

Energy Levels of Light Nuclei $A = 10$

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 $A = 10$ 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 July 01, 1965)

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 $A = 10$

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: [\$^{10}\text{Be}\$](#) , [\$^{10}\text{B}\$](#) , [\$^{10}\text{C}\$](#)

B. Tables of Recommended Level Energies:

[Table 10.1](#): Energy levels of ^{10}Be

[Table 10.6](#): Energy levels of ^{10}B

[Table 10.24](#): Energy levels of ^{10}C

C. [References](#)

D. Figures: [\$^{10}\text{Be}\$](#) , [\$^{10}\text{B}\$](#) , [\$^{10}\text{C}\$](#) , [Isobar diagram](#)

^{10}Be

(Figs. 19 and 22)

GENERAL: See (1956KU1A, 1957FR1B, 1959BA1F, 1960KU1B, 1960TA1C, 1961BA1E, 1961TR1B, 1963BU1C, 1963VL1A, 1963WA1M, 1964FR1D, 1964GR1J, 1964VO1B, 1964WA1K, 1964WA1F).

1. $^{10}\text{Be}(\beta^-)^{10}\text{B}$ $Q_m = 0.555$

The weighted mean end-point energy is 0.556 ± 0.003 MeV (1951LI26). The mean half life is $(2.7 \pm 0.4) \times 10^6$ y (1949HU19): $\log ft = 13.65$ (1951FE1A). The spectrum is of the D_2 type (1950WU1A).

2. (a) $^7\text{Li}(t, \alpha)^6\text{He}$ $Q_m = 9.834$ $E_b = 17.250$
(b) $^7\text{Li}(t, 2n)^8\text{Be}$ $Q_m = 8.770$
(c) $^7\text{Li}(t, n)^9\text{Be}$ $Q_m = 10.435$
(d) $^7\text{Li}(t, n)^5\text{He} + ^4\text{He}$ $Q_m = 7.907$

The neutron yield exhibits broad resonances at $E_t = 0.84$ and 1.70 MeV (1951CR1A), 0.71 ± 0.02 MeV (1962SE1A), 0.765 and 1.735 MeV (1961VA43), and a weak structure at $E_t = 0.24$ MeV (1960SE12). The width of the 0.77 MeV resonance is 160 ± 50 keV (1962SE1A).

Excitation functions for α_0 , α_1 and α_2 (corresponding to $^6\text{He}^*(0, 1.8, 3.4)$ see, however, (1965AJ01) for evidence relevant to the existence of a state at 3.4 MeV in ^6He) show a weak maximum at 1.10 MeV, a weak minimum at 1.30 MeV and a broad maximum at 1.80 MeV ($\Gamma \approx 0.5$ MeV). Angular distributions are complex and suggest direct interaction: the maximum at $E_t = 1.80$ MeV may result from interference effects (1961HO23). Angular distributions of α_0 and α_1 at $E_t = 0.24$ MeV suggest $J = 2^+$ for the 17.8 MeV state (1954AL38). See also (1963JA1E) and (1959AJ76).

3. $^7\text{Li}(\alpha, p)^{10}\text{Be}$ $Q_m = -2.564$

Angular distributions of p_0 at $E_\alpha = 13.6$ and 14.7 MeV (1962KO13) and 30 MeV (1960KL03) show an oscillatory character with strong peaking in the back hemisphere. The p_1 distributions are smoother, but they also show backward peaks (see also (1956WA29)). An explanation in terms of heavy-particle stripping is discussed by (1962HO1C). See also (1962MA59) and (1960MA15).

4. $^7\text{Li}(^7\text{Li}, \alpha)^{10}\text{Be}$ $Q_m = 14.783$

Table 10.1: Energy levels of ^{10}Be

E_x (MeV \pm keV)	J^π	Γ (keV)	Decay	Reactions
g.s.	0^+	$\tau_{1/2} = (2.7 \pm 0.4) \times 10^6 \text{ y}$	β^-	1, 3, 4, 5, 11, 14, 17, 19, 21
3.366 ± 3	2^+	$\tau_m = 0.15 \pm 0.03 \text{ psec}$	γ	3, 4, 5, 11, 17
5.959 ± 5^a	$1^-, 2^-$	$\tau_m < 0.08 \text{ psec}$	γ	4, 5, 6, 11
6.178 ± 9	0^+	$\tau_m > 0.5 \text{ psec}$	π, γ	4, 11
6.262 ± 9	2^-		γ	4, 11
7.377 ± 10	3^-	16	n	4, 6, 11
7.548 ± 10	2^+	6	n	4, 6, 11
9.27	(4^-)	100	n	4, 6, 10
(9.4)	(2^+)	≈ 400	n	4, 6, 10, 17
10.7	≥ 1		n, α	4, 6, 17
(17.42)			n, t	2
17.79	(2^+)	110 ± 35	n, t, α	2
18.47		≈ 500	n, t, α	2
24				17

^a See *Note added in proof* section in the Introduction here.

See (1964CA16).

$$5. \text{}^9\text{Be}(n, \gamma)\text{}^{10}\text{Be} \quad Q_m = 6.815$$

The thermal capture cross section is $9.5 \pm 1.0 \text{ mb}$ (1964ST25). Reported γ -transitions are listed in Table 10.2 (1960BA01, 1961JA19, 1963DR02).

$$6. \text{}^9\text{Be}(n, n)\text{}^9\text{Be} \quad E_b = 6.815$$

The total cross section data is summarized in (1964ST25). Angular distributions are summarized in (1963GO1M). The coherent scattering length (thermal, bound) is 7.7 fm (1961WI1A). The spin dependent thermal cross section is $< 30 \text{ mb}$ (1952PA1A).

In the region $E_n = 0$ to 16 MeV, four resonances are reported, at 0.62, 0.81, 2.73 and 4.3 MeV: see Table 10.3.

Table 10.2: Neutron capture gamma rays in ^{10}Be

E_γ (MeV \pm keV)	Transition	Intensities ^a		
		A	B	C
6.807 ± 7	capt. \rightarrow g.s.	62	70	65
5.956 ± 6	$5.96 \rightarrow$ g.s.	1.4	2	$\lesssim 2$
3.441 ± 3	capt. \rightarrow 3.37	11	15	11
3.365 ± 3	$3.37 \rightarrow$ g.s.	37	28	28
2.590 ± 3	$5.96 \rightarrow$ 3.37	28	17	21
0.855 ± 3	capt. \rightarrow 5.96	29.4	16	24

A: ((1960BA01): see (1963DR02)).

B: (1961JA19).

C: (1963DR02).

^a Gamma rays per 100 captures.

Table 10.3: Resonances in $^9\text{Be}(n, n)^9\text{Be}$

E_{res} ^a (MeV \pm keV)	$^{10}\text{Be}^*$ (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	J^π	l	R (fm)	γ_n^2 (keV)		θ^2 %	References
						$J_c = 1$	$J_c = 2$		
0.625 ± 10	7.377	16	3^-	2	5.6	82	82	7.5	(1951BO45, 1964LA04)
0.815 ± 10	7.548	6	2^+	1	5.6	0.8	5.3	0.28	(1951BO45, 1955WI25, 1964LA04)
2.73	9.27	≈ 100	(4^-)						(1951BO45, 1959FO1A)
(2.85)	9.4	≈ 400	(2^+)	(1)					(1951BO45, 1959FO1A)
4.3	10.7		≥ 1						(1961FO07)

^a (1962PE10) report an additional anomaly in the cross section at $E_n = 207$ keV.

Polarization and differential cross sections are reported for $E_n = 0.2$ to 2 MeV by (1961LA1A, 1962EL01, 1964LA04). Analysis of these data indicates that the $E_n = 0.62$ MeV ($E_x = 7.37$ MeV) resonance has $J^\pi = 3^-$, formed by $l = 2$, with equal participation of channels $J_c = 1$ and 2. Interference with hard-sphere ($R = 5.6$ fm) s-wave background and with a broad $l = 1$, $J = 3^+$ state is observed. Below $E_n = 0.5$ MeV, the scattering cross section reflects the effect of bound 1^- and 2^- states with $E_\lambda \approx -0.2$ MeV, $\gamma^2 \approx 0.05$ MeV, presumably to be identified with $^{10}\text{Be}^*(5.96, 6.26)$. The resonant behavior near 0.815 MeV is consistent with $J^\pi = 2^+$, formed by $l = 1$ (1964LA04). See also (1963GO1N). The finding that the level at $E_x = 7.37$ MeV has $J = 3^-$ is in good accord with comparisons of reduced widths with the presumed $T = 1$, $T_z = 0$ analogue in ^{10}B at $E_x = 8.89$ MeV; for $R = 5.8$ fm,

$$[\gamma_p^2 + \gamma_n^2](^{10}\text{B})/\gamma_n^2(^{10}\text{Be}) = 1.07 \text{ (1962AL1A)}.$$

The structure at $E_n = 2.73$ MeV is ascribed to two levels: a broad state at about 2.85 MeV with $J = 2^+$, and a narrow one, $\Gamma \approx 100$ keV, at $E_n = 2.73$ MeV with a tentative assignment of $J = 4^-$ (1951BO45, 1959FO1A). A weak dip near 4.3 MeV is ascribed to a level with $J \geq 1$ (1961FO07).

Elastic scattering studies for $E_n > 14$ MeV are reported by (1958NA09, 1960PE1B, 1960MC04, 1960SA25). See also (1959AJ76). Optical model analyses have been carried out by (1960HO14, 1963LU10).

See also (1960WA07, 1962OT01, 1962PE10, 1963NE1H, 1964CR1B).

7. (a) $^9\text{Be}(n, n')^9\text{Be}^*$

$$E_b = 6.815$$

(b) $^9\text{Be}(n, 2n)^8\text{Be}$

$$Q_m = -1.665$$

Data on non-elastic cross sections are summarized by (1964ST25). The processes involved include $(n, 2n)$ and $(n, n')^9\text{Be}^* \rightarrow n + ^8\text{Be}$; the (n, α) process is relatively weak. The total non-elastic cross section rises rapidly from threshold at $E_n \approx 2.5$ MeV to ≈ 600 mb at $E_n = 6$ MeV, and then falls slowly to 500 mb at 14 MeV. In the range 3.5 to 6.0 MeV, $^9\text{Be}(n, n')^9\text{Be}^*(2.43)$ accounts for about half of the non-elastic cross section (1959MA34: see (1964ST25)): see also ^9Be . At $E_n = 14$ MeV, $^8\text{Be}^*(2.9)$ is frequently involved (1959CH1E, 1961MY01).

See also ^9Be and (1959MA1C, 1961CA1F, 1961CO1E, 1963DI1F, 1963GO1M, 1963KU1F, 1963MC1C, 1963ZU1B).

8. $^9\text{Be}(n, p)^9\text{Li}$

$$Q_m = -12.832$$

$$E_b = 6.815$$

At $E_n \approx 15.5$ MeV, $\sigma(n, p) = 0.7$ mb (1959AL83, 1963AL18, 1964ST25). See also (1960BU1C).

9. $^9\text{Be}(n, t)^7\text{Li}$

$$Q_m = -10.435$$

$$E_b = 6.815$$

At $E_n = 14$ MeV, $\sigma(n, t) = 18 \pm 1.5$ mb (1958WY67). See also (1958VA33). Measurement of γ -rays from ${}^9\text{Be}(n, t){}^7\text{Li}^*(0.48)$ gives $\sigma(n, t_1) = 20, 10,$ and 30 mb at $E_n = 13.6, 14.1$ and 14.7 MeV (1960BE18).

10. ${}^9\text{Be}(n, \alpha){}^6\text{He}$

$$Q_m = -0.601$$

$$E_b = 6.815$$

The cross section for production of ${}^6\text{He}$ has been measured for $E_n = 0.7$ to 8.6 MeV (1957ST95, 1958VA33, 1961BA53); see also (1964ST25). (1957ST95) find only a smooth rise to a broad maximum of 104 ± 7 mb at 3.0 MeV, followed by a gradual decrease to 70 mb at 4.4 MeV. No indication of resonance is found at $E_n = 2.7$ MeV. From $E_n = 3.9$ to 8.6 MeV, the cross section decreases smoothly from 100 mb to 32 mb (1961BA53). The cross section at $E_n = 14$ MeV is 10 ± 1 mb (1953BA04). See also (1960BU1C, 1963CH1C, 1964GA11).

11. ${}^9\text{Be}(d, p){}^{10}\text{Be}$

$$Q_m = 4.590$$

Parameters of levels observed in this reaction are listed in Tables 10.4 and 10.5. Angular distributions of proton groups have been studied at many energies: see (1958ZE1A, 1959AJ76, 1960MA32, 1961IS01, 1961RE04, 1962SL04, 1964SC12). Except at the lowest energies, the stripping process appears to dominate: see (1959BO1C, 1960BE1B, 1960LU1B, 1960LU04, 1960NA1A, 1963SM05, 1963TA1A, 1964BA1V). See also (1964ZA1B).

The mean life of the 3.37 MeV level is 0.15 ± 0.03 psec (1965WA1P), some ten times shorter than the single-particle value. On the I.P.M. an effective charge $[1 + (0.5 \pm 0.2)]e$ is required; strong collective effects are indicated (1963WA03, 1963WA1M): see also (1959BO49, 1959KO1B). For the 6.18 MeV level, $\tau_m > 0.5$ psec, consistent with an E0 transition (1963WA17). Internal pair correlations establish the multiplicities of the transitions: 3.37 (E2), 5.96 (E1), and 6.18 (E0) (1964WA05); however, (1965FO1G) report that $J^\pi(5.96) = 2^-$ from γ - γ correlation studies [†]. The mean life of ${}^{10}\text{Be}^*(5.96)$ is < 0.08 psec (1965WA1P). The absence of a ground-state transition from ${}^{10}\text{Be}^*(6.26)$ supports the assignment $J^\pi = 2^-$ for this level (1958ME81, 1963WA17): see also (1959CH28, 1959GO78).

The $(p-\gamma)$ correlation through ${}^{10}\text{Be}^*(3.37)$ has the form $1 + AP_2(\cos \theta_\gamma)$, where θ_γ is measured from the recoil direction. Reported values of A lie in the range -0.2 to -0.4 (1957CO54, 1959TA01, 1959ZA01, 1960GO18, 1961RE04, 1962KO14, 1963AC01, 1963NE09, 1964ZA03). These values are consistent with the assumption of a 3P_2 state in LS coupling, but not with 1D_2 . Pure jj coupling leads to $A = 0$, as does the collective model. Approximate agreement can be obtained in intermediate coupling with $a/k = 4.5$ (1962PI1A): see also (1960KU1B, 1961RO1K). Polarization of the protons has been studied by (1959HI1E, 1960HI09, 1960GR11, 1961VA03, 1962AL10, 1962PA12, 1963NE16, 1963NE09, 1964RE04, 1965HE1B). See also (1961TE02).

[†] See *Note added in proof* section in the Introduction here.

Table 10.4: Levels of ^{10}Be from $^9\text{Be}(d, p)^{10}\text{Be}$ ^d

E_x ^a (MeV \pm keV)	Γ (keV)	J^π	l_n	θ_n^2 (%)			
				A	B	C	D
0		0^+	1	5 – 9	9.3	7.5	9
3.368 ± 9		2^+	1	1	1.1	1.1	2.5
5.959 ± 9		$1^-, 2^-$ ^b	0	15	17	12	
6.178 ± 9		0^+ ^b		(0.5)			
6.262 ± 9		2^-	0	8	18	3.2	
7.37	≈ 25	3^-	2^c	1.3	4.1	2	
7.54	< 10	$2^{(+)}$		0.34			

A: (1958ME81).

B: (1960MA32).

C: (1964SC12).

D: (1961RE04): all PWBA.

^a (1954JU23).

^b (1963WA17, 1964WA05, 1965FO1G).

^c (1964SC12).

^d See *Note added in proof* section in the Introduction here.

12. $^9\text{Be}(t, d)^{10}\text{Be}$ $Q_m = 0.558$

Not reported.

13. $^9\text{Be}(\alpha, ^3\text{He})^{10}\text{Be}$ $Q_m = -13.763$

Not reported.

14. $^{10}\text{B}(n, p)^{10}\text{Be}$ $Q_m = 0.228$

See (1948EG1A, 1955JA18, 1964PA1M).

15. $^{10}\text{B}(t, ^3\text{He})^{10}\text{Be}$ $Q_m = -0.536$

Table 10.5: Radiative transitions in ${}^9\text{Be}(d, p){}^{10}\text{Be}$ ^a

Transition	ΔJ^π	E_γ ^b (keV)	Mult.	Branch (%)	τ_m (psec)
3.37 \rightarrow g.s.	$2^+ \rightarrow 0^+$	3374 ± 10	E2	100	0.15 ± 0.03
5.96 \rightarrow g.s.	$1^- \rightarrow 0^+$	5965 ± 10	E1	48 ± 2 ^c	< 0.08
5.96 \rightarrow 3.37	$1^- \rightarrow 2^+$	2584 ± 15		52 ± 2 ^c	
6.18 \rightarrow g.s.	$0^+ \rightarrow 0^+$		E0	(100)	> 0.5
6.18 \rightarrow 3.37	$0^+ \rightarrow 2^+$				
6.26 \rightarrow g.s.	$2^- \rightarrow 0^+$			< 0.4 ^d	
6.26 \rightarrow 3.37	$2^- \rightarrow 2^+$			> 99.6 ^d	

^a (1963WA03, 1963WA17, 1964WA05, 1965WA1P).

^b Corrected for Doppler shift.

^c $(22 \pm 6)/(78 \pm 12)$ (1958ME81), $(41 \pm 4)/(59 \pm 4)$ (1965FO1G): however, see ${}^9\text{Be}(n, \gamma)$.

^d See also (1965FO1G).

Not reported.

16. ${}^{11}\text{B}(n, d){}^{10}\text{Be}$ $Q_m = -9.004$

Not reported.

17. ${}^{11}\text{B}(p, 2p){}^{10}\text{Be}$ $Q_m = -11.228$

In the summed proton spectrum, structure is observed corresponding to $Q = -10.9 \pm 0.35$, -14.7 ± 0.4 , -21.1 ± 0.4 , -35 ± 1 MeV (1958TY49, 1962GA09, 1962GA23, 1962GO1P, 1964TI02, 1965RI1A, 1966TY01). See also (1958MA1B, 1963BE42, 1963RI1B, 1964BA1C), and ${}^{11}\text{B}$.

18. ${}^{11}\text{B}(d, {}^3\text{He}){}^{10}\text{Be}$ $Q_m = -5.735$

Not reported.

19. $^{11}\text{B}(t, \alpha)^{10}\text{Be}$ $Q_m = 8.586$

See (1961HO01).

20. $^{12}\text{C}(^{11}\text{B}, ^{10}\text{Be})^{13}\text{N}$ $Q_m = -9.285$

See (1963SA1K).

21. $^{13}\text{C}(n, \alpha)^{10}\text{Be}$ $Q_m = -3.836$

See ^{14}C .

¹⁰B
(Figs. 20 and 22)

GENERAL: See (1959BA1F, 1959BR1E, 1960TA1C, 1961TR1B, 1962IN02, 1963BU1C, 1963KU03, 1963ME01, 1963MO1F, 1963OL1B, 1963VL1A, 1963WA1M, 1964AM1D, 1964BA29, 1964FR1D, 1964GR1J, 1964MA1G, 1964NE1E, 1964OL1A, 1964ST1B, 1964VA1D, 1965FA1C, 1965NE1C).

Ground State:

$$\begin{aligned}\mu &= +1.8007 \text{ nm (1965FU1G).} \\ Q &= +0.08 \text{ b (1965FU1G).}\end{aligned}$$

1. ${}^6\text{Li}(\alpha, \gamma){}^{10}\text{B}$ $Q_m = 4.461$

Six resonances are observed in the range $E_\alpha = 0.5$ to 2.6 MeV, corresponding to ${}^{10}\text{B}^*(4.76 - 6.06 \text{ MeV})$: see Table 10.8. No other resonances appear for $E_\alpha < 3.8$ MeV (${}^{10}\text{B}^*(6.74)$) (1957ME27, 1961SP02).

The 4.77 MeV state decays mainly to ${}^{10}\text{B}^*(0.7)$: the ground state decay is $< 3\%$ (1957WA07), 8% (1957ME27): see also Table 10.7. The angular distribution of γ -rays indicates $J = 2^+$, with $E2/M1 = 1.8$ (1957ME27), 0.64 (1957WA07). The measured $\omega\Gamma_s \equiv \omega\Gamma_\gamma\Gamma_\alpha/(\Gamma_\gamma + \Gamma_\alpha)$ is 0.05 eV: $\Gamma(M1) \approx 0.01 \Gamma_W$, $\Gamma(E2) \gtrsim 10\Gamma_W$, consistent with the ΔT selection rule for M1 and considerable collective enhancement for E2 (1957ME27, 1957WA07, 1958ME81, 1963WA17).

The angular distribution of the γ -rays from the 5.11-MeV state can be made consistent with $J = 2^-$; $T = 0$ if $M2/E1 \approx 0.01$ is assumed (1957ME27, 1958ME81). The distributions from $E_x = 5.17$ MeV are consistent with $J^\pi = 2^+$ (1957ME27): observations in ${}^9\text{Be}(d, n){}^{10}\text{B}$ indicate $\Gamma_\alpha \approx \Gamma_\gamma = 1.3$ eV and hence $T = 1$ (1958ME81, 1959WA16, 1962WA21).

A study of α -capture near $E_\alpha = 1.18$ MeV shows the formation of a broad $J = 1$; $T = 0$ state ($E_x = 5.18$ MeV, $\Gamma_{\text{c.m.}} = 200 \pm 30$ keV), and its subsequent decay via 3.44 MeV γ -rays to the $J^\pi = 0^+$; $T = 1$ state at 1.74 MeV. The observed width corresponds to 0.86 of the single particle limit for s-wave α -formation (1961SP02: see, however, (1962DE10)). See also (1962WA21).

For the 5.92 MeV level, $J^\pi = 2^\pm, 3^+, \text{ and } 4^+$ are possible. Only $J^\pi = 4^+$ gives a satisfactory account of the angular distribution from the 6.03 MeV level (1957ME27).

2. (a) ${}^6\text{Li}(\alpha, p){}^9\text{Be}$	$Q_m = -2.126$	$E_b = 4.461$
(b) ${}^6\text{Li}(\alpha, d){}^8\text{Be}$	$Q_m = -1.567$	
(c) ${}^6\text{Li}(\alpha, \alpha){}^6\text{Li}$		
(d) ${}^6\text{Li}(\alpha, n){}^9\text{B}$	$Q_m = -3.977$	

Table 10.6: Energy levels of ^{10}B

E_x (MeV \pm keV)	$J^\pi; T$	Γ (keV) or τ_m (psec)	Decay	Reactions
g.s.	$3^+; 0$	stable	—	1, 3, 4, 5, 6, 11, 12, 13, 14, 15, 20, 21, 22, 27, 28, 30, 33, 35
0.7173 ± 0.8	$1^+; 0$	1010 ± 20 psec	γ	1, 3, 4, 5, 6, 11, 12, 19, 20, 22, 26, 28, 30, 33, 35
1.740 ± 2	$0^+; 1$	0.15 ± 0.02 psec	γ	1, 3, 6, 11, 12, 20, 26, 28, 30, 33, 35
2.154 ± 3	$1^+; 0$	1.35 ± 0.16 psec	γ	1, 3, 6, 11, 12, 20, 22, 28, 30, 33, 35
3.585 ± 4	$2^+; 0$	0.096 ± 0.036 psec	γ	4, 6, 11, 12, 20, 22, 28, 30, 33
4.774 ± 3	$(2^+); 0$	< 10	γ, α	1, 4, 5, 11, 12, 20, 22, 30, 33
5.114 ± 4	$(2^-); 0$	1.2	γ, α	1, 11, 12, 20, 22, 30, 33
5.166 ± 4	$2^+; 1$	0.003	γ, α	1, 11, 12, 20, 30
5.183 ± 8	$1^+; 0$	120 ± 20	γ, α	1, 2, 6, 11, 20, 22, 33
5.923 ± 4	$2^+; 0$	< 5	γ, α	1, 2, 11, 12, 20, 22, 30, 33
6.029 ± 4	4^+	< 1	γ, α	1, 2, 11, 12, 18, 20, 22, 30, 33
6.133 ± 4		< 5	α	2, 11, 12, 20, 22, 30
6.566 ± 6		≈ 70	α	2, 11, 12, 20, 22, 30
6.884	$1^-; 0$	≈ 140	γ, p, d, α	2, 6, 8, 10
7.00		95 ± 10	p, d, α	2, 10, 20, 22
7.431 ± 10	$2^-; 0$	140 ± 30	γ, p, d, α	6, 10
(7.468 ± 10)	(2^+)	80	γ, p	6, 8, 18
7.479 ± 2	$(2^-; 1)$	72 ± 4	γ, p	6, 8, 20, 30
7.561 ± 1	$0^+; 1$	3.3 ± 0.3	γ, p	6, 8, 30
7.62 ± 50	$(1^+; 0)$	220 ± 50	p, d, α	8, 10
7.77 ± 30	$2^-; 1$	210 ± 60	γ, p, α	2, 6, 8
8.07 ± 100	$(2^-; 0)$	800 ± 200	p, d, α	10
8.892 ± 6	$3^{(-)}; (1)$	84 ± 7	n, p	7, 8, 16
8.896 ± 2	$2^+; 1$	36 ± 2	γ, p, α	6, 8, 10
9.7	; 1	≈ 600	n, p, α	7, 10
10.83 ± 30	; 1	≈ 500	γ, n, p, α	6, 7, 10, 16
(11.4)	(+)		γ	16, 18, 20, 28
(14)	(+)		γ	16, 18, 20
18.6		< 500	$\gamma, {}^3\text{He}$	4
18.8	$(2^+, 1^-; 1)$	< 600	$\gamma, {}^3\text{He}, \alpha$	4
19.3	$(2^+, 1^-; 1)$	350	$\gamma, n, {}^3\text{He}, \alpha$	4
20.1		broad	$n, p, {}^3\text{He}$	4

Table 10.7: Electromagnetic transitions in ^{10}B

Initial State	Γ_γ (total) (eV)	Relative intensities to final states at:						References
		g.s.	0.72	1.74	2.15	3.59	5.18	
0.72	6.6×10^{-7}	100						Table 10.20 (1964SI03, 1965LO04) (1961SP04, 1964HO02, 1965WA1P) (1958ME81, 1964BR06, 1964HO02, 1964SI03, 1965WA1P) Table 10.8, (1963WA17) Table 10.8, (1963WA17) Tables 10.8 and 10.19, (1963WA17) Table 10.8 Table 10.8 Table 10.8 (1964JA03) Table 10.13 Table 10.13 ^d (1965SP04) Table 10.13 ^d Table 10.13 ^d Table 10.13 ^d (1964GR1A)
1.74	4.4×10^{-3}	< 2	100					
2.15	4.9×10^{-4}	22	27	51				
3.59	6.9×10^{-3}	15	65	< 3	20			
4.77	0.03	8	92					
5.11	0.07	96	4					
5.17	0.6	5.5	29.5		65			
5.18	0.06			100				
5.92		100						
6.03		100						
6.4	0.75 ^c							
6.88	(4.8)	< 3	24	56	17	4	< 11	
7.43	2.4	< 2	1.3	< 0.1	0.62	0.5	< 1	
7.47	11							
7.48	25.8	25	0.3	< 0.1	0.49	0	< 1	
7.56	8.5	< 0.2	6.7	< 0.3	0.8	< 0.2	1.0	
7.77	8.5	6.6	0.9	< 0.1	0.3	0.3	0.4	
8.89	0.6							
11.8 ^a								
14 ^a								
18.6 ^b								
18.8 ^b								
19.3 ^b								

^a See (1962ED02).

^b See Table 10.10.

^c $B(\text{E}2\uparrow) = 29 \text{ fm}^4$.

^d Partial Γ_γ in eV (1964HO02).

Table 10.8: Levels of ^{10}B from $^6\text{Li}(\alpha, \gamma)^{10}\text{B}$ (1957ME27, 1961SP02)

E_{res} (keV)	E_x (MeV)	$J^\pi; T$	Γ_{lab} (keV)	E_γ ^a (MeV)	Branch %	$\omega\Gamma_s$ ^b (eV)	
500 ± 25 ^c	4.76	$(2^+); 0$		4.76	8		
				4.05	92	0.05 ^d	E2/M1 = 1.8
1085	5.112	$2^-; 0$	2 ^e	5.1	96	0.10	M2/E1 \approx 0.01
				4.4	4	0.005	
1175	5.167	$2^+; 1$	< 0.5 ^e	5.16	7	0.04	E2/M1 = 0.02
				4.44	29	0.15	E2/M1 = 0.01
				3.01	64	0.32	E2/M1 = 0.01
1210 ± 35	5.188	$1^+; 0$	340 ± 50	3.44	≈ 100	^f	
2435	5.923	2^+	20	5.9	100		E2/M1 = 0.01 ^g
2605	6.025	4^+	< 1.5 ^e	6.0	100		E2/M1 = 9.0

^a Primary radiation: see Table 10.7.

^b $\omega\Gamma_s \equiv \omega\Gamma_\alpha\Gamma_\gamma/(\Gamma_\alpha + \Gamma_\gamma)$.

^c (1953WI32, 1954JO09).

^d (1957WA07): E2/M1 = 0.64, $\gamma(\text{g.s.}) < 3\%$; $\Gamma_\gamma/\Gamma < 4 \times 10^{-4}$ (1965RO01).

^e See (1958ME81) and $^9\text{Be}(\text{d}, \text{n})^{10}\text{B}$.

^f $\Gamma_\gamma = 0.06 \pm 0.03$ (1961SP02).

^g 0.01 or 10 (1957ME27).

Reported anomalies in the elastic scattering are listed in Table 10.9 (1962BA03, 1962DE10, 1965SI1B). Angular distributions indicate $J^\pi = 1^+$ and 2^+ , respectively for the 5.18 and 5.92 MeV states. The 1^+ assignment supports the proposal by (1961TR1B) that the 5.18 MeV state is a member of the doublet formed by two-nucleon excitation into the 2s shell, whose other member is the $0^+; T = 1$ state at 7.56 MeV.

The excitation functions for α_0 and α_1 (to the 2.18 MeV state of ^6Li) particles (1963BL20: $E_\alpha = 9.50$ to 12.50 MeV), d_0 particles (to the ground state of ^8Be) (1963BL20: $E_\alpha = 9.50$ to 11.4 MeV) and neutrons (1963ME08: from threshold, $E_\alpha = 6.623$ MeV, to 15.5 MeV) do not show resonance structure. See also (1956WA29, 1964DE1K).

3. (a) $^6\text{Li}(^6\text{Li}, \text{d})^{10}\text{B}$ $Q_m = 2.989$
 (b) $^6\text{Li}(^7\text{Li}, \text{t})^{10}\text{B}$ $Q_m = 1.994$
 (c) $^6\text{Li}(^9\text{Be}, ^5\text{He})^{10}\text{B}$ $Q_m = 1.933$

Table 10.9: ^{10}B levels from $^6\text{Li}(\alpha, \alpha)^6\text{Li}$

E_α (MeV)	E_α (MeV)	E_x (MeV)	Γ_{lab} (keV)	$J^\pi; T$	θ_α^2	References
1.21		5.19	175	$1^+; 0$	≈ 2	(1962DE10)
2.44	2.44	5.93	≈ 30	$2^+; 0$	≈ 0.05	(1962DE10, 1965SI1B)
	2.605	6.03				(1965SI1B)
	2.80	6.14				(1965SI1B)
3.52	3.51	6.58	120			(1962BA03, 1965SI1B)
	4.05	6.89				(1965SI1B)
4.18	4.24	7.01	230			(1962BA03, 1965SI1B)
	5.50	7.76				(1965SI1B)

Reactions (a) and (b) have been studied up to 6 MeV bombarding energy. Deuteron and triton groups have been observed leading to the first four states of ^{10}B with intensities which depend on the incident energy: typically the group to the 0.7 MeV state is very strong and that to the 1.74 MeV state is very weak (1960MO17, 1961BR35, 1961MO02, 1964KI02). See also (1962BE24, 1962BU1C, 1962MC12, 1963LE09, 1964BL1C). For reaction (c) see (1962MC12, 1963NO02).

4. (a) $^7\text{Li}({}^3\text{He}, n)^9\text{B}$	$Q_m = 9.349$	$E_b = 17.786$
(b) $^7\text{Li}({}^3\text{He}, p)^9\text{Be}$	$Q_m = 11.199$	
(c) $^7\text{Li}({}^3\text{He}, d)^8\text{Be}$	$Q_m = 11.759$	
(d) $^7\text{Li}({}^3\text{He}, \alpha)^6\text{Li}$	$Q_m = 13.325$	
(e) $^7\text{Li}({}^3\text{He}, \gamma)^{10}\text{B}$	$Q_m = 17.786$	

The excitation curve for reaction (a) is smooth up to $E({}^3\text{He}) = 1.8$ MeV (1962SE1A, 1963DU12), and shows resonance behavior at $E({}^3\text{He}) = 2.2$ and 3.25 MeV: the 2.2 MeV resonance has $\Gamma \approx 280$ keV; the 3 MeV resonance is broader (1963DI01, 1963DU12, 1964DI1C).

Capture γ -rays have been observed for $E({}^3\text{He}) = 0.8$ to 3.0 MeV. The excitation functions for the transitions to the ground and 4.77 MeV states show peaks at $E({}^3\text{He}) = 1.1$ and 2.2 MeV; those to the 0.72 and 3.59 MeV states show a broad maximum at 1.4 MeV. The observed gamma widths are comparatively large (see Table 10.10) (1965PA02).

The yield of protons (reaction (b)) is relatively flat for $E({}^3\text{He}) = 2.5$ to 4.8 MeV, with some indication of a weak maximum at ≈ 3.3 MeV at 20° and 50° (1961WO05). The yield of ground state α -particles at 8° (reaction (d)) shows a broad maximum at ≈ 2 MeV, a minimum at 3 MeV, followed by a steep rise which flattens off between $E({}^3\text{He}) = 4.5$ and 5.5 MeV. Integrated α_0 and α_1 yields rise monotonically to 4 MeV and then tend to decrease. Angular distributions of α_1 in the

Table 10.10: Resonances in ${}^7\text{Li} + {}^3\text{He}$

E_{res} (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	E_x (MeV)	$\omega\Gamma^{\text{a}}$ for transition to				Γ_{α}	References
			g.s.	0.72	3.59	4.77		
1.1	< 500	18.6	35			140	< 80	(1965PA02)
1.4	< 600	18.8		100	100		< 20	(1965PA02, 1965PA03)
2.2	280 – 420	19.3	85			200		^b
3.25	broad	20.1						(1963DI01, 1964DI1C)

^a Lower limits of $(2J + 1)\Gamma_{\gamma}$ in eV.

^b (1963DI01, 1963DU12, 1964DI1C, 1965PA02, 1965PA03).

Table 10.11: Slow neutron thresholds ^a in ${}^7\text{Li}(\alpha, n){}^{10}\text{B}$

E_{α} (threshold) (MeV)		E_x (MeV)
(1957BI84)	(1963ME08)	
4.379 ± 0.006	4.380 ± 0.020	0
5.51	5.5	0.72
	(11.90)	4.77
	(14.53)	6.42

^a See also (1956RO06).

Table 10.12: Resonances in ${}^9\text{Be}(p, \gamma){}^{10}\text{B}$

E_p (MeV \pm keV)	E_x (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	$J^\pi; T$	Γ_p/Γ	Γ_γ ^a (eV)	References
0.330	6.88	≈ 140	$1^-; 0$	0.30	4.8	(1956CL69)
0.938 ± 10 (0.98)	7.43 (7.47)	140 ± 30	$(2^-); 0$ (2^+)	0.7	2.4	(1962EL06, 1964HO02) (1962EL06)
0.992 ± 2	7.48	72 ± 4	$2^-; 1$	≈ 0.65	25.8	(1964HO02)
1.0832 ± 0.4	7.562	3.25 ± 0.33	$0^+; 1$	1.0	8.5	(1964BO13, 1964HO02)
1.29	7.75	210 ± 60	$2^-; (1)$	≈ 0.65	8.5	(1964HO02)
2.567 ± 2	8.896	36 ± 2	$2^+; 1$			(1953MA1A, 1956MA55)
4.72	10.83	≈ 500				(1952HA10)

^a See Table 10.13 for decay schemes.

range $E({}^3\text{He}) = 2$ to 5.5 MeV suggest that the reaction proceeds mainly by pickup (1965FO07: see also (1961WO05)). Angular distributions for $E({}^3\text{He}) = 0.8$ to 3.0 MeV give indications of the resonances at $E({}^3\text{He}) = 1.4$ and 2.2 MeV seen in ${}^7\text{Li}({}^3\text{He}, \gamma)$: $J^\pi = 2^+$ or 1^- ; $T = (1)$ for both: Γ_α is small (1965PA03).

5. ${}^7\text{Li}(\alpha, n){}^{10}\text{B}$ $Q_m = -2.792$

Observed slow neutron thresholds are listed in Table 10.11 (1957BI84, 1963ME08). At $E_\alpha = 13.5$ and 13.9 MeV, angular distributions of the ground-state neutrons have been determined (1962KJ05). See also (1959HE1B, 1962GA1L).

6. ${}^9\text{Be}(p, \gamma){}^{10}\text{B}$ $Q_m = 6.587$

Parameters of observed resonances are listed in Tables 10.12 and 10.13. Table 10.7 summarizes the γ -transitions from this and other reactions.

The $E_p = 0.33$ MeV resonance (${}^{10}\text{B}^*(6.88)$) is ascribed to s-wave protons because of its comparatively large proton width [see ${}^9\text{Be}(p, p)$] and because of the isotropy of the γ -radiation. The strong transition to ${}^{10}\text{B}^*(1.74)$ requires E1 and hence $J^\pi = 1^-$; $T = 0$. $T = 0$ is also indicated by the large deuteron width. On the other hand, the strength of E1 transitions to ${}^{10}\text{B}^*(0.7, 2.1)$ indicate a $T = 1$ admixture of 20% or more (1956WI16, 1959ME1A). A small P_2 term in

Table 10.13: Radiative transitions in ${}^9\text{Be}(p, \gamma){}^{10}\text{B}$

Initial state (MeV)	$\Gamma_\gamma(\text{tot})$ (eV)	Relative intensities to final states						Remarks	Ref.
		ground 3 ⁺ ; 0	0.72 1 ⁺ ; 0	1.74 0 ⁺ ; 1	2.15 1 ⁺ ; 0	3.59 2 ⁺ ; 0	5.18 1 ⁺ ; 0		
6.88 $E_p = 0.33$ 1 ⁻ ; 0	[10] 4.8	2.4	6	15	3	5	3.6	$ M ^2\text{E1}$	(1957BI75)
		15	40	100	45		0.65		(1955CA25)
		< 0.7	6.4	15	4.5	≈ 1	< 2.9		(1959ME1A)
			0.006	0.025	0.009	≈ 0.00			(1959ME1A)
7.43 $E_p = 0.94$ 2 ⁻ ; 0	[2.4]	< 2	(res) 1.3	[< 0.14]	0.62	0.5	[< 1]	$ M ^2\text{E1}$	(1962EL06)
			0.013		0.013	0.03			(1964HO02)
7.48 $E_p = 0.99$ 2 ⁻ ; 1	[25.8]	400	< 10	19	22	< 7	< 13	$ M ^2\text{E1}$	(1959ME1A)
		25	0.3	[< 0.14]	0.49	0	[< 1]		(1964HO02)
		0.19	0.003		0.10				(1964HO02)
7.56 $E_p = 1.08$ 0 ⁺ ; 1	4.8 6.6 [8.5]	< 3	1.0	2.6	0.5	< 4	0.65	$ M ^2\text{M1}$	(1956CL69)
			100	< 8	< 8	< 4	23		(1959ME1A)
			76		9		15		(1961SP04)
			100	< 2	10		40		(1962ME1A)
		< 0.2	6.7	< 0.3	0.8	< 0.2	1.0		(1964HO02)
		1.0		0.24		3.5	(1964HO02)		
7.75 $E_p = 1.29$ 2 ⁻ ; 1	14.6 [8.5]	83%						$ M ^2\text{E1}$	(1963FU11)
		6.6	0.9	< 0.08	0.3	0.3	0.4		(1964HO02)
		0.044	0.008		0.006	0.013	0.08		(1964HO02)

the angular distribution at resonance suggests a d-wave admixture. The angular correlation of $6.88 \rightarrow 0.72 \rightarrow \text{g.s.}$ is consistent with $J^\pi = 1^-$ but does not exclude 2^- (1964BI18).

The proton capture data near $E_p = 1$ MeV appears to require at least 5 resonant states, at $E_p = 938, (980), 992, 1086$ and 1290 keV. The narrow $E_p = 1086$ keV level (${}^{10}\text{B}^*(7.56)$) is formed by p-wave protons, $J^\pi = 0^+$ [see ${}^9\text{Be}(p, p)$ and ${}^9\text{Be}(p, \alpha)$]. The isotropy of the gamma rays supports this assignment (1961TA02). The strong M1 transitions to $J = 1^+; T = 0$ levels at $0.7, 2.15$ and 5.18 MeV (Table 10.13) indicate $T = 1$ (1959WA16).

The excitation function for ground-state radiation shows resonance at $E_p = 992$ ($\Gamma = 80$ keV) and 1290 keV ($\Gamma = 230$ keV) (1962EL06, 1964HO02). Elastic scattering studies indicate s-wave formation and $J = 2^-$ for both (1956MO90). For the lower level ($E_x = 7.48$ MeV) the intensity of the g.s. capture radiation, $\Gamma_\gamma = 25$ eV (1964HO02) indicates E1 and $T = 1$. The angular distribution of γ -rays, $1 + 0.1 \sin^2 \theta$, is consistent with s-wave formation with some d-wave admixture (1953PA22) or with some contribution from a nearby p-wave resonance (1956MO90); possibly a $J^\pi = 2^+$ level at $E_p = 980$ keV (1956MO90, 1962EL06: see, however, (1964HO02)).

The angular correlation of internal pairs is consistent with an E1/M1 mixture of 3 : 2 (1962EL06). Earlier difficulties with the $T = 1$ assignment may be resolved if the (p, d) and (p, α) resonances are ascribed to another level (1964HO02).

The angular distribution of ground-state radiation at $E_p = 1330$ keV is isotropic and $\Gamma_\gamma = 14.6 \pm 1.5$ eV (1963FU11), 8.5 eV (1964HO02), supporting E1, $T = 1$ for this level, $E_x = 7.75$ MeV.

Transitions to $^{10}\text{B}^*(0.7)$ show resonance at $E_p = 992, 1290$ and 938 keV, $\Gamma = 155$ keV (1962EL06, 1964HO02). The latter is presumably also a resonance for (p, d) and (p, α). An assignment of $J^\pi = 2^-$; $T = 0$ is consistent with the data, although the E1 radiation then seems somewhat too strong for a $\Delta T = 0$ transition (1964HO02).

A resonance for capture radiation at $E_p = 2.567 \pm 0.003$ ($E_x = 8.896$ MeV) has a width of 40 ± 2 keV and decays mainly via $^{10}\text{B}^*(0.7)$ (1953MA1A). It appears from the width that this resonance corresponds to that observed in $^9\text{Be}(p, \alpha)$, $J = 2^+$; $T = 1$ and not to the $^9\text{Be}(p, n)$ resonance at the same energy (1956MA55). A fourth resonance is reported at $E_p = 4.72 \pm 0.01$ MeV, $\Gamma \approx 0.5$ MeV (1952HA10).

For the mean life of the 0.7 MeV state, see Table 10.20.

See also (1959KA69, 1959SI1C, 1960GO23, 1960SI04, 1961RI08, 1962BL10, 1962HU05, 1963CO1K, 1964SI03).

7. $^9\text{Be}(p, n)^9\text{B}$

$$Q_m = -1.851$$

$$E_b = 6.587$$

Resonances in neutron yield occur at $E_p = 2.56$ and 4.6 MeV: see Table 10.14. There is some indication of a broad maximum near $E_p = 3.5$ MeV; a peak reported at $E_p = 4.9$ MeV for n_1 neutrons may reflect the effect of this level (1959MA20). A sharp break at $E_p = 6.55 \pm 0.03$ MeV is ascribed to a level in ^9B at 4.04 MeV (1964BA16). Angular distributions in the range $E_p = 2$ to 11 MeV are reported by (1956MA55, 1961AL07, 1963KE03, 1965WA04). Polarization studies have been made by (1961CR1A, 1963KE03, 1965WA04).

The $E_p = 2.56$ MeV resonance is considerably broader than that observed at the same energy in $^9\text{Be}(p, \alpha)$ and $^9\text{Be}(p, \gamma)$ and the two resonances are believed to be distinct (1956MA55). The shape of the resonance and the magnitude of the cross section can be accounted for with $J = 3^-$ or 3^+ : the former assignment is in better accord with charge symmetry and indicates correspondence with $^{10}\text{Be}^*(7.38)$. For $J^\pi = 3^-$, $\theta_n^2 = 0.135$, $\theta_p^2 = 0.115$ ($R = 4.47$ fm). The $J^\pi = 2^+$ level should contribute about 10% to the cross section at $E_p = 2.56$ MeV (1962AL1A). See also (1963HA1G, 1963VA1C).

8. $^9\text{Be}(p, p)^9\text{Be}$

$$E_b = 6.587$$

Elastic scattering has been studied for $E_p = 0.2$ to 2.6 MeV by (1956DE33, 1956MO90): see Table 10.15. Below $E_p = 0.7$ MeV, only s-waves are present, exhibiting resonance at $E_p = 330$

Table 10.14: Resonances in ${}^9\text{Be}(p, n){}^9\text{B}$

E_{res} (MeV \pm keV)	Γ_{lab} (keV)	E_x (MeV)	$J^\pi; T$	σ_{max} (mb)	References
2.562 ± 6	85 ± 10 100 ± 10	8.892	$3^{(-)}; (1)$	160	(1956MA55, 1962AL1A) (1959GI47)
3.5	≈ 700	9.7		240	(1956MA55, 1959MA20) (1959GI47)
4.72 ± 10	500	10.83			(1952HA10)
4.68 ± 30					(1955MA84)
4.6				470	(1959GI47)
4.62 ± 30					(1959MA20)
4.94 ± 30	≈ 100				(1955MA84)
4.85				510	(1959GI47)
4.82 ± 60				^a	(1959MA20)

^a Resonance for n_1 only: possibly due to 3.5 MeV resonance.

keV, $J = 1^-$ or 2^- : both proton and deuteron widths are large, while θ_α^2 is small. Further s-wave resonances, with $J = 2^-$, appear at $E_p = 998$ and 1330 keV and a sharp p-wave resonance, $J = 0^+$, occurs at 1084 keV. The behavior of p-wave phase shifts indicates an additional $J = 2^+$ resonance at 980 keV (1956MO90) or near 1100 keV (1956DE33). The behavior at $E_p = 2.56$ MeV requires $J \geq 2$ and a large proton width (1956DE33). See also (1959AJ76, 1963AN12, 1964HO02).

The yield of p_0 and p_1 (to 2.43 MeV state of ${}^9\text{Be}$) has been determined by (1961RE03) in the range $E_p = 3.6$ to 6.0 and 4.2 to 6.0 MeV, respectively, and for $E_p = 5.7$ to 8 MeV by (1963BL20). Total cross sections and yields of the p_1 group have also been determined by (1964BI1K) for $E_p = 5$ to 15 MeV: a broad maximum near $E_p = 8$ MeV is indicated. Total cross sections have also been measured at $E_p = 10.2, 142$ and 180 MeV (1961JO17, 1961TA06, 1962IG1A, 1963WI1E, 1963WI1D). See also (1961JO18) and (1959AJ76).

Elastic scattering of polarized protons has been studied at $E_p = 8.5$ and 11.4 MeV (1961RO05, 1961RO13); inelastic scattering has been studied at $E_p = 7$ and 12 MeV (1965FU03). See also (1964BE03, 1964CR1B, 1965BO1L).

Table 10.15: Resonances in ${}^9\text{Be}(p, p){}^9\text{Be}$

E_{res} (keV)	E_x (MeV)	Γ_{lab} (keV)	J^π	Γ_p/Γ	θ_p^2	References
330	6.88		1^-	0.30	0.5	(1956MO90)
$(980 \pm 10)^a$	(7.47)	90	(2^+)	0.9	0.07	(1956MO90)
998	7.48	150 ± 50	2^-	0.65	0.02	(1956DE33, 1956MO90)
1084 ± 2	7.56	3	0^+	1.0		(1956MO90)
$(1100)^a$	(7.58)	200		small		(1956DE33)
1330	7.79	400 ± 100	2^-	0.65	0.05	(1956MO90)
1350 ± 50		500	2^-	0.8		(1956DE33)
2560	8.89		≥ 2	large		(1956DE33)

^a Postulated to account for p-wave structure near 1 MeV.

Table 10.16: Resonances in ${}^9\text{Be}(p, d){}^8\text{Be}$ and ${}^9\text{Be}(p, \alpha){}^6\text{Li}$

E_p (MeV)	E_x (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	$J^\pi; T$	Γ_p/Γ	θ_p^2	θ_d^2	θ_α^2	References
0.33	6.88		$1^-; 0$	0.30	0.5	0.4	0.05	(1956MO90)
(0.47)	(7.01)							(1949TH05, 1951NE03)
(0.68)	(7.20)							(1949TH05, 1951NE03)
0.94	7.43	140	$(2^-; 0)$	0.7	0.04	0.02		(1956WE37, 1964HO02)
1.15	7.62	225 ± 50	$(1^+; 0)$	≈ 0.4	≈ 0.1			(1956WE37, 1964HO02)
1.65	8.07	800 ± 200	$(2^-; 0)$	≈ 0.07	0.18	0.21		(1956WE37, 1964HO02)
(2.3)	(8.7)	(≈ 220)						(1956WE37, 1965MO1K)
2.56	8.89	36 ± 2	$2^+; 1$				^a	(1956WE37)
3.5	9.7		; 1				^a	(1959MA20)
4.49	10.63		; 1				^a	(1959MA20)

^a Resonance for α_2 , to ${}^6\text{Li}^*(3.56), 0^+; T = 1$.

Table 10.17: Levels from ^{10}B of $^9\text{Be}(d, n)^{10}\text{B}$

$^{10}\text{B}^*$ (MeV)	J^π	l_p	θ^2 ^a	References ^b
0	3^+	1	1	(1952AJ22, 1961MO15)
0.72	1^+	1	2.1	(1952AJ22, 1961MO15)
1.74	0^+	1	1.4	(1952AJ22, 1961MO15)
2.15	1^+	1	0.65	(1952AJ22, 1961MO15)
3.59	2^+	1	0.44	(1952AJ22, 1963FE1B)
4.77	(2^+)	(1)		(1963FE1B)
5.11	(2^-)	0		(1963RI08)
5.17	(2^+)	1		(1963RI08)
(5.18)				(1963FE1B)
5.58				(1952AJ22)
5.92		(1)		(1963FE1B)
6.02				(1963FE1B)
6.16				(1952AJ22, 1963FE1B)
6.38				(1952AJ22)
6.58				(1952AJ22)
(6.77)				(1952AJ22)

^a Relative values (1952AJ22, 1960MA32).

^b See also (1959AJ76).

9. $^9\text{Be}(p, t)^7\text{Be}$

$$Q_m = -12.079$$

$$E_b = 6.587$$

See ^7Be .

10. (a) $^9\text{Be}(p, d)^8\text{Be}$

$$Q_m = 0.559$$

$$E_b = 6.587$$

(b) $^9\text{Be}(p, \alpha)^6\text{Li}$

$$Q_m = 2.126$$

The (p, d) and (p, α) reactions have been studied in the range $E_p = 0.8$ to 3.0 MeV by (1949TH05, 1951NE03, 1956MO90, 1956WE37), $E_p = 1$ to 4.6 MeV by (1965MO1K) and for $E_p = 3.5$ to 12.5 MeV by (1963BL20); the (p, α_2) reaction, leading to $^6\text{Li}^*(3.56)$, has been studied from $E_p = 2.3$ to 5.4 MeV by (1954MA26, 1956MA55, 1959MA20). Observed resonances are exhibited in Table 10.16.

Both alphas and deuterons are isotropic at the $E_p = 0.33$ MeV resonance, confirming its s-wave formation: proton and deuteron widths are large, while θ_α^2 is small (1956MO90). A strong maximum for α and d appears at $E_p = 0.93$ MeV, $\Gamma = 130 \pm 30$ keV, followed by weaker maxima for d at $E_p = 1.25, 1.65$ and 2.3 MeV. Alpha particles show a weak effect at the $E_p = 2.56$ MeV, $T = 1$ resonance, indicating a small isospin impurity (1956WE37). Angular distributions in the range $E_p = 0.4$ to 1.0 MeV (1951NE03) and 0.8 to 3.0 MeV (1956WE37) show strong interference effects. Analysis of the latter data suggests contributions from three levels, at $E_p = 0.938$ (2^-), 1.15 (1^+) and 1.65 MeV (2^-) (1964HO02). There is no evidence of further structure in the yield of d_0, α_0 or α_1 for $E_p < 12$ MeV: in this range direct interaction appears to dominate (1961RE03, 1963BL20, 1965MO1K). Polarization of d_0 has been studied by (1960BA26, 1961LA17, 1964BO33).

The yield of 3.56 MeV γ -rays, associated with α_2 leading to ${}^6\text{Li}^*(3.56)$ ($J^\pi = 0^+; T = 1$), shows strong resonances at $E_p = 2.56$ and 4.49 MeV and a broad rise at $E_p = 3.5$ MeV, suggesting that these states, which are also observed in (p, n), have $T = 1$ and are the analogues of ${}^{10}\text{Be}^*(7.55, 9.26, 9.4)$ (1959MA20). See also (1959LE27, 1961BE1E, 1961ST1D).

11. ${}^9\text{Be}(d, n){}^{10}\text{B}$

$$Q_m = 4.363$$

Neutron groups are observed corresponding to ${}^{10}\text{B}$ states listed in Table 10.17. There have been various reports of additional states: see (1960HJ01, 1960JU04, 1961GA1G, 1962CO23, 1962MO12, 1963KO15) and (1959AJ76). Thresholds for slow neutron production corresponding to ${}^{10}\text{B}$ states from 4.77 to 6.57 MeV are reported in Table 10.18 (1954BO79). Angular distributions have been studied at many energies (see (1959AJ76) for a summary of the earlier work and (1960BA46, 1961MO15, 1963FE1B, 1964BU14, 1965SI12)). The data, analyzed by stripping theories, show $J \leq 3$ and even parity for the first five states of ${}^{10}\text{B}$ (1952AJ22, 1961MO15) and for the 5.17 MeV state (1962GA11, 1963RI08) while the 5.11 MeV state is well fitted by $l_p = 0$ (1963RI08).

Observed γ -transitions are listed in Tables 10.7 and 10.19. Reported values of the mean life of the 0.72 MeV state are given in Table 10.20. With an intermediate coupling parameter $a/K = 4.75$, a mean E2 lifetime of 4 nsec is predicted: the experimental value indicates either a lower value of a/K or some collective enhancement (1957FR1B, 1957KU58, 1962LO02). [Since the ${}^{10}\text{C}$ β -decay is allowed, $J = 0^+, 1^+$ for $E_x = 0.72$ MeV; the γ -transition from $E_x = 1.74$ MeV established $J = 1^+$.]

The 1.74 MeV state, $J = 0^+; T = 1$ analogue of ${}^{10}\text{Be}$ and ${}^{10}\text{C}$, decays via the 0.72 MeV state. The 2.15 MeV state decays relatively strongly to $E_x = 1.74$ MeV, arguing against $J = 0, 2, 3$: therefore $J = 1^+$. The E2 branch to the ground state is relatively strong compared to IPM predictions (1957KU58). The mean life is 1.35 ± 0.16 psec (1965WA1P).

Correlation measurements in the cascade $E_x = 3.59 \rightarrow 0.7 \rightarrow \text{g.s.}$ exclude $J = 0$ or 3 for the 3.59 MeV state (1956SH94); a spin 1 assignment would permit a strong transition to $E_x = 1.74$ MeV, therefore $J = 2^+$. The $3.59 \rightarrow 0.7$ transition is either $M1/E2 = 93/7$ or pure E2 (1956SH94). The n- γ correlation is isotropic (1962GA11). The large intensity relative to the

Table 10.18: Slow neutron thresholds in ${}^9\text{Be}(d, n){}^{10}\text{B}$ (1954BO79)

E_d (MeV)	E_x (MeV)	Γ (keV)
0.52	4.79	< 10
0.92 ^a	5.12	< 10
0.99 ^a	5.17	< 10
1.92	5.93	< 10
2.08	6.06	< 10
2.20	6.16	< 20
2.53	6.43	
2.70	6.57	≈ 30

^a 0.921 ± 0.009 and 0.989 ± 0.009 MeV (1962WA21).

Table 10.19: Gamma rays observed in ${}^9\text{Be}(d, n){}^{10}\text{B}$

Transition	E_γ (keV)	Branching ratio ^d (%)
0.7 \rightarrow g.s.	716.6 ± 1 ^a	100
1.7 \rightarrow g.s.		< 2
1.7 \rightarrow 0.7	1022 ± 2 ^a	100
2.15 \rightarrow g.s.	2152 ± 15 ^a	22
2.15 \rightarrow 0.7	1433 ± 5 ^a	27
2.15 \rightarrow 1.7	413.5 ± 1 ^a	51
3.59 \rightarrow g.s.	3583 ± 13 ^{b,c}	15 ^e
3.59 \rightarrow 0.7	2872 ± 15 ^{b,c}	65 ^e
3.59 \rightarrow 2.15		20
5.17 \rightarrow g.s.	5159 ± 16 ^b	5.5 ± 0.7 ^b
5.17 \rightarrow 0.7	4461 ± 13 ^{b,c}	29.5 ± 2 ^b
5.17 \rightarrow 2.15	3028 ± 15 ^b	65 ± 2 ^b

^a (1949RA02).

^b (1963WA17): Doppler corrected.

^c M1 + E2 (1964WA05).

^d See Table 10.7.

^e Ratio 1 : 4.42 ± 0.15 (1964BR06).

Table 10.20: Mean life of $^{10}\text{B}^*(0.72)$

τ_m (nsec)	Reaction	References
0.7 ± 0.2	$^9\text{Be}(d, n)^{10}\text{B}$	(1953TH14)
0.85 ± 0.20	ibid	(1956SE08)
1.18 ± 0.33	ibid	(1961KN02) ^a
0.96 ± 0.10	ibid	(1958DA11)
1.04 ± 0.02	and (p, p')	(1962LO02)
1.05 ± 0.10	$^{10}\text{B}(p, p')^{10}\text{B}^*$	(1957BL02)
0.90 ± 0.1	ibid	(1958HO97)
0.94 ± 0.05	ibid	(1959BI10)
1.00 ± 0.03	ibid	(1962GA15)
1.0 ± 0.1	ibid	(1961SA21)
1.013 ± 0.015		mean

^a See also (1958KN1B, 1958GO47, 1960GO23, 1962LO02, 1961RI08).

ground state transition does not fit the IPM (1963WA17). The mean life is 0.096 ± 0.036 psec (1965WA1P). See also (1959CH28, 1959GO78).

The 4.77 MeV state has $J^\pi = 2^+$; $T = 0$ [see $^6\text{Li}(\alpha, \gamma)$]. No gamma radiation is observed in the present reaction: $\Gamma_\gamma/\Gamma < 0.05$. The relative weakness of the ground-state branch and the absence of the present level in the IPM scheme suggests a collective excitation based on $E_x = 0.72$ MeV (1963WA17).

Three levels exist near 5 MeV, at 5.11, 5.17 and 5.18 MeV. For the $E_x = 5.17$ MeV level, the small Γ_α and large Γ_γ suggest $T = 1$ (1959WA16) [confirmed in $^{10}\text{B}(d, d')$]: $\Gamma_\alpha \approx \Gamma_\gamma = 0.6$ eV (1963WA17), $\Gamma_\gamma/\Gamma = 0.7 \pm 0.35$ (1962WA21), $\Gamma_\gamma/\Gamma = 1 \pm 0.2$ (1963RI08). The mean life is < 0.08 psec (1965WA1P). Angular correlations confirm the even parity assignment and indicate $J^\pi = 2^+$ (1962GA11, 1963WA17). The 5.18 MeV level is excited only weakly, if at all, in the present reaction (1963FE1B, 1963RI08).

See also (1959HA1K, 1959LE1E, 1959SI1A, 1961HO1D, 1962LE1C, 1963MO1L, 1964BA1V, 1964SI02, 1965MA1K).

12. $^9\text{Be}(^3\text{He}, d)^{10}\text{B}$

$$Q_m = 1.094$$

At $E(^3\text{He}) = 5.7, 8.8$ and 10.2 MeV, deuteron groups are observed corresponding to the ground state and to states at 0.72, 1.74, 2.15 and 3.58 MeV (1959HI69, 1960HI08: see Table 10.21).

Table 10.21: Levels of ^{10}B from $^9\text{Be}(^3\text{He}, \text{d})^{10}\text{B}$ (1960HI08) ^a

E_x (MeV \pm keV)	J^π	l_p	R (fm)	θ^2 ^b
0	3^+	1	7.0	2.6
0.717 ± 10	1^+	1	7.0	6.4
1.744 ± 10	0^+	1	7.0	9.9
2.156 ± 10	1^+	1	5.5	3.1
3.58	2^+	1	6.0	1.3

^a See also (1965CR1C, 1965YO1E).

^b Relative reduced widths, $E(^3\text{He}) = 10.23$ MeV.

Angular distributions of deuterons to these states have been determined at a number of energies up to $E(^3\text{He}) = 25$ MeV (1959HI69, 1960HI08, 1960WE04). Deuteron groups have also been observed to $^{10}\text{B}^*(4.77, 5.11, 5.17, 5.92, 6.03, 6.13$ and 6.57 MeV). There is no indication of earlier reported levels at $E_x = 5.58$ and 6.40 MeV (1965CR1C, 1965YO1E). See also (1962WE1C).

13. $^9\text{Be}(\alpha, \text{t})^{10}\text{B}$ $Q_m = -13.227$

See (1960GO04, 1960VL03, 1962WE1C).

14. $^9\text{Be}(^{14}\text{N}, ^{13}\text{C})^{10}\text{B}$ $Q_m = -0.963$

See (1964BO1M).

15. $^{10}\text{Be}(\beta^-)^{10}\text{B}$ $Q_m = 0.555$

See ^{10}Be .

16. (a) $^{10}\text{B}(\gamma, \text{n})^9\text{B}$ $Q_m = -8.438$

(b) $^{10}\text{B}(\gamma, \text{p})^9\text{Be}$ $Q_m = -6.587$

(c) $^{10}\text{B}(\gamma, \text{d})^8\text{Be}$ $Q_m = -6.028$

(d) $^{10}\text{B}(\gamma, \alpha)^6\text{Li}$ $Q_m = -4.461$

Energy levels are reported in ^{10}B [from reaction (a)] at $E_x = 10.25, 10.75, 11.85, 12.25, 14.7$ and 16.9 MeV, assuming that the neutron transitions are to the ground state of ^9B . The giant dipole resonance appears to peak at 11 MeV (1962FI07). Cross sections have been measured with monoenergetic γ -rays for $E_\gamma = 8.9$ to 10.8 MeV: the value at 8.9 MeV leads to $\Gamma_\gamma = 0.6 \pm 0.3$ eV for the $E_x = 8.89$ MeV level(s) (1964GR1A). For reactions (b), (c), (d), see (1959AJ76) and (1962CH1B, 1962VO1D).

17. $^{10}\text{B}(\gamma, \gamma)^{10}\text{B}$

See (1964LO1C).

18. $^{10}\text{B}(e, e)^{10}\text{B}$

Elastic scattering at $\theta = 180^\circ$ gives evidence of an M3 contribution (1965GO1K: see also (1965RO1P)). At $E_e = 41.5$ MeV ($\theta = 180^\circ$) evidence is reported for the M1 excitation of three states with $J^\pi = 2^+, 3^+$ or 4^+ at $E_x = 7.9, 11.8$ and 14.0 MeV, with Γ_γ in the range 10 to 40 eV (1962ED02). At $E_e = 55$ MeV, transitions are observed to $^{10}\text{B}^*(6.02 \pm 0.02$ and 7.48 ± 0.02 MeV), the latter with $\Gamma = 40$ keV, $\Gamma_\gamma(\text{M1}) = 11 \pm 2$ eV, assuming $J^\pi = 2^+$ (1965SP04: see $E_x = 7.47$, Table 10.15). See also (1959ME24, 1962BA1D, 1963GO04, 1963RO1M). At 100 – 200 MeV, (1965FR07) find strong E2 excitation of the 6.02 MeV level.

19. $^{10}\text{B}(n, n')^{10}\text{B}^*$

See (1956DA23, 1961AN1A, 1963GL1F).

20. $^{10}\text{B}(p, p')^{10}\text{B}^*$

Excited states observed in inelastic scattering are listed in Table 10.22. Levels observed at $E_x = 5.92, 6.03, 6.13$ and 6.55 MeV correspond well with those reported in $^9\text{Be}(d, n)^{10}\text{B}$: no level at $E_x = 6.43$ MeV is seen in the present reaction. A broad level at $E_x = 7.00$ MeV may correspond to a peak reported in $^9\text{Be}(p, d)$ at $E_p = 0.48$ MeV. The $J = 2^-; T = 1, 7.48$ MeV state is seen here, but not in (d, d') (1964AR04). At $E_p = 17.9$ MeV angular distributions are strongly peaked forward. Comparison of $\sigma(p, p')$ with E2 transition rates suggests that the strongest (p, p') transitions correspond to states having large E2 coupling to the ground state: the strength of the 6.04 MeV 4^+ level is particularly significant (1962SC12), $B(\text{E2}) = 29 \text{ fm}^4$ (1964JA03). At $E_p = 185$ MeV, the $Q = -6.1$ MeV peak is dominant. Others are observed corresponding to

$E_x = 0, 2.2, 3.6, 5.2, 7.55, 11.0$ and 13.0 MeV. The angular distribution of the $Q = -7.55$ MeV group is similar to that of the $Q = -3.6$ MeV group of ${}^6\text{Li}$ (1965HA17). Inelastic cross sections at $E_p = 153$ MeV yield $|M|^2 = 11, 0.02,$ and 0.66 for γ -transitions from ${}^{10}\text{B}^*(2.15)$ to g.s., 0.7 and 1.74 (1961CL09).

At $E_p > 3$ MeV, γ -rays with $E_\gamma = 710 \pm 15, 1023 \pm 5, 1438 \pm 5, 2120 \pm 60, 2880 \pm 10$ and 3560 ± 50 keV are observed (1957HU79, 1957MC35). Upper limits to the transitions $1.74 \rightarrow$ g.s. and $3.59 \rightarrow 1.74$ are 2 and 3% (1964SI03). See also (1965SE1F).

21. ${}^{10}\text{B}(p, 2p){}^9\text{Be}$ $Q_m = -6.587$

The summed proton energy spectrum, observed at $E_p = 150$ to 460 MeV shows peaks corresponding to removal of an $l \neq 0$ proton at $Q = -6.7, -11.9$ and -17.1 MeV; for removal of an $l = 0$ proton, $Q = -30.5$ MeV (1966TY01). See also (1962DI1A, 1963BE42, 1964BA1C, 1964LI1D, 1965RI1A) and ${}^9\text{Be}$.

22. ${}^{10}\text{B}(d, d'){}^{10}\text{B}^*$

Deuteron groups have been observed corresponding to eleven excited states of ${}^{10}\text{B}$: see Table 10.22. The absence of the groups (upper limit to intensity 1.5% – 4%) corresponding to the 1.74 and 5.17 MeV states is good evidence of their $T = 1$ character (1962AR02). See also (1959TO1A, 1962SL03).

23. ${}^{10}\text{B}(t, t){}^{10}\text{B}$

See (1963HO19).

24. ${}^{10}\text{B}(\alpha, \alpha'){}^{10}\text{B}^*$

See (1956BO25, 1964ST1K).

25. ${}^{10}\text{B}({}^{20}\text{Ne}, {}^{20}\text{Ne}){}^{10}\text{B}$

See (1961AN07).

Table 10.22: ^{10}B levels from $^{10}\text{B}(\text{p}, \text{p}')^{\text{a}}$, $^{10}\text{B}(\text{d}, \text{d}')^{\text{b}}$ and $^{12}\text{C}(\text{d}, \alpha)^{10}\text{B}$

E_x^{b} (MeV)	Relative Intensities ^b		E_x^{c} (p, p')	E_x^{d} (d, d')	E_x^{d} $^{12}\text{C}(\text{d}, \alpha)$	E_x^{e} (MeV)	Γ^{e} (keV)
	(p, p')	(d, d')					
0	100	100	0				
0.717 ^f	4	7	0.72	0.72	0.72		
1.739	1	< 0.15	1.74	^g	^g		
2.152	3	4	2.15	2.15	2.15		
3.583	7	7	3.58	3.58	3.58		
4.771			4.77	4.77	4.77		
			5.11	5.11	5.11		
			5.16	^g	^g		
				5.18			$110 \pm 10^{\text{h}}$
						5.92	< 5
						6.03	< 5
						6.13	< 5
						6.55	25 ± 5
						7.00	95 ± 10
						7.48 ⁱ	90 ± 15

^a See also (1964JA03, 1965HA17).

^b (1953BO70): energies ± 5 keV. Relative intensities at $\theta = 90^\circ$, $E = 7.6$ MeV.

^c (1962AR02): energies ± 10 keV. $E_{\text{p}} = 10.0$ MeV, $\theta_{\text{L}} = 90^\circ, 120^\circ$.

^d (1962AR02): energies ± 10 keV. $E_{\text{d}} = 10.0$ MeV, $\theta_{\text{L}} = 60^\circ, 90^\circ$.

^e (1964AR04): E_{p} and $E_{\text{d}} = 11$ MeV, $\theta_{\text{L}} = 45^\circ, 60^\circ$; energies ± 10 keV.

^f 719 ± 1.6 keV (1952CR30), 718 ± 5 keV (1954DA20).

^g Absent: intensity of $E_x = 5.17$ MeV group < 1% relative to average of $T = 0$ levels.

^h c.m. width (1962AR01).

ⁱ Relative intensity in (d, d') < 2%.

26. $^{10}\text{C}(\beta^+)^{10}\text{B}$ $Q_m = 3.606$

The half life is 19.48 ± 0.05 sec (1962EA02), 19.27 ± 0.08 sec (1963BA52): $E_{\beta^+}(\text{max}) = 1.865 \pm 0.015$ MeV (1963BA52). The β^+ decay is to the first two excited states of ^{10}B : relative transition probabilities to the 0.72, 1.74 and 2.15 MeV levels are $98.4/1.65 \pm 0.2 / < 0.1$ (1953SH38): ft (from $\tau_{1/2} = 19.41$ sec, Q_m above) are 1.0×10^3 and 2.2×10^3 to the 0.72 and 1.74 MeV states, respectively (1966BA1A).

27. $^{11}\text{B}(\gamma, n)^{10}\text{B}$ $Q_m = -11.456$

See (1951SH63).

28. $^{11}\text{B}(\text{p}, \text{d})^{10}\text{B}$ $Q_m = -9.231$

At $E_p = 19$ MeV, the ground state and the first four excited states have been observed. From the angular distributions, analyzed by PWBA, $l_n = 1$, $\theta^2 = 0.011, 0.029, 0.011$ and 0.0031 (1961LE1A, 1963LE03). At $E_p = 155$ MeV, deuteron groups are reported to states at 0, 2.0, 5.0, 6.9 and 11.4 MeV (1963BA2F). See also (1956RE04, 1960NE1C, 1961CL09, 1964SH07).

29. $^{11}\text{B}(\text{d}, \text{t})^{10}\text{B}$ $Q_m = -5.199$

See (1960VL05, 1963OG1A).

30. $^{11}\text{B}(^3\text{He}, \alpha)^{10}\text{B}$ $Q_m = 9.122$

Reported levels are listed in Table 10.23. No evidence is found for previously reported levels at $E_x = 2.86, 5.58$ and 6.40 MeV (1963GA03, 1965GO05). See also (1965RO01). The apparent absence of the $E_x = 5.18$ MeV group is ascribed partly to its breadth and partly to its presumptive two-excited nucleon character (1965GO05). The angular distributions of alpha particles corresponding to the lower states indicate strong direct interactions, $l = 1$ at $E(^3\text{He}) = 2.3$ to 5.5 MeV (1960TA12, 1965FO06: see also (1965GO05)); the distributions of α_2 ($E_x = 1.74$ MeV) vary strongly with energy (1965FO06). Alpha-gamma coincidence studies yield $\Gamma_\gamma/\Gamma < 4 \times 10^{-4}$ for $^{10}\text{B}^*(4.77)$, ≈ 1 for $^{10}\text{B}^*(5.17)$ (1965RO01). See also (1961BO33, 1964EL1B, 1964GA1B). The τ_m of the 1.74 MeV state is 0.15 ± 0.02 psec (1965LO04).

Table 10.23: ^{10}B levels from $^{11}\text{B}(^3\text{He}, \alpha)^{10}\text{B}$

E_x^a (MeV \pm keV)	$d\sigma/d\Omega^b$ (mb/sr)	E_x^c (MeV \pm keV)	$d\sigma/d\Omega^d$ (mb/sr)
0	0.69	0	0.30
0.725 ± 10	0.38	0.718 ± 7	0.09
1.741 ± 10	0.29	1.744 ± 7	0.06
2.149 ± 10	0.34	2.157 ± 6	0.13
3.594 ± 15	0.26	3.587 ± 6	0.12
		4.777 ± 5	0.09
		5.114 ± 5	0.10
		5.166 ± 5	0.49
		5.923 ± 5	0.09
		6.028 ± 5	0.09
		6.131 ± 5	0.09
		6.573 ± 8	0.06
		7.475 ± 10	0.30
		7.567 ± 10	0.05

^a (1960TA12): $E(^3\text{He}) = 5.2$ MeV.

^b At θ_{max} (1960TA12).

^c (1965GO05).

^d $E(^3\text{He}) = 4.96$ MeV, $\theta = 60^\circ$: see (1965GO05) for other angles.

31. $^{12}\text{C}(n, t)^{10}\text{B}$

$$Q_m = -18.931$$

Not reported.

32. (a) $^{12}\text{C}(p, ^3\text{He})^{10}\text{B}$

$$Q_m = -19.695$$

(b) $^{12}\text{C}(p, pd)^{10}\text{B}$

$$Q_m = -25.188$$

See (1961CL09, 1964BA1C).

33. $^{12}\text{C}(\text{d}, \alpha)^{10}\text{B}$

$$Q_{\text{m}} = -1.341$$

$$Q_0 = -1.3401 \pm 0.0012 \text{ (1965BR28)}.$$

Alpha groups have been observed to all of the known states of ^{10}B up to 5.1 MeV: the intensity of the α_2 -group to the 0^+ ; $T = 1$ state at 1.74 MeV is usually sharply reduced (1957EL12, 1961PE09, 1961YA08, 1962AR02, 1963AL16, 1963YA1B, 1965BA06, 1966HA09, 1965VO1B); but its yield varies appreciably with small energy changes (1963AL16). The identification of the α -groups to the 5.1 MeV states indicates that the $T = 1$ state at 5.17 MeV is not excited at $E_{\text{d}} = 10$ MeV (1962AR02). See Table 10.22. Angular distributions of the α_0 -, α_1 -, α_3 - and α_4 -groups have been determined for $E_{\text{d}} = 9.2$ to 19.7 MeV (1961YA08, 1963YA1B, 1965BA06). See also (1958CA1F, 1959HE1C, 1961GA13, 1963JA03, 1963PE07, 1964BA2E).

34. $^{12}\text{C}(\alpha, ^6\text{Li})^{10}\text{B}$

$$Q_{\text{m}} = -23.716$$

See (1962ZA01, 1964BR1L).

35. $^{13}\text{C}(\text{p}, \alpha)^{10}\text{B}$

$$Q_{\text{m}} = -4.063$$

At $E_{\text{p}} = 12.2$ MeV, α -groups are observed to the ground state and to the first three excited states (1963PE07). See also (1962HA1F).

36. (a) $^{14}\text{N}(\gamma, \alpha)^{10}\text{B}$

$$Q_{\text{m}} = -11.613$$

(b) $^{14}\text{N}(\text{p}, \alpha\text{p})^{10}\text{B}$

$$Q_{\text{m}} = -11.613$$

For reaction (a) see (1959AJ76); for reaction (b) see (1961CL09).

Table 10.24: Energy levels of ^{10}C

E_x (MeV \pm keV)	J^π	Γ (keV)	Decay	Reactions
g.s.	(0^+)	$\tau_{1/2} = 19.41 \pm 0.04$ sec	β^+	1, 2, 4, 5
3.360 ± 17			γ	2, 5
5.6 ± 100				2, 5
(7.2 ± 200)				5
10.2 ± 200		≈ 1500		5

^{10}C
(Figs. 21 and 22)

GENERAL: See (1960TA1C, 1962IN02, 1964GR1J, 1964VO1B).

Mass of ^{10}C : From the Q -value of the $^{10}\text{B}(p, n)^{10}\text{C}$ reaction (1961TA12: $Q_0 = -4.393 \pm 0.025$ MeV) and the β^+ end-point energy (1963BA52: $E_{\beta^+}(\text{max}) = 1.865 \pm 0.015$ MeV), the mass excess of ^{10}C is 15.658 ± 0.013 MeV, based on $^{12}\text{C} \equiv 0$ (1965MA54).

1. $^{10}\text{C}(\beta^+)^{10}\text{B}$ $Q_m = 3.606$

The decay is complex. See ^{10}B .

2. $^{10}\text{B}(p, n)^{10}\text{C}$ $Q_m = -4.388$

The ground state threshold occurs at $E_p = 4.835 \pm 0.025$ MeV (1961TA12). A sharp rise in the cross section curve at $E_p = 8.55$ MeV is attributed to a state in ^{10}C at $E_x = 3.38 \pm 0.03$ MeV (1963EA01). This state has also been observed directly as a neutron group ($E_x = 3.34 \pm 0.2$ MeV) at $E_p = 17.2$ MeV. Wide or unresolved states at $E_x \approx 5.1$ MeV may also be indicated (1954AJ32). The γ -decay of the first excited state has been observed: $E_x = 3.35 \pm 0.02$ MeV (1965SE1F). See also (1965VA1E) and ^{11}C .

3. $^{10}\text{B}(^3\text{He}, t)^{10}\text{C}$ $Q_m = -3.624$

See (1964OS1A).

4. $^{12}\text{C}(\gamma, 2\text{n})^{10}\text{C}$ $Q_{\text{m}} = -31.801$

See (1959OC07).

5. $^{12}\text{C}(\text{p}, \text{t})^{10}\text{C}$ $Q_{\text{m}} = -23.319$

At $E_{\text{p}} = 155$ MeV, triton groups are observed to the ground state of ^{10}C and to excited states at 3.4 ± 0.1 , 5.6 ± 0.1 , (7.2 ± 0.2) , and 10.2 ± 0.2 MeV. The 10.2 MeV state has a width of ≈ 1.5 MeV (1965BA17). See also (1960RA12, 1961RA1B, 1962CO17).

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.

- 1948EG1A Egglar, Hughes and Huddleston, Phys. Rev. 74 (1948) 1238
- 1949HU19 D.J. Hughes, C. Egglar and C.M. Huddleston, Phys. Rev. 75 (1949) 515
- 1949RA02 V. K. Rasmussen, W.F. Hornyak and T. Lauritsen, Phys. Rev. 76 (1949) 581
- 1949TH05 R.G. Thomas, S. Rubin, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 75 (1949) 1612
- 1950WU1A Wu, Revs. Mod. Phys. 22 (1950) 386
- 1951BO45 C.K. Bockelman, D.W. Miller, R.K. Adair and H.H. Barschall, Phys. Rev. 84 (1951) 69
- 1951CR1A Crews, Phys. Rev. 82 (1951) 100
- 1951FE1A A.M. Feingold, Revs. Mod. Phys. 23 (1951) 10
- 1951LI26 C.W. Li, W. Whaling, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 83 (1951) 512
- 1951NE03 J.A. Neuendorffer, D.R. Inglis and S.S. Hanna, Phys. Rev. 82 (1951) 75
- 1951SH63 R. Sher, J. Halpern and A.K. Mann, Phys. Rev. 84 (1951) 387
- 1952AJ22 F. Ajzenberg, Phys. Rev. 88 (1952) 298
- 1952CR30 D.S. Craig, D.J. Donahue and K.W. Jones, Phys. Rev. 88 (1952) 808
- 1952HA10 T.M. Hahn, C.W. Snyder, H.B. Willard, J.K. Bair, E.D. Klema, J.D. Kington and F.P. Green, Phys. Rev. 85 (1952) 934
- 1952PA1A Palevsky and Smith, Phys. Rev. 86 (1952) 604A
- 1953BA04 M.E. Battat and F.L. Ribe, Phys. Rev. 89 (1953) 80
- 1953BO70 C.K. Bockelman, C.P. Browne, W.W. Buechner and A. Sperduto, Phys. Rev. 92 (1953) 665
- 1953MA1A Mackin, Thesis, CalTech (1953)
- 1953PA22 E.B. Paul and H.E. Gove, Proc. Roy. Soc. Canada 47 (1953) 145A
- 1953SH38 R. Sherr and J.B. Gerhart, Phys. Rev. 91 (1953) 909
- 1953TH14 J. Thirion and V.L. Telegdi, Phys. Rev. 92 (1953) 1253
- 1953WI32 D.H. Wilkinson and G.A. Jones, Phys. Rev. 91 (1953) 1575
- 1954AJ32 F. Ajzenberg and W. Franzen, Phys. Rev. 95 (1954) 1531

1954AL38 E. Almqvist, T.P. Pepper and P. Lorrain, *Can. J. Phys.* 32 (1954) 621
1954BO79 T.W. Bonner and C.F. Cook, *Phys. Rev.* 96 (1954) 122
1954DA20 R.B. Day and T. Huus, *Phys. Rev.* 95 (1954) 1003
1954JO09 G.A. Jones and D.H. Wilkinson, *Phil. Mag.* 45 (1954) 703
1954JU23 J.J. Jung and C.K. Bockelman, *Phys. Rev.* 96 (1954) 1353
1954MA26 R.J. Mackin, Jr., *Phys. Rev.* 94 (1954) 648
1955CA25 R.R. Carlson and E.B. Nelson, *Phys. Rev.* 98 (1955) 1310
1955JA18 D.B. James, W. Kubelka, S.A. Heiberg and J.B. Warren, *Can. J. Phys.* 33 (1955) 219
1955MA84 J.B. Marion, T.W. Bonner and C.F. Cook, *Phys. Rev.* 100 (1955) 91
1955WI25 H.B. Willard, J.K. Bair and J.D. Kington, *Phys. Rev.* 98 (1955) 669
1956BO25 T.W. Bonner, A.A. Kraus, Jr., J.B. Marion and J.P. Schiffer, *Bull. Amer. Phys. Soc.* 1 (1956) 94, M6
1956CL69 A.B. Clegg, *Phil. Mag.* 1 (1956) 1116
1956DA23 R.B. Day, *Phys. Rev.* 102 (1956) 767
1956DE33 G. Dearnaley, *Phil. Mag.* 1 (1956) 821
1956KU1A Kurath, *Phys. Rev.* 101 (1956) 216
1956MA55 J.B. Marion, *Phys. Rev.* 103 (1956) 713
1956MO90 F.S. Mozer, *Phys. Rev.* 104 (1956) 1386
1956RE04 J.B. Reynolds and K.G. Standing, *Phys. Rev.* 101 (1956) 158
1956RO06 A.B. Robbins, *Phys. Rev.* 101 (1956) 1373
1956SE08 J.C. Severiens and S.S. Hanna, *Phys. Rev.* 104 (1956) 1612
1956SH94 S.M. Shafroth and S.S. Hanna, *Phys. Rev.* 104 (1956) 399
1956WA29 H.J. Watters, *Phys. Rev.* 103 (1956) 1763
1956WE37 G. Weber, L.W. Davis and J.B. Marion, *Phys. Rev.* 104 (1956) 1307
1956WI16 D.H. Wilkinson and A.R. Clegg, *Phil. Mag.* 1 (1956) 291
1957BI75 G.R. Bishop and J.C. Bizot, *J. Phys. Rad.* 18 (1957) 434
1957BI84 H. Bichsel and T.W. Bonner, *Phys. Rev.* 108 (1957) 1025
1957BL02 S.D. Bloom, C.M. Turner and D.H. Wilkinson, *Phys. Rev.* 105 (1957) 232
1957CO54 S.A. Cox and R.M. Williamson, *Phys. Rev.* 105 (1957) 1799
1957EL12 F.A. El Bedewi and I. Hussein, *Proc. Phys. Soc. (London)* A70 (1957) 233
1957FR1B French and Fujii, *Phys. Rev.* 105 (1957) 652
1957HU79 S.E. Hunt, R.A. Pope and W.W. Evans, *Phys. Rev.* 106 (1957) 1012

1957KU58 D. Kurath, Phys. Rev. 106 (1957) 975
 1957MC35 J.H. McCrary, T.W. Bonner and W.A. Ranken, Phys. Rev. 108 (1957) 392
 1957ME27 L. Meyer-Schutzmeister and S.S. Hanna, Phys. Rev. 108 (1957) 1506
 1957ST95 P.H. Stelson and E.C. Campbell, Phys. Rev. 106 (1957) 1252
 1957WA07 H. Warhanek, Phil. Mag. 2 (1957) 1085
 1958CA1F Catala, Bonet and Villar, An. Real. Soc. Espan. Fis. Y Quim. A54 (1958) 247
 1958DA11 W.K. Dawson, G.C. Neilson and J.T. Sample, Bull. Amer. Phys. Soc. 3 (1958) 323, H12
 1958GO47 S. Gorodetzky and A. Knipper, J. Phys. Rad. 19 (1958) 83
 1958HO97 R.E. Holland, F.J. Lynch and S.S. Hanna, Phys. Rev. 112 (1958) 903
 1958KN1B Knipper, Ph.D. Thesis, Univ. of Strasbourg (1958)
 1958MA1B Th.A.J. Maris, P. Hillman and H. Tyren, Nucl. Phys. 7 (1958) 1
 1958ME81 W.E. Meyerhof and L.F. Chase, Jr., Phys. Rev. 111 (1958) 1348
 1958NA09 M.P. Nakada, J.D. Anderson, C.C. Gardner and C. Wong, Phys. Rev. 110 (1958) 1439
 1958TY49 H. Tyren, P. Hillman and T.A.J. Marris, Nucl. Phys. 7 (1958) 10
 1958VA33 S.S. Vasilev, V.V. Komarov and A.M. Popova, Dokl. Akad. Nauk SSSR 119 (1958) 914; Sov. Phys. Dokl. 3 (1958) 354
 1958WY67 M.E. Wyman, E.M. Fryer and M.M. Thorpe, Phys. Rev. 112 (1958) 1264
 1958ZE1A Zeidman and Fowler, Phys. Rev. 112 (1958) 2020
 1959AJ76 F. Ajzenberg and T. Lauritsen, Nucl. Phys. 11 (1959) 1
 1959AL83 D.E. Alburger, A. Elwyn, A. Gallmann, J.V. Kane, S. Ofer and R.E. Pixley, Phys. Rev. Lett. 2 (1959) 110
 1959BA1F Balashov and Tulinov, Zh. Eksp. Teor. Fiz. 36 (1959) 615; JETP (Sov. Phys.) 9 (1959) 426
 1959BI10 M. Birk, G. Goldring and Y. Wolfson, Phys. Rev. 116 (1959) 730
 1959BO1C Bockelman, Nucl. Phys. 13 (1959) 205
 1959BO49 A.N. Boyarkina and A.F. Tulinov, Zh. Eksp. Teor. Fiz. 36 (1959) 353; JETP (Sov. Phys.) 9 (1959) 244
 1959BR1E Brink and Kerman, Nucl. Phys. 12 (1959) 314
 1959CH1E Chuan, J. Phys. Rad. 20 (1959) 621
 1959CH28 P. Chevallier, Ann. Phys. 4 (1959) 1389
 1959FO1A Fowler and Cohn, Bull. Amer. Phys. Soc. 4 (1959) 385
 1959GI47 J.H. Gibbons and R.L. Macklin, Phys. Rev. 114 (1959) 571

1959GO78 S. Gorodetzky, P. Chevallier, R. Armbruster and G. Sutter, Nucl. Phys. 12 (1959) 349
 1959HA1K Hasegawa and Ichikawa, Prog. Theor. Phys. 21 (1959) 569
 1959HE1B Hess, Ann. Phys. 6 (1959) 115
 1959HE1C Henley and Jacobsohn, Phys. Rev. 113 (1959) 225
 1959HI1E Hird, Cookson and Bokhari, Congres Int. de Phys. Nucl., 1958 (Dunod, Paris, 1959) 470
 1959HI69 S. Hinds and R. Middleton, Proc. Phys. Soc. (London) A74 (1959) 196
 1959KA69 J. Kantele, Ann. Acad. Sci. Fennicae, Ser. A VI, No. 37 (1959)
 1959KO1B Kohler, Ph.D. Thesis, CalTech (1959)
 1959LE1E Lefevre and Russell, Rev. Sci. Instrum. 30 (1959) 159
 1959LE27 R.J.A. Levesque and S.M. Shafroth, Phys. Rev. 114 (1959) 1354
 1959MA1C MacGregor, Congr. Int. De Phys. Nucl., 1958 (Dunod, Paris, 1959) 612
 1959MA20 J.B. Marion and J.S. Levin, Phys. Rev. 115 (1959) 144
 1959MA34 J.B. Marion, J.S. Levin and L. Cranberg, Phys. Rev. 114 (1959) 1584
 1959ME1A Meyerhof, Tanner and Hudson, Phys. Rev. 115 (1959) 1227
 1959ME24 U. Meyer-Berkhout, K.W. Ford and A.E.S. Green, Ann. Phys. 8 (1959) 119
 1959OC07 J. O'Connell, P. Dyal and J. Goldemberg, Phys. Rev. 116 (1959) 173
 1959SI1A Sitenko, Usp. Fiz. Nauk 67 (1959) 377
 1959SI1C Singh, Phys. Rev. 114 (1959) 871
 1959TA01 R.T. Taylor, Phys. Rev. 113 (1959) 1293
 1959TO1A Tobocman, Phys. Rev. 115 (1959) 98
 1959WA16 E.K. Warburton, Phys. Rev. 113 (1959) 595
 1959ZA01 N.I. Zaika and O.F. Nemets, Izv. Akad. Nauk SSSR Ser. Fiz. 23 (1950) 1460
 1960BA01 W.D. Barfi eld, H.T. Motz and R.E. Carter, Bull. Amer. Phys. Soc. 5 (1960) 44, MA4
 1960BA26 R. Barloutaud, H. Farraggi, L. Rosen and S.M. Shafroth, J. Phys. Rad. 21 (1960) 369
 1960BA46 R. Bardes and G.E. Owen, Phys. Rev. 120 (1960) 1369
 1960BE18 J. Benveniste, A.C. Mitchell, C.D. Schrader and J.H. Zenger, Nucl. Phys. 19 (1960) 52
 1960BE1B Belyaev, Zakhar'ev and Neudachin, Atomn. Energ. (USSR) 9 (1960) 298, Sov. J. At. Energy 9 (1961) 833
 1960BU1C Bullock and Moore, Phys. Rev. 119 (1960) 721
 1960GO04 J. Gonzalez-Vidal, H.C. Conzett and W.H. Wade, Bull. Amer. Phys. Soc. 5 (1960) 230, C9

- 1960GO18 S. Gorodetzky, J. Samuel and A. Gallmann, *J. Phys. Rad.* 21 (1960) 349
- 1960GO23 S. Gorodetzky, R. Richert, R. Manquenouille and A. Knipper, *Nucl. Phys.* 17 (1960) 684
- 1960GR11 J.A. Green and W.C. Parkinson, *Bull. Amer. Phys. Soc.* 5 (1960) 345, F1
- 1960HI08 S. Hinds and R. Middleton, *Proc. Phys. Soc. (London)* 75 (1960) 754
- 1960HI09 B. Hird and A. Strzalkowski, *Proc. Phys. Soc. (London)* 75 (1960) 868
- 1960HJ01 E. Hjalmar and H. Slati, *Ark. Fys.* 18 (1960) 193
- 1960HO14 P.E. Hodgson, *Nucl. Phys.* 21 (1960) 21
- 1960JU04 J. Juna, P. Horvath and K. Konecny, *Czech. J. Phys.* 10 (1960) 715
- 1960KL03 P.R. Klein, N. Cindro, L.W. Swenson and N.S. Wall, *Nucl. Phys.* 16 (1960) 374
- 1960KU1B Kunz, *Ann. Phys.* 11 (1960) 275
- 1960LU04 C.R. Lubitz, *Bull. Amer. Phys. Soc.* 5 (1960) 346, F2
- 1960LU1B Lubitz, *Bull. Amer. Phys. Soc.* 5 (1960) 18
- 1960MA15 K.V. Makariunas and S.V. Starodubtsev, *Zh. Eksp. Teor. Fiz.* 38 (1960) 372; *JETP (Sov. Phys.)* 11 (1960) 271
- 1960MA32 R.D. Macfarlane and J.B. French, *Revs. Mod. Phys.* 32 (1960) 567
- 1960MC04 J.H. McCrary, J.T. Prudhomme and I.L. Morgan, *Bull. Amer. Phys. Soc.* 5 (1960) 229, C5
- 1960MO17 G.C. Morrison, *Phys. Rev. Lett.* 5 (1960) 565
- 1960NA1A Nagarajan and Banerjee, *Nucl. Phys.* 17 (1960) 341
- 1960NE1C Neudachin, Teplov and Tulinov, *JETP (Sov. Phys.)* 10 (1960) 387
- 1960PE1B Peterson, Bratenel and Stoering, *Phys. Rev.* 120 (1960) 521
- 1960RA12 P. Radvanyi and J. Genin, *J. Phys. Rad.* 21 (1960) 322
- 1960SA25 G.L. Salmon, *Nucl. Phys.* 21 (1960) 15
- 1960SE12 R. Seltz and D. Magnac-Valette, *Compt. Rend.* 251 (1960) 2006
- 1960SI04 L. Simons, *Soc. Sci. Fenn. Comm. Phys. Math.* 24, No. 8 (1960)
- 1960TA12 I.J. Taylor, F.de S. Barros, P.D. Forsyth, A.A. Jaffe and S. Ramavataram, *Proc. Phys. Soc. (London)* A75 (1960) 772
- 1960TA1C Talmi and Unna, *Ann. Revs. Nucl. Sci.* 10 (1960) 353
- 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
- 1960VL05 N.A. Vlasov, S.P. Kalinin, A.A. Ogloblin and V.I. Chuev, *Zh. Eksp. Teor. Fiz.* 39 (1960) 1618; *JETP (Sov. Phys.)* 12 (1961) 1129

- 1960WA07 R.B. Walton, N.F. Wikner, J.L. Wood and J.R. Beyster, *Bull. Amer. Phys. Soc.* 5 (1960) 288, WA5
- 1960WE04 H.E. Wegner and W.S. Hall, *Phys. Rev.* 119 (1960) 1654
- 1961AL07 R.D. Albert, S.D. Bloom and N.K. Glendenning, *Phys. Rev.* 122 (1961) 862
- 1961AN07 D.S. Andreev, V.D. Vasilev, G.M. Gusinskii, K.I. Erokhina and I.K. Lemberg, *Izv. Akad. Nauk SSSR Ser. Fiz.* 25 (1961) 832; *Bull. Acad. Sci. USSR* 25 (1962) 842
- 1961AN1A Androsenko, Broder and Lashuk, *Sov. J. At. Energy* 9 (1961) 945
- 1961BA1E Balashov, Neudachin and Smirnov, *Izv. Akad. Nauk SSSR Ser. Fiz.* 25 (1961) 170; *Bull. Acad. Sci. USSR Phys.* 25 (1961) 165
- 1961BA53 R. Bass, T.W. Bonner and H.P. Haenni, *Nucl. Phys.* 23 (1961) 122
- 1961BE1E Beckner, Jones and Philips, *Phys. Rev.* 123 (1961) 255
- 1961BO33 B. Bourotte, I. Nicolas, R. Bilwes and D. Magnac-Valette, *J. Phys. Rad.* 22 (1961) 583
- 1961BR35 D.A. Bromley, K. Nagatani, L.C. Northcliffe, R. Ollerhead and A.R. Quinton, *Proc. Rutherford Jub. Int. Conf., Manchester, England*; Ed. J.B. Birks (Academic Press Inc., New York, 1961) 597
- 1961CA1F Catron et al, *Phys. Rev.* 123 (1963) 218
- 1961CL09 A.B. Clegg, K.J. Foley, G.L. Salmon and R.E. Segel, *Proc. Phys. Soc. (London)* 78 (1961) 681
- 1961CO1E Cohen, *React. Sci. and Tech.; J. Nucl. Energ.* 14 (1961) 180
- 1961CR1A Cranberg, *Helv. Phys. Acta Suppl.* 6 (1961) 324
- 1961FO07 D.B. Fossan, R.L. Walter, W.E. Wilson and H.H. Barschall, *Phys. Rev.* 123 (1961) 209
- 1961GA13 J. Gastebois, J. Jastrzebski, J.L. Picou, J. Quidort and J.P. Schapira, *J. Phys. Rad.* 22 (1961) 580
- 1961GA1G Galloway and Sillitto, *Proc. Roy. Soc. Edinburgh* 65 Part III, 1959-1960 (1961)
- 1961HO01 H.D. Holmgren and L.M. Cameron, *Bull. Amer. Phys. Soc.* 6 (1961) 36, MA2
- 1961HO1D Honda and Ui, *Prog. Theor. Phys.* 25 (1961) 635
- 1961HO23 H.D. Holmgren and L.M. Cameron, *Proc. Rutherford Jub. Int. Conf., Manchester, England*; Ed. J.B. Birks (Academic Press Inc., New York, 1961) 537
- 1961IS01 T. Ishimatsu, N. Takano, Y. Hachiya and T. Nakashima, *J. Phys. Soc. Jpn.* 16 (1961) 367
- 1961JA19 von L. Jarczyk, J. Lang, R. Muller and W. Wolfli, *Helv. Phys. Acta* 34 (1961) 483
- 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

- 1961KN02 A. Knipper, *Ann. Phys.* 6 (1961) 211
- 1961LA17 J.M. Lambert, L. Madansky and G.E. Owen, *Phys. Rev.* 124 (1961) 1959
- 1961LA1A Lane, Langsdorf, Monahan and Elwyn, *Ann. Phys.* 12 (1961) 135
- 1961LE1A Legg, Unpublished Thesis, Princeton Univ. (1961)
- 1961MO02 G.C. Morrison, *Phys. Rev.* 121 (1961) 182
- 1961MO15 G.C. Morrison, A.T.G. Ferguson and J.E. Evans, *Proc. Rutherford Jub. Int. Conf., Manchester, England; Ed. J.B. Birks (Academic Press Inc., New York, 1961) 575*
- 1961MY01 S.A. Myachkova and V.P. Pereygin, *Zh. Eksp. Teor. Fiz.* 40 (1961) 1244; *JETP (Sov. Phys.)* 13 (1961) 876
- 1961PE09 F. Pellegrini, *Nucl. Phys.* 24 (1961) 372
- 1961RA1B Radvanyi et al, *Proc. Rutherford Jub. Int. Conf., Manchester, England; Ed. J.B. Birks (Academic Press Inc., New York, 1961) 197*
- 1961RE03 F.H. Read and J.M. Calvert, *Proc. Phys. Soc. (London)* 77 (1961) 65
- 1961RE04 F.H. Read, J.M. Calvert and G. Schork, *Nucl. Phys.* 23 (1961) 386
- 1961RI08 R. Richert, *Ann. Phys.* 6 (1961) 1437
- 1961RO05 L. Rosen, J.E. Brolley, Jr. and L. Stewart, *Phys. Rev.* 121 (1961) 1423
- 1961RO13 L. Rosen, J.E. Brolley, Jr., M.L. Gursky and L. Stewart, *Phys. Rev.* 124 (1961) 199
- 1961RO1K Rook and Hodgson, *Proc. Rutherford Jub. Int. Conf., Manchester, England; Ed. J.B. Birks (Academic Press Inc., New York, 1961) 503*
- 1961SA21 J.-J. Samueli and A. Sarazin, *J. Phys. Rad.* 22 (1961) 692
- 1961SP02 E.L. Sprenkel, J.W. Olness and R.E. Segel, *Phys. Rev. Lett.* 7 (1961) 174
- 1961SP04 E.K. Sprinkel and J.W. Daughtry, *Phys. Rev.* 124 (1961) 854
- 1961ST1D Stoltzfus, Ph.D. Thesis, Univ. of Iowa (1961)
- 1961TA02 N.W. Tanner and S.S. Hanna, *Nucl. Phys.* 23 (1961) 319
- 1961TA06 A.E. Taylor and E. Wood, *Nucl. Phys.* 25 (1961) 642
- 1961TA12 S. Takayanagi, N.H. Gale, J.B. Garg and J.M. Calvert, *Nucl. Phys.* 28 (1961) 494
- 1961TE02 A. Tejera, M. Mazari, A. Jaidar and G. Lopez, *Rev. Mex. Fis.* 10 (1961) 229
- 1961TR1B True and Warburton, *Nucl. Phys.* 22 (1961) 426
- 1961VA03 A.M.K. Van Beek and G.O. Andre, *Nucl. Phys.* 24 (1961) 102
- 1961VA43 A.K. Val-ter, P.I. Vatsset, L.Y. Kolesnikov, S.G. Tonapetyan, K.K. Chernyavskii and A.I. Shpetnyi, *Atomn. Energ. (USSR)* 10 (1961) 577; *Sov. J. At. Energy* 10 (1962) 574
- 1961WI1A Wilkinson, Wollan and Koehler, *Ann. Rev. Nucl. Sci.* 11 (1961) 303

1961WO05 E.A. Wolicki and A.R. Knudson, Bull. Amer. Phys. Soc. 6 (1961) 415, B2
 1961YA08 T. Yanabu, J. Phy. Soc. Jpn. 16 (1961) 2118
 1962AL10 R.G. Allas, R.W. Bercaw and F.B. Shull, Phys. Rev. 127 (1962) 1252
 1962AL1A Altman, MacDonal and Marion, Nucl. Phys. 35 (1962) 85
 1962AR01 B.H. Armitage and R.E. Meads, Phys. Lett. 1 (1962) 284; Erratum Phys. Lett. 2 (1962) 164
 1962AR02 B.H. Armitage and R.E. Meads, Nucl. Phys. 33 (1962) 494
 1962BA03 B.K. Barnes, T.A. Belote and J.R. Risser, Bull. Amer. Phys. Soc. 7 (1962) 111, A3
 1962BA1D Barber, Ann. Rev. Nucl. Sci. 12 (1962) 1
 1962BE24 E. Berkowitz, S. Bashkin, R.R. Carlson, S.A. Coon and E. Norbeck, Phys. Rev. 128 (1962) 247
 1962BL10 S.L. Blatt and W.E. Meyerhof, Bull. Amer. Phys. Soc. 7 (1962) 624, W8
 1962BU1C Bunakov, Zh. Eksp. Teor. Fiz. 43 (1962) 2224; JETP (Sov. Phys.) 16 (1963) 1571
 1962CH1B Chizhov et al, Nucl. Phys. 34 (1962) 562
 1962CO17 C.F. Coleman, P.E. Cavanagh, B.W. Ridley and J.F. Turner, Conf. Low Energy Nucl. Phys. Harwell, AERE-R-4131, 8, 3.3; Sept. 1962 (1962)
 1962CO23 R.A. Coombe and J. Walker, Proc. Phys. Soc. (London) 80 (1962) 1218
 1962DE10 G. Dearnaley, D.S. Gemmell and S.S. Hanna, Nucl. Phys. 36 (1962) 71
 1962DI1A Dietrich, Phys. Lett. 2 (1962) 139
 1962EA02 L.G. Earwaker, J.G. Jenkin and E.W. Titterton, Nature 195 (1962) 271
 1962ED02 R.D. Edge and G.A. Peterson, Phys. Rev. 128 (1962) 2750
 1962EL01 A.J. Elwyn and R.O. Lane, Nucl. Phys. 31 (1962) 78
 1962EL06 R.J. Ellison and B. Dickinson, Nucl. Phys. 35 (1962) 606
 1962FI07 F.W.K. Firk and E.M. Bowey, AERE-R-4131 (1962)
 1962GA09 J.P. Garron, J.C. Jacmart, M. Riou, C. Ruhla, J. Teillac and K. Strauch, Nucl. Phys. 37 (1962) 126
 1962GA11 J.B. Garg, N.H. Gale and J.M. Calvert, Nucl. Phys. 37 (1962) 319
 1962GA15 N.H. Gale, J.B. Garg and J.M. Calvert, Nucl. Phys. 38 (1962) 222
 1962GA1L Galloway, Proc. Roy. Soc. Edinburgh A66 (1962) 47
 1962GA23 J.P. Garron, Ann. Phys. (Paris) 7 (1962) 301
 1962GO1P Gottschalk, Unpublished Thesis, Harvard Univ. (1962)
 1962HA1F Hay and Lawrence, Aust. J. Sci. 25 (1962) 77
 1962HO1C Honda and Ui, Nucl. Phys. 34 (1962) 609

- 1962HU05 T. Husain, J. Nat. Sci. Math. (Pakistan) 2 (1962) 1; Nucl. Sci. Abs. 16, 3016, Abs. 23051 (1962); Phys. Abs. 667 (1963)
- 1962IG1A Igo and Wilkins, Phys. Lett. 2 (1962) 342
- 1962IN02 D.R. Inglis, Nucl. Phys. 30 (1962) 1
- 1962KJ05 J. Kjellman, A. Nilsson and S. Schwarz, Ark. Fys. 21 (1962) 169
- 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
- 1962KO14 G.A. Kosinov and O.F. Nemets, Izv. Akad. Nauk SSSR Ser. Fiz. 26 (1962) 1518; Columbia Tech. Transl. 26 (1963) 1543
- 1962LE1C Lefevre, Borchers and Poppe, Rev. Sci. Instrum. 33 (1962) 1231
- 1962LO02 J. Lowe, C.L. McClelland and J.V. Kane, Phys. Rev. 126 (1962) 1811
- 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)
- 1962MC12 R.L. McGrath, Phys. Rev. 127 (1962) 2138
- 1962ME1A Mehta and McIldowie, Nucl. Phys. 33 (1962) 502
- 1962MO12 G.C. Morrison, R.E. White and A.T.G. Ferguson, AERE-R 4131, 13, 5.5 (Sept. 1962)
- 1962OT01 P.S. Otvavnov and V.I. Popov, Zh. Eksp. Teor. Fiz. 43 (1962) 385; JETP (Sov. Phys.) 16 (1963) 276
- 1962PA12 M.V. Pasechnik, L.S. Saltykov and D.I. Tambovtsev, Zh. Eksp. Teor. Fiz. 43 (1962) 1575; JETP (Sov. Phys.) 16 (1963) 1111
- 1962PE10 A. Perrin, G. Surget, C. Thibault and F. Verriere, Compt. Rend. 255 (1962) 277
- 1962PI1A Pinkston, Nucl. Phys. 29 (1962) 690
- 1962SC12 G. Schrank, E.K. Warburton and W.W. Daehnick, Phys. Rev. 127 (1962) 2159
- 1962SE1A Serov and Guzhovskii, Atomn. Energ. (USSR) 12 (1962) 5
- 1962SL03 R.J. Slobodrian, Nucl. Phys. 32 (1962) 684
- 1962SL04 R.J. Slobodrian, Phys. Rev. 126 (1962) 1059
- 1962VO1D Volkov, Kulikov and Chizhov, Zh. Eksp. Teor. Fiz. 42 (1962) 61; JETP (Sov. Phys.) 15 (1962) 42
- 1962WA21 W.K. Warburton and L.F. Chase, Jr., Nucl. Phys. 34 (1962) 517
- 1962WE1C Wegner, Rev. Sci. Instrum. 33 (1962) 271
- 1962ZA01 C.D. Zafiratos, Bull. Amer. Phys. Soc. 7 (1962) 454, GA11
- 1963AC01 R. Achari, P. Roussel and J. Zamudio, J. Phys. 24 (1963) 874
- 1963AL16 R.G. Allas, J.R. Erskine, L. Meyer-Schutzmeister and D. von Ehrenstein, Bull. Amer. Phys. Soc. 8 (1963) 538, S7

- 1963AL18 D.E. Alburger, Phys. Rev. 132 (1963) 328
- 1963AN12 G.B. Andreev, A.S. Deineko and I.Y. Malakhov, Izv. Akad. Nauk SSSR Ser. Fiz. 27 (1963) 1305; Bull. Acad. Sci. URRS 27 (1963) 1282
- 1963BA2F Bachelier, Bernas, Brissaud, Detraz and Radvanyi, J. Phys. 24 (1963) 1055
- 1963BA52 F.J. Bartis, Phys. Rev. 132 (1963) 1763
- 1963BE42 T. Berggren and G. Jacob, Nucl. Phys. 47 (1963) 481
- 1963BL20 H.R. Blieden, G.M. Temmer and K.L. Warsh, Nucl. Phys. 49 (1963) 209
- 1963BU1C Bunakov, Phys. Lett. 7 (1963) 14
- 1963CH1C Chatterjee, Nucl. Phys. 49 (1963) 686
- 1963CO1K Cohen, Moyer, Shaw and Waddell, Phys. Rev. 130 (1963) 1505
- 1963DI01 G.U. Din and J.L. Weil, Bull. Amer. Phys. Soc. 8 (1963) 115, I4
- 1963DI1F Didier and Dillemann, J. Phys. 24 (1963) 805
- 1963DR02 J.E. Draper and C.O. Bostrom, Nucl. Phys. 47 (1963) 108
- 1963DU12 J.L. Duggan, P.D. Miller and R.F. Gabbard, Nucl. Phys. 46 (1963) 336
- 1963EA01 L.G. Earwaker, J.G. Jenkin and E.W. Titterton, Nucl. Phys. 42 (1963) 521
- 1963FE1B Ferguson, Gale, Morrison and White, Padua (1963) 510
- 1963FU11 B. Furubayashi, E. Teranishi and M. Kageyama, J. Phys. Soc. Jpn. 18 (1963) 1235
- 1963GA03 A. Gallmann, D.E. Alburger, D.H. Wilkinson and F. Hibou, Phys. Rev. 129 (1963) 1765
- 1963GL1F Glazkov, Atomn. Energ. (USSR) 15 (1963) 416
- 1963GO04 J. Goldemberg and Y. Torizuka, Phys. Rev. 129 (1963) 312
- 1963GO1M Goldberg, May and Stehn, BNL-400, 2nd Ed., Vol. 1 (1963)
- 1963GO1N Gorlov, Lebedeva and Morozov, Dokl. Akad. Nauk SSSR 158 (1964) 574
- 1963HA1G Haeberli, in Fast Neutron Phys., Eds. Marion and Fowler (Academic Press, 1963) 1379
- 1963HO19 H.D. Holmgren, L.M. Cameron and R.L. Johnston, Nucl. Phys. 48 (1963) 1
- 1963JA03 J. Jastrzebski, F. Picard, J.P. Schapira and J.L. Picou, Nucl. Phys. 40 (1963) 400
- 1963JA1E Jarmie and Diven, Nucl. Sci. Eng. 17 (1963) 433
- 1963KE03 C.A. Kelsey, G.P. Lietz, S.F. Trevino and S.E. Darden, Phys. Rev. 129 (1963) 759
- 1963KO15 E. Koltay, Acta Phys. Acad. Sci. Hung. 16 (1963) 93
- 1963KU03 D. Kurath, Phys. Rev. 130 (1963) 1525
- 1963KU1F Kukhtevich et al, Sov. Prog. in Neutron Phys., Consult. Bureau (1963) 205; Phys. Abs. 12240 (1964)

1963LE03 J.C. Legg, Phys. Rev. 129 (1963) 272
 1963LE09 C. Lemeille, L. Marquez and N. Saunier, Phys. Lett. 5 (1963) 267
 1963LU10 H.F. Lutz, J.B. Mason and M.D. Karvelis, Nucl. Phys. 47 (1963) 521
 1963MC1C McTaggart and Goodfellow, J. Nucl. Energy 17 (1963) 437
 1963ME01 J.B. Mead, L.B. Geesaman and H.B. Knowles, Bull. Amer. Phys. Soc. 8 (1963) 292, A15
 1963ME08 M.K. Mehta, W.E. Hunt, H.S. Plendl and R.H. Davis, Nucl. Phys. 48 (1963) 90
 1963MO1F Morpurgo, Nucl. Spectroscopy; Ed. Racah (Academic Press, 1962)
 1963MO1L Morrison, Ferguson and White, Padua (1963) 562A
 1963NE09 O.F. Nemets, M.V. Pasechnik and N.N. Pucherov, Nucl. Phys. 45 (1963) 1
 1963NE16 O.F. Nemets, M.V. Pasechnik and N.N. Pucherov, Atomn. Energ. (USSR) 14 (1963) 159; Sov. J. At. Energy 14 (1963) 149
 1963NE1H Nemilov and Pobedonotsev, Zh. Eksp. Teor. Fiz. 45 (1963) 103; JETP (Sov. Phys.) 18 (1964) 76
 1963NO02 E. Norbeck, S.A. Coon, R.R. Carlson and E. Berkowitz, Phys. Rev. 130 (1963) 1971
 1963OG1A Ogloblin, Nucl. Phys. 47 (1963) 408
 1963OL1B Ollerhead, Chasman and Bromley, Padua (1963) 984
 1963PE07 R.R. Perry, I.J. Taylor and P.D. Forsyth, Bull. Amer. Phys. Soc. 8 (1963) 302, D4
 1963RI08 P.J. Riley, D.W. Braben and G.C. Neilson, Nucl. Phys. 47 (1963) 150
 1963RI1B Riou, Padua (1963) 18
 1963RO1M Rose and Weigert, Eastern Theor. Phys. Conf. (Gordon and Breach, 1963)
 1963SA1K Sachs, Chasman and Bromley, Padua (1963) 987
 1963SM05 W.R. Smith and E.V. Ivash, Phys. Rev. 131 (1963) 304
 1963TA1A Tanifuji, Nucl. Phys. 40 (1963) 357
 1963VA1C Valentin, Albouy, Cohen and Gusakov, Phys. Lett. 7 (1963) 163
 1963VL1A Vlasov, Zh. Eksp. Teor. Fiz. 45 (1963) 160; JETP (Sov. Phys.) 18 (1964) 160
 1963WA03 E.K. Warburton, D.E. Alburger and D.H. Wilkinson, Phys. Rev. 129 (1963) 2180
 1963WA17 E.K. Warburton, D.E. Alburger and D.H. Wilkinson, Phys. Rev. 132 (1963) 776
 1963WA1M Warburton, Alburger, Wilkinson and Soper, Phys. Rev. 129 (1963) 2191
 1963WI1D Wilkins, UCR-10783 (1963)
 1963WI1E Wilkins and Igo, Phys. Rev. 129 (1963) 2198
 1963YA1B Yanabu et al, J. Phys. Soc. Jpn. 18 (1963) 747

- 1963ZU1B Zubov, Lebedeva and Morozov, Sov. Prog. in Neutron Phys. (New York, Consultants Bureau, 1963) 219; Phys. Abs. 12242
- 1964AM1D Amit and Latz, Nucl. Phys. 58 (1964) 297
- 1964AR04 B.H. Armitage and R.E. Meads, Phys. Lett. 8 (1964) 346
- 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
- 1964BA1V Ballot, Dumontet, Picinbono and Saya, Nucl. Phys. 51 (1964) 401
- 1964BA29 R.W. Bauer, J.D. Anderson and C. Wong, Nucl. Phys. 56 (1964) 117
- 1964BA2E Barshay and Temmer, Phys. Rev. Lett. 12 (1964) 728
- 1964BE03 R.W. Bercaw, E.T. Boschitz and J.S. Vincent, Bull. Amer. Phys. Soc. 9 (1964) 55, FA2
- 1964BI18 J.C. Bizot, Ann. Phys. (Paris) 9 (1964) 421
- 1964BI1K Bingham, Brussel and Steben, Nucl. Phys. 55 (1964) 265
- 1964BL1C Blieden, Phys. Lett. 9 (1964) 176
- 1964BO13 R.O. Bondelid and J.W. Butler, Nucl. Phys. 53 (1964) 618
- 1964BO1M Bock, Duhm, Hortig and Rudel, Paris (1964) 136
- 1964BO33 M.S. Bokhari and V.V. Verbinski, Bull. Amer. Phys. Soc. 9 (1964) 627, E8
- 1964BR06 D.J. Bredin, J.W. Olness and E.K. Warburton, Bull. Amer. Phys. Soc. 9 (1964) 407, CA7
- 1964BR1L Bromley, Symp. on Nucl. Spectrosc. with Direct Reactions, ANL 6878 (1964)
- 1964BU14 S.G. Buccino and A.B. Smith, Bull. Amer. Phys. Soc. 9 (1964) 628, E9
- 1964CA16 R.R. Carlson, R.L. McGrath and E. Norbeck, Phys. Rev. 136 (1964) B1687
- 1964CR1B Cromer and Palmieri, Ann. Phys. 30 (1964) 32
- 1964DE1K Demortier and Deconninck, Congres. Int. de Phys. Nucl., Paris (1964)
- 1964DI1C Din, Unpublished Thesis, Rice Univ. (1964)
- 1964EL1B El-Nadi and Riad, Nucl. Phys. 50 (1964) 33
- 1964FR1D Francis, Goldman and Lubitz, Ann. Phys. 29 (1964) 232
- 1964GA11 N. Gangas, S. Kossionides, R. Rigopoulos and M.L. Ahmad, Phys. Lett. 12 (1964) 233
- 1964GA1B Gallman, Nucl. Instrum. Meth. 28 (1964) 33
- 1964GR1A Green and Donahue, Phys. Rev. 135 (1964) B701
- 1964GR1J Green, Nucl. Phys. 54 (1964) 505
- 1964HO02 W.F. Hornyak, C.A. Ludemann and M.L. Roush, Nucl. Phys. 50 (1964) 424

1964JA03 J.C. Jacmart, J.P. Garron, M. Riou and C. Ruhla, Phys. Lett. 8 (1964) 269
 1964KI02 K.G. Kibler and R.R. Carlson, Bull. Amer. Phys. Soc. 9 (1964) 406, CA1
 1964LA04 R.O. Lane, A.J. Elwyn and A. Langsdorf, Jr., Phys. Rev. 133 (1964) B409
 1964LI1D Lim and McCarthy, Phys. Rev. 133 (1964) B1006
 1964LO1C Loiseaux, Langevin and Maison, Congres Int. de Phys. Nucl., Paris (1964)
 1964MA1G Mamasakhlisov, Izv. Akad. Nauk SSSR Ser. Fiz. 28 (1964) 1550
 1964NE1E Neudachin, Shevchenko and Yudin, Phys. Lett. 10 (1964) 180
 1964OL1A Ollerhead, Chasman and Bromley, Phys. Rev. 134 (1964) B74
 1964OS1A Osgood, Patterson and Titterton, Phys. Lett. 10 (1964) 75
 1964PA1M Paic, Slaus, Valkovic and Cerineo, Congres Int. de Phys. Nucl., Paris (1964)
 1964RE04 L.H. Reber and J.X. Saladin, Phys. Rev. 133 (1964) B1155
 1964SC12 U. Schmidt-Rohr, R. Stock and P. Turek, Nucl. Phys. 53 (1964) 77
 1964SH07 T.H. Short and N.M. Hintz, Bull. Amer. Phys. Soc. 9 (1964) 391, BA16
 1964SI02 R.H. Siemssen, M. Cosack and R. Felst, Bull. Amer. Phys. Soc. 9 (1964) 55, FA3
 1964SI03 P.P. Singh, R.E. Segel, R.G. Allas, S.S. Hanna and M.A. Grace, Bull. Amer. Phys. Soc. 9 (1964) 56, FA8
 1964ST1B Stovall, Phys. Rev. 133 (1964) B268
 1964ST1K Starodubtsev and Khrushchev, Atomn. Energ. (USSR) 17 (1964) 59
 1964ST25 J.R. Stehn, M.D. Goldberg, B.N. Magurno and R. Wiener-Chasman, BNL-325, 2nd Ed., Suppl. 2, Vol. 1 (1964)
 1964TI02 G. Tibell, O. Sundberg and P.U. Renberg, Ark. Fys. 25 (1964) 433
 1964VA1D Valentin, Albouy, Cohen and Gusakow, J. Physique 25 (1964) 704
 1964VO1B Volkov, Phys. Lett. 12 (1964) 118
 1964WA05 E.K. Warburton, D.E. Alburger, A. Gallmann, P. Wagner and L.F. Chase, Jr., Phys. Rev. 133 (1964) B42
 1964WA1F Waghmare, Phys. Rev. 134 (1964) B1185
 1964WA1K Waghmare, Phys. Rev. 136 (1964) B1261
 1964ZA03 J. Zamudio, R. Achari and P. Roussel, Nucl. Phys. 51 (1964) 212
 1964ZA1B Zaika, Nemets and Tokarevskii, Izv. Akad. Nauk SSSR Ser. Fiz. 28 (1964) 1637
 1965AJ01 F. Ajzenberg-Selove, J.W. Watson and R. Middleton, Phys. Rev. 139 (1965) B592
 1965BA06 F. Baldeweg, V. Bredel, H. Guratzsch, R. Klages, B. Kuhn and G. Stiller, Nucl. Phys. 64 (1965) 55

- 1965BA17 C.D. Bachelier, M. Bernas, I. Brissaud, P. Radvanyi and M. Roy, Phys. Lett. 16 (1965) 304
- 1965BO1L Bondouk, Asfour, Gontchar and Machali, Nucl. Phys. 65 (1965) 490
- 1965BR28 C.P. Browne, W.E. Dorenbusch and F.H. O'Donnell, Nucl. Phys. 72 (1965) 194
- 1965CR1C Crosby, Legg and Roy, Bull. Amer. Phys. Soc. 10 (1965) 439
- 1965FA1C Wang, Chen and Sze, Acta Phys. Sin. 21 (1965) 140
- 1965FO06 P.D. Forsyth, I.J. Taylor and R.R. Perry, Nucl. Phys. 66 (1965) 376
- 1965FO07 P.D. Forsyth and R.R. Perry, Nucl. Phys. 67 (1965) 517
- 1965FO1G Forsyth, Roush, Nelson and Hornyak, Bull. Amer. Phys. Soc. 10 (1965) 439
- 1965FR07 G. Fricke, G.R. Bishop and D.B. Isabelle, Nucl. Phys. 67 (1965) 187
- 1965FU03 K. Fukunaga, J. Phys. Soc. Jpn. 20 (1965) 1
- 1965FU1G Fuller and Cohen, Appendix I, Nucl. Data Sheets 6-5 (1965)
- 1965GO05 S. Gorodetzky, A. Gallmann and R. Rebmeister, Phys. Rev. 137 (1965) B1466
- 1965GO1K Goldemberg et al, Phys. Lett. 16 (1965) 141
- 1965HA17 D. Hasselgren, P.U. Renberg, O. Sundberg and G. Tibell, Nucl. Phys. 69 (1965) 81
- 1965HE1B Henkel, Bull. Amer. Phys. Soc. 10 (1965) 601
- 1965LO04 J.A. Lonergan and D.J. Donahue, Phys. Rev. 139 (1965) B1149; Erratum Phys. Rev. 145 (1966) 998
- 1965MA1K Marion, Nucl. Phys. 68 (1965) 463
- 1965MA54 J.H.E. Mattauch, W. Thiele and A.H. Wapstra, Nucl. Phys. 67 (1965) 1
- 1965MO1K S. Morita, T. Tohei, T. Nakagawa, T. Hasegawa, H. Ueno and C.-C. Hsu, Nucl. Phys. 66 (1965) 17
- 1965NE1C Neudatchin and Smirnov, Nucl. Phys. 66 (1965) 25
- 1965PA02 P. Paul, S.L. Blatt and D. Kohler, Phys. Rev. 137 (1965) B493
- 1965PA03 P. Paul, S.L. Blatt and D. Kohler, Phys. Rev. 137 (1965) B499
- 1965RI1A Riou, Revs. Mod. Phys. 37 (1965) 375
- 1965RO01 M.L. Roush, P. Forsyth, F.C. Young, W.F. Hornyak and J.B. Marion, Bull. Amer. Phys. Soc. 10 (1965) 9, AC6
- 1965RO1P G. Roy, S.D. Baker, G.C. Phillips and G.K. Walters, Bull. Amer. Phys. Soc. 10 (1965) 51
- 1965SE1F Segel and Singh, Bull. Amer. Phys. Soc. 10 (1965) 426
- 1965SI12 R.H. Siemssen, M. Cosack and R. Felst, Nucl. Phys. 69 (1965) 209
- 1965SI1B Singh and Gemmell, Bull. Amer. Phys. Soc. 10 (1965) 538

- 1965SP04 E. Spamer and F. Gudden, Phys. Lett. 14 (1965) 210
- 1965VA1E Valentin, Nucl. Phys. 62 (1965) 81
- 1965VO1B Von Ehrenstein, Meyer-Schutzmeister and Allas, Bull. Amer. Phys. Soc. 10 (1965) 440
- 1965WA04 B.D. Walker, C. Wong, J.D. Anderson and J.W. McClure, Phys. Rev. 137 (1964) B1504
- 1965WA1P Warburton, Olness, Jones, Chasman, Ristinen and Wilkinson, (1965)
- 1965YO1E Young, Forsyth and Knudson, Bull. Amer. Phys. Soc. 10 (1965) 439
- 1966BA1A J.N. Bahcall, Nucl. Phys. 75 (1966) 10
- 1966HA09 E.T. Hazzard, F. Ajzenberg-Selove and P.V. Hewka, Nucl. Phys. 75 (1966) 592; Erratum Nucl. Phys. 89 (1966) 706
- 1966TY01 H. Tyren, S. Kullander, O. Sundberg, R. Ramachandran, P. Isacson and T. Berggren, Nucl. Phys. 79 (1966) 321; Erratum Nucl. Phys. A119 (1968) 692