		2
(0.80 ± 0.05) [a]		0.05 ± 0.03		2

[a] *Note added in proof*: See, however, (1959FA02).

^{8}B
(Fig. 9)

Mass of ^{8}B: The mass excess of ^{8}B is 25.287 ± 0.008 MeV, from the threshold energy of the ^{6}Li(^{3}He, n)^{8}B reaction.

1. ^{8}B(β^+)^{8}Be $\qquad Q_m = 17.978$

$Q_0 = 17.91 \pm 0.12$ MeV (1958VE20).

The half-life of ^{8}B is 0.78 ± 0.01 sec (1958DU78), 0.61 ± 0.11 sec (1952SH44), 0.65 ± 0.1 sec (1950AL57), 0.75 ± 0.02 sec (1958VE20). The decay proceeds mainly to the 2.9-MeV state of ^{8}Be, $\log ft = 5.72$ (1958VE20). See also (1958DU78) and ^{8}Be.

2. ^{6}Li(^{3}He, n)^{8}B $\qquad Q_m = -1.976$

The threshold has been observed, both in production of slow neutrons and of ^{8}B positron activity, at $E(^{3}\text{He}) = 2.9661 \pm 0.0017$ MeV, yielding a mass excess of 25.287 ± 0.008 MeV. ^{8}B is then stable with respect to ^{7}Be + ^{1}H by 138 ± 9 keV. Two additional thresholds [1] for slow neutron production are reported, in the range $E(^{3}\text{He}) = 2.9$ to 6.0 MeV, at 3.9 ± 0.1 and 4.16 ± 0.05 MeV which may correspond to excited states of ^{8}B at $E_x = 0.6 \pm 0.1$ MeV ($\Gamma = 0.2 \pm 0.1$ MeV) and 0.80 ± 0.05 MeV ($\Gamma = 0.07 \pm 0.04$ MeV). It is pointed out that the existence of two low-lying levels in ^{8}B would be rather surprising in view of the level structure of ^{8}Li (1958DU78).

3. (a) ^{9}Be(p, 2n)^{8}B $\qquad Q_m = -20.418$

(b) ^{10}B(p, t)^{8}B $\qquad Q_m = -18.528$

(c) ^{12}C(p, nα)^{8}B $\qquad Q_m = -26.136$

[1] *Note added in proof*: See, however, (1959FA02).

See (1950AL57).

4. (a) ^{10}B(γ, 2n)^{8}B $\qquad Q_{\mathrm{m}} = -27.002$
   (b) ^{11}B(γ, 3n)^{8}B $\qquad Q_{\mathrm{m}} = -38.456$
   (c) ^{12}C(γ, p3n)^{8}B $\qquad Q_{\mathrm{m}} = -54.423$

See (1952SH44).

References

(Closed December 01, 1958)

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.

1941RI1A Richards, Phys. Rev. 59 (1941) 796

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

1948BO21 T.W. Bonner, J.E. Evans, Phys. Rev. 73 (1948) 666

1948BR1A Breit and Bloch, Phys. Rev. 74 (1948) 397

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

1948HE1B Heydenburg, Hudson, Inglis and Whitehead, Phys. Rev. 73 (1948) 241

1948IN1A Inglis, Phys. Rev. 74 (1948) 21

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

1950BU1B Burcham and Freeman, Phil. Mag. 41 (1950) 921

1950DE1A Devons and Lindsey, Proc. Phys. Soc. (London) A63 (1950) 1202

1950GR1A J.C. Grosskreutz and K.B. Mather, Phys. Rev. 77 (1950) 580

1950JO57 C.H. Johnson and H.H. Barschall, Phys. Rev. 80 (1950) 818

1950KR1A Krone, Hanna and Inglis, Phys. Rev. 80 (1950) 603

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

1950WH1B Whitehead, Phys. Rev. 79 (1950) 393

1951BA79 S. Bashkin and H.T. Richards, Phys. Rev. 84 (1951) 1124

1951BL1A Blaser, Boehm, Marmier and Scherrer, Helv. Phys. Acta 24 (1951) 465

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

1951HA1A Harvey, Phys. Rev. 82 (1951) 298; M.I.T. Prog. Rept. (LNSE), Jan. (1951)

1951HA1B Haefner, Rev. Mod. Phys. 23 (1951) 228

1951LI1B Li and Whaling, Phys. Rev. 81 (1951) 661
1951MA1B Mather, Phys. Rev. 82 (1951) 126
1951PE1B Perkin, Phys. Rev. 81 (1951) 892
1951PH1B Phillips, Cowie and Heydenburg, Phys. Rev. 83 (1951) 1049
1951WH1A Whitehead, Phys. Rev. 82 (1951) 553
1952AJ38 F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys. 24 (1952) 321
1952BA1B Bair, Willard, Snyder, Hahn, Kingston and Green, Phys. Rev. 85 (1952) 946
1952BA64 L.M. Baggett and S.J. Bame, Jr., Phys. Rev. 85 (1952) 434
1952CR30 D.S. Craig, D.J. Donahue and K.W. Jones, Phys. Rev. 88 (1952) 808
1952CU1A Cuer and Jung, Compt. Rend. 234 (1952) 204
1952CU1B Cuer and Magnac-Valette, Compt. Rend. 234 (1952) 1049
1952GR1A Graves, Phys. Rev. 85 (1952) 703A
1952HU1C Hunt, Proc. Phys. Soc. (London) A65 (1952) 982
1952KI1A King, Dismuke and Way, ORNL 1450 (1952)
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
1952TH1B Thomson, Cohen, French and Hutchinson, Proc. Phys. Soc. (London) A65 (1952) 745
1953BA04 M.E. Battat and F.L. Ribe, Phys. Rev. 89 (1953) 80
1953BE61 O. Beckman, T. Huus and C. Zupancic, Phys. Rev. 91 (1953) 606.
1953BU35 D.S. Bunbury, Phys. Rev. 90 (1953) 1121; Erratum Phys. Rev. 91 (1953) 1580
1953CH1A Christy, Phys. Rev. 89 (1953) 839
1953CO1C Cohen, Newman, Handley and Timnick, Phys. Rev. 90 (1953) 323
1953CU1B Cuer and Jung, Phys. Rev. 89 (1953) 1151
1953CU1C Cuer and Jung, Compt. Rend. 236 (1953) 2401
1953ER1A Erdos, Scherrer and Stoll, Helv. Phys. Acta 26 (1953) 207
1953GE01 R.W. Gelinas and S.S. Hanna, Phys. Rev. 89 (1953) 483
1953GE1B Gell-Mamm and Telegdi, Phys. Rev. 91 (1953) 169
1953GL1A Glattli and Stoll, Helv. Phys. Acta 26 (1953) 428
1953GU1A Gurewitsch, Diss. E.T.H. Zurich, Paper 2205 (1953); Phys. Abs. 3103 (1955)
1953KU24 W.E. Kunz, C.D. Moak and W.D. Good, Phys. Rev. 91 (1953) 676
1953LI1A Liberman and Christy, Phys. Rev. 92 (1953) 1085A

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

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

1953TI1C Titterton, Aust. J. Sci. 15 (1953) 174

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

1953TR1B Trumpy, Grotdal and Graue, Univ. Bergen Arbok, No. 8 (1953); Phys. Abs. 2736 (1954)

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

1954AD1A Adair, Phys. Rev. 96 (1954) 709

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

1954BA1B Banta and Macklin, Phys. Rev. 94 (1954) 807A

1954BO79 T.W. Bonner and C.F. Cook, Phys. Rev. 96 (1954) 122

1954BU1B Butler, NRL Quarterly on Nucl. Sci. Tech.; Prog. Rept. July-Sept. (1954)

1954CA1A Carver, Knodaiah and McDaniel, Phil. Mag. 45 (1954) 948

1954CR1A Cranberg, Moffatt and Smith, Los Alamos Rept. 1654 (1954)

1954CU1A Cuer, Jung and Bilwes, Compt. Rend. 238 (1954) 1405

1954DE1D Devons and Goldring, Proc. Phys. Soc. (London) A67 (1954) 413

1954FI35 R.G. Finke, Thesis, Univ. California (1954); UCRL-2789 (1954)

1954FR03 G.M. Frye Jr., Phys. Rev. 93 (1954) 1086

1954GI1A Gilbert, Phys. Rev. 93 (1954) 499

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

1954IN1A Inall, Phil. Mag. 45 (1954) 768

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

1954MA1E Macklin and Banta, Science 119 (1954) 350

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

1954MO92 C.D. Moak, W.M. Good and W.E. Kunz, Phys. Rev. 96 (1954) 1363

1954NI10 W.E. Nickell, Phys. Rev. 95 (1954) 426

1954PR1A Price, Proc. Phys. Soc. (London) A67 (1954) 849

1954RE1A Reid, Proc. Phys. Soc. (London) A67 (1954) 466

1954RI15 F.L. Ribe and J.D. Seagrave, Phys. Rev. 94 (1954) 934

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

1954SN1A Snyder, Phys. Rev. 96 (1954) 1333

1954TI1C Titterton, Phys. Rev. 94 (1954) 206

1954TR1A Trail and Johnson, Phys. Rev. 95 (1954) 1363

1954WI1A Wilkinson, Phil. Mag. 45 (1954) 259

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

1954WI42 H.B. Willard, J.K. Bair and J.D. Kington, Phys. Rev. 95 (1954) 1359

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

1955AL57 E. Almqvist, K.W. Allen and C.B. Bigham, Phys. Rev. 99 (1955) 631A

1955BA1K Batchelor, Proc. Phys. Soc. (London) A68 (1955) 452

1955BA1L Batchelor and Morrison, Proc. Phys. Soc. (London) A68 (1955) 1081

1955BE1D Beyster, Henkel and Nobles, Phys. Rev. 97 (1955) 563

1955BE62 R.D. Bent, T.W. Bonner and R.F. Sippel, Phys. Rev. 98 (1955) 1237

1955BU1A Bumiller, Ph.D. Thesis, Univ. of Zurich (1955)

1955CA19 J.H. Carver, H.J. Hay and E.W. Titterton, Phil. Mag. 46 (1955) 841

1955CA1A Catala, Aguilar and Senent, An. Real. Soc. Espan. Fis. y Quim. A51 (1955) 173

1955CA1C Catala, Senent, Aguilar and Font, An. Real. Soc. Espan. Fis. y Quim. A51 (1955) 127

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

1955CU1C Cuer, Samman and Combe, Compt. Rend. 240 (1955) 1527

1955DA1D Dabrowski and Sawicki, Acta Phys. Pol. 14 (1955) 143

1955DA1E Dabrowski and Sawicki, Acta Phys. Pol. 14 (1955) 407; Erratum Acta Phys. Pol. 15 (1956) 431

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

1955GE1A Geer, Nelson and Wolicki, Phys. Rev. 100 (1955) 215

1955GI1A Gilbert, Phys. Rev. 98 (1955) 275A

1955GI1B Gibson and Prowse, Phil. Mag. 46 (1955) 807

1955GL1A Glattli, Loepfe and Stoll, Helv. Phys. Acta 28 (1955) 366

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

1955HA1D Havlicek and Dobovisek, Phys. Rev. 100 (1955) 1355

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

1955HE1E Herzenberg, Nuovo Cim. 1 (1955) 986, 1008

1955HO48 R.E. Holland, D.R. Inglis, R.E. Malm and F.P. Mooring, Phys. Rev. 99 (1955) 92

1955HU1B Hughes and Harvey, BNL-325 (1955)

1955IH1A Ihsan, Phys. Rev. 98 (1966) 689

1955IH1B Ihsan, Proc. Phys. Soc. (London) A68 (1955) 393

1955JA18 D.B. James, W. Kubelka, S.A. Heiberg and J.B. Warren, Can. J. Phys. 33 (1955) 219

1955JA1C Jancovici, Nuovo Cim. 1 (1955) 840

1955JU10 M.K. Juric, Phys. Rev. 98 (1955) 85

1955JU1B Juric, Bull. Inst. Nucl. Sci. Boris Kidrich 5 (1955) 7

1955KH31 L.M. Khromchenko and V.A. Blinov, Zh. Eksp. Teor. Fiz. 28 (1955) 741; JETP (Sov. Phys.) 1 (1955) 596

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

1955KO1A Kolar, UCRL 3012 (1955)

1955LA1C Lane and Wilkinson, Phys. Rev. 97 (1955) 1199

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

1955MA84 J.B. Marion, T.W. Bonner and C.F. Cook, Phys. Rev. 100 (1955) 91

1955MO1A Morita and Yamada, Prog. Theor. Phys. 13 (1955) 114, 225

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

1955OK01 A. Okazaki, Phys. Rev. 99 (1955) 55

1955PE1C Perez Ferreira and Waloschek, U.N. A/Conf. 8/P/1076 (1955)

1955RE16 J.B. Reynolds, Phys. Rev. 98 (1955) 1289

1955RI1A Riviere and Treacy, Aust. J. Phys. 8 (1955) 408

1955SA1D Sawicki, Acta Phys. Pol. 14 (1955) 135; Erratum Acta Phys. Pol. 15 (1956) 358

1955SU1A Summers-Gill, Phys. Rev. 100 (1955) 1795A

1955SW1A Swann, Rothman, Porter and Mandeville, Phys. Rev. 98 (1955) 1183A

1955TI1A Titterton, Prog. Nucl. Phys. 4 (1955) 1

1955TI1B Titterton, Proc. Glasgow Conf. (Pergamon Press, 1955)

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

1955TR1B Trail and Johnson, Phys. Rev. 98 (1955) 249A

1955WI1D Williamson and Jones, Phys. Rev. 100 (1955) 960A

1956AR21 A.H. Armstrong and G.M. Frye Jr., Phys. Rev. 103 (1956) 335

1956BA1E Barjon, Magnac-Valette and Schmouker, Compt. Rend. 242 (1956) 896

1956BE14 J. Benveniste, R.G. Finke and E.A. Martinelli, Phys. Rev. 101 (1956) 655

1956BE98 R.L. Becker and H.H. Barschall, Phys. Rev. 102 (1956) 1384

1956BO1F Bogdanov, Vlasov, Kalinin, Rybakov and Sidorov, Physica 22 (1956) 1150

1956BO1H Boyle, Nucl. Phys. 1 (1956) 581

1956BO1J Bockelman and Leveque, J. Phys. Rad. 17 (1956) 557

1956BO43 G.F. Bogdanov, N.A. Vlasov, S.P. Kalinin, B.V. Rybakov and V.A. Sidorov, Zh. Eksp. Teor. Fiz. 30 (1956) 981; JETP (Sov. Phys.) 3 (1956) 793

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

1956CA1A Campbell, Aust. J. Phys. 9 (1956) 156

1956CA1B Catala, Aguilar, Senent and Font, An. Real. Soc. Espan. Fis. y Quim. A52 (1956) 33

1956CA1C Cameron, Bull. Amer. Phys. Soc. 1 (1956) 324

1956CO56 D.R. Connors and W.C. Miller, Bull. Amer. Phys. Soc. 1 (1956) 340, P12

1956CR47 D.S. Craig, W.G. Gross and R.G. Jarvis, Phys. Rev. 103 (1956) 1427

1956DA1C Dawson and Livesey, Can. J. Phys. 34 (1956) 241

1956DA1D Dabrowski and Sawicki, Acta Phys. Pol. 15 (1956) 3

1956FR18 G.M. Frye Jr. and J.H. Gammel, Phys. Rev. 103 (1956) 328

1956GE1A Gelinas and Hanna, Phys. Rev. 104 (1956) 1681

1956GL25 S. Glashow and W. Selove, Phys. Rev. 102 (1956) 200

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

1956HA1C Hayakawa, Hayashi, Imoto and Kikuchi, Prog. Theor. Phys. 16 (1956) 507

1956HA90 J.W. Haffner, Phys. Rev. 103 (1956) 1398

1956HE1B Henry, Phillips, Reich and Russell, Bull. Amer. Phys. Soc. 1 (1956) 96

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

1956JU1D Jung and Cuer, J. Phys. Rad. 17 (1956) 555

1956KA1A Kavanagh, Ph.D. Thesis, CalTech (1956)

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

1956KO1B Kopaleishvili, Zh. Eksp. Teor. Fiz. 30 (1956) 1145; JETP (Sov. Phys.) 3 (1957) 973

1956KO1C Koltypin and Morozov, Dokl. Akad. Nauk SSSR 111 (1956) 331

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

1956LA1A LaVier, Hanna and Gelinas, Phys. Rev. 103 (1956) 143

1956LE46 O.I. Leipunskii, V.V. Miller, A.M. Morozov and P.A. Yampolskii, Dokl. Akad. Nauk SSSR 109 (1956) 935; Sov. Phys. Dokl. 1 (1956) 505

1956LI05 D.L. Livesey, Can. J. Phys. 34 (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

1956PE1A Perring and Skyrme, Proc. Phys. Soc. (London) A69 (1956) 600

1956PO1A Post, Rev. Mod. Phys. 28 (1956) 338

1956RA32 S.W. Rasmussen, Phys. Rev. 103 (1956) 186

1956RE04 J.B. Reynolds and K.G. Standing, Phys. Rev. 101 (1956) 158

1956RI37 A.C. Riviere, Nucl. Phys. 2 (1956) 81

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

1956SA1B Sawicki, Acta Phys. Pol. 15 (1956) 71

1956SA1C Samman, Compt. Rend. 242 (1956) 2232

1956SA1D Samman, Compt. Rend. 242 (1956) 3062

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

1956ST30 K. Strauch and F. Titus, Phys. Rev. 104 (1956) 191

1956SU1A Summers-Gill, UCRL 3388 (1956)

1956TA07 N.W. Tanner, Phil, Mag. 1 (1956) 47

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

1956WA29 H.J. Watters, Phys. Rev. 103 (1956) 1763

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

1956WI1E Willard, Bair, Cohn and Kington, Bull. Amer. Phys. Soc. 1 (1956) 54

1957BE49 E.F. Bennett, Bull. Amer. Phys. Soc. 2 (1957) 208, P10

1957BI1C Biel, Phil. Mag. A70 (1957) 866

1957BO1F Bogdanov, Vlasov, Kalinin, Rybakov and Sidorov, Sov. J. At. Energy 3 (1957) 987

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

1957BU44 M.T. Burgy, W.C. Davidson, T.B. Novey, G.J. Perlow and G.R. Ringo, Bull. Amer. Phys. Soc. 2 (1957) 206, M8

1957CA14 J. Catala, R. Font, J. Aguilar, F. Senent and M. de la Cuadra, An. Real. Soc. Espan. Fis. y Quim. A53 (1957) 229

1957CO59 C.W. Cook, W.A. Fowler, C.C. Lauritsen and T. Lauritsen, Phys. Rev. 107 (1957) 508

1957CO63 H.E. Conzett, G. Igo, H.C. Shaw and R.J. Slobodrian, Bull. Amer. Phys. Soc. 2 (1957) 305, E11

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

1957GR1C Grechukhin, Zh. Eksp. Teor. Fiz. 32 (1957) 1460

1957HA1F Harmon and Curtis, Bull. Amer. Phys. Soc. 2 (1957) 350

1957JA1B Jannelli and Mezzanares, Nuovo Cim. 5 (1957) 1047

1957JA37 N. Jarmie, J.D. Seagrave et al., LA-2014 (1957)

1957KA1B Katsaurov, Musaelian and Popov, Sov. J. At. Energy, Suppl. 5 (1957) 67

1957KA1C Kalinin, Ogloblin and Petrov, Sov. J. At. Energy 2 (1957) 193

1957KH1A Khaletskii, Dokl. Akad. Nauk SSSR 113 (1957) 305; Sov. Phys., Dokl. 2 (1958) 129

1957KU1B Kurath, Bull. Amer. Phy. Soc. 2 (1957) 206

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

1957MA1F Maxson and Horie, Bull. Amer. Phys. Soc. 2 (1957) 29

1957MU1C Muto, Takekoshi, Nakamura, Imamura and Tsuneoka, J. Phys. Soc. Jpn. 12 (1957) 109

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

1957RO1C Roberts, Bull. Amer. Phys. Soc. 2 (1957) 234

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

1957SM78 R.K. Smither, Phys. Rev. 107 (1957) 196

1957TI1A Titterton and Brinkley, Nature 179 (1957) 369

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

1958BR16 A. Bratenahl, J.M. Peterson and J.P. Steering, Phys. Rev. 110 (1958) 927

1958BU38 W.E. Burcham, G.P. McCauley, D. Bredin, W.M. Gibson, D.J. Prowse and J. Rotblat, Nucl. Phys. 5 (1958) 141

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

1958CH35 R. Chiba, H.E. Conzett, H. Morinaga, N. Mutsuro, K. Shoda and M. Kimura, Bull. Amer. Phys. Soc. 3 (1958) 419, N10

1958CL98 J.D. Clement, F. Boreli, H.R. Striebel, S.E. Darden and W. Haeberli, Nucl. Phys. 6 (1958) 177

1958CR85 L. Cranberg, Bull. Amer. Phys. Soc. 3 (1958) 365, G8

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

1958FR03 J.M. Freeman, R.C. Hanna and J.H. Montague, Nucl. Phys. 5 (1958) 148

1958GI15 J.H. Gibbons and R.L. Macklin, Bull. Amer. Phys. Soc. 3 (1958) 26, J4

1958HA10 E.W. Hamburger and A.I. Hamburger, Bull. Amer. Phys. Soc. 3 (1958) 187, K4

1958HA1G E.W. Hamburger and A.I. Hamburger, Bull. Amer. Phys. Soc. 3 (1958) 222

1958HU18 D.J. Hughes and R.B. Schwartz, BNL-325, 2nd Ed. (1958); BNL-325, 2nd Ed., Suppl. I (1960)

1958IM1A Imhof, Johnson, Vaughn and Walt, Bull. Amer. Phys. Soc. 3 (1958) 322

1958KA31 R.W. Kavanagh and C.A. Barnes, Phys. Rev. 112 (1958) 503

1958LA07 K.H. Lauterjung, B. Schimmer and H. Maier-Leibnitz, Z. Phys. 150 (1958) 657

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

1958MC1C McDaniels, Blair and Henley, Bull. Amer. Phys. Soc. 3 (1958) 330

1958ME78 V. Meyer and H.H. Staub, Helv. Phys. Acta 31 (1958) 205

1958MO1D Morita, Phys. Rev. Lett. 1 (1958) 112

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

1958SE08 R.E. Segel, J.V. Kane and D.G. Wilkinson, Phil. Mag. 3 (1958) 204

1958SH1A Shapiro, Usp. Fiz. Nauk 65 (1958) 33

1958SP1A Spicer, Aust. J. Phys. 11 (1958) 490

1958ST28 H.R. Striebel, S.E. Darden and W. Haeberli, Nucl. Phys. 6 (1958) 188

1958SU14 R.G. Summers-Gill, Phys. Rev. 109 (1958) 1591

1958TA03 Y.-K. Tai, G.P. Millburn, S.N. Kaplan and B.J. Moyer, Phys. Rev. 109 (1958) 2086

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

1958VA1B Van der Spuy and Pienaar, Nucl. Phys. 7 (1958) 397

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

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

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

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

1959MA20 J.B. Marion and J.S. Levin, Phys. Rev. 115 (1959) 144