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.

^{10}Be

(Figs. 19 and 22)

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

1. ^{10}Be(β^-)^{10}B $\qquad Q_\mathrm{m} = 0.555$

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}Li(t, α)^{6}He $\qquad Q_\mathrm{m} = 9.834 \qquad E_\mathrm{b} = 17.250$
   (b) ^{7}Li(t, 2n)^{8}Be $\qquad Q_\mathrm{m} = 8.770$
   (c) ^{7}Li(t, n)^{9}Be $\qquad Q_\mathrm{m} = 10.435$
   (d) ^{7}Li(t, n)^{5}He + ^{4}He $\qquad Q_\mathrm{m} = 7.907$

The neutron yield exhibits broad resonances at $E_\mathrm{t} = 0.84$ and 1.70 MeV (1951CR01), 0.71 ± 0.02 MeV (1962SE1A), 0.765 and 1.735 MeV (1961VA43), and a weak structure at $E_\mathrm{t} = 0.24$ 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}He*(0, 1.8, 3.4) see, however, (1965AJ01) for evidence relevant to the existence of a state at 3.4 MeV in ^{6}He) 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 $E_\mathrm{t} = 1.80$ MeV may result from interference effects (1961HO23). Angular distributions of α_0 and α_1 at $E_\mathrm{t} = 0.24$ MeV suggest $J = 2^+$ for the 17.8 MeV state (1954AL38). See also (1963JA1E) and (1959AJ76).

3. ^{7}Li(α, p)^{10}Be $\qquad Q_\mathrm{m} = -2.564$

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}Li(^{7}Li, α)^{10}Be $\qquad Q_\mathrm{m} = 14.783$

Table 10.1: Energy levels of ^{10}Be

E_x (MeV ± keV)	J^π	Γ (keV)	Decay	Reactions
g.s.	0^+	$\tau_{1/2} = (2.7 \pm 0.4) \times 10^6$ y	β^-	1, 3, 4, 5, 11, 14, 17, 19, 21
3.366 ± 3	2^+	$\tau_m = 0.15 \pm 0.03$ psec	γ	3, 4, 5, 11, 17
5.959 ± 5 [a]	$1^-, 2^-$	$\tau_m < 0.08$ psec	γ	4, 5, 6, 11
6.178 ± 9	0^+	$\tau_m > 0.5$ 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. ^{9}Be(n, γ)^{10}Be $\qquad Q_m = 6.815$

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

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

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 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}Be(n, n)^{9}Be

$E_{\rm res}$ [a] (MeV $\pm$ keV)	^{10}Be* (MeV)	$\Gamma_{\rm c.m.}$ (keV)	J^π	l	R (fm)	$\gamma_{\rm n}^2$ (keV)		θ^2 %	References
						$J_{\rm c} = 1$	$J_{\rm c} = 2$		
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 $E_{\rm n} = 207$ 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}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 (1964GO1L). 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, 1960MC04, 1960PE25, 1960SA25). See also (1959AJ76). Optical model analyses have been carried out by (1960HO14, 1963LU10).

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

7. (a) ^{9}Be(n, n′)^{9}Be* $E_b = 6.815$

(b) ^{9}Be(n, 2n)^{8}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}Be* → n + ^{8}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}Be(n, n′)^{9}Be*(2.43) accounts for about half of the non-elastic cross section (1959MA34: see (1964ST25)): see also ^{9}Be. At $E_n = 14$ MeV, ^{8}Be*(2.9) is frequently involved (1959CH1E, 1961MY01).

See also ^{9}Be and (1959MA1C, 1961CA23, 1961CO1E, 1963DI1F, 1963GO1M, 1963KU1F, 1963MC1C, 1963ZU1B).

8. ^{9}Be(n, p)^{9}Li $Q_m = -12.832$ $E_b = 6.815$

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

9. ^{9}Be(n, t)^{7}Li $Q_m = -10.435$ $E_b = 6.815$

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

10. ^{9}Be(n, α)^{6}He $\qquad Q_{\rm m} = -0.601 \qquad E_{\rm b} = 6.815$

The cross section for production of ^{6}He has been measured for $E_{\rm n} = 0.7$ 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 $E_{\rm n} = 2.7$ MeV. From $E_{\rm n} = 3.9$ to 8.6 MeV, the cross section decreases smoothly from 100 mb to 32 mb (1961BA53). The cross section at $E_{\rm n} = 14$ MeV is 10 ± 1 mb (1953BA04). See also (1960BU1C, 1963CH1C, 1964GA11).

11. ^{9}Be(d, p)^{10}Be $\qquad Q_{\rm m} = 4.590$

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 (1958ZE01, 1959AJ76, 1960MA32, 1961IS01, 1961RE04, 1962SL04, 1964SC12). Except at the lowest energies, the stripping process appears to dominate: see (1959BO1C, 1960BE1B, 1960LU04, 1960LU1B, 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, $\tau_{\rm m} > 0.5$ psec, consistent with an E0 transition (1963WA17). Internal pair correlations establish the multipolarities 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}Be*(5.96) is < 0.08 psec (1965WA1P). The absence of a ground-state transition from ^{10}Be*(6.26) supports the assignment $J^\pi = 2^-$ for this level (1958ME81, 1963WA17): see also (1959CH28, 1959GO78).

The (p-γ) correlation through ^{10}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 ^{3}P$_2$ state in LS coupling, but not with ^{1}D$_2$. 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, 1960GR11, 1960HI09, 1961VA03, 1962AL10, 1962PA12, 1963NE09, 1963NE16, 1964RE04, 1965HE1B). See also (1961TE02).

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

Table 10.4: Levels of ^{10}Be from ^{9}Be(d, p)^{10}Be [d]

E_x [a] (MeV ± 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}Be(t, d)^{10}Be $\qquad Q_m = 0.558$

Not reported.

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

Not reported.

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

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

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

Table 10.5: Radiative transitions in ^{9}Be(d, p)^{10}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}Be(n, γ).
[d] See also (1965FO1G).

Not reported.

16. ^{11}B(n, d)^{10}Be $\qquad Q_{m} = -9.004$

Not reported.

17. ^{11}B(p, 2p)^{10}Be $\qquad Q_{m} = -11.228$

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}B.

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

Not reported.

19. ^{11}B(t, α)^{10}Be $Q_{\rm m} = 8.586$

See (1961HO01).

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

See (1963SA1K).

21. ^{13}C(n, α)^{10}Be $Q_{\rm m} = -3.836$

See ^{14}C.

^{10}B

(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:

$\mu = +1.8007$ nm (1965FU1G).
$Q = +0.08$ b (1965FU1G).

1. ^{6}Li(α, γ)^{10}B $\qquad Q_{\rm m} = 4.461$

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

The 4.77 MeV state decays mainly to ^{10}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 $\omega\Gamma_{\rm s} \equiv \omega\Gamma_\gamma\Gamma_\alpha/(\Gamma_\gamma + \Gamma_\alpha)$ is 0.05 eV: Γ(M1) $\approx 0.01\ \Gamma_{\rm W}$, Γ(E2) $\gtrsim 10\Gamma_{\rm W}$, 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 ≈ 0.01 is assumed (1957ME27, 1958ME81). The distributions from $E_{\rm x} = 5.17$ MeV are consistent with $J^\pi = 2^+$ (1957ME27): observations in ^{9}Be(d, n)^{10}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 ($E_{\rm x} = 5.18$ MeV, $\Gamma_{\rm c.m.} = 200 \pm 30$ 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^+, 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}Li(α, p)^{9}Be $\qquad Q_{\rm m} = -2.126 \qquad E_{\rm b} = 4.461$
(b) ^{6}Li(α, d)^{8}Be $\qquad Q_{\rm m} = -1.567$
(c) ^{6}Li(α, α)^{6}Li
(d) ^{6}Li(α, n)^{9}B $\qquad Q_{\rm m} = -3.977$

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	γ, ^{3}He	4
18.8	$(2^+, 1^-; 1)$	< 600	γ, ^{3}He, α	4
19.3	$(2^+, 1^-; 1)$	350	γ, n, ^{3}He, α	4
20.1		broad	n, p, ^{3}He	4

Table 10.7: Electromagnetic transitions in ^{10}B

Initial State	Γ_γ (total) (eV)	Relative intensities to final states at: g.s.	0.72	1.74	2.15	3.59	5.18	References
0.72	6.6×10^{-7}	100						Table 10.20
1.74	4.4×10^{-3}	< 2	100					(1964SI03, 1965LO04)
2.15	4.9×10^{-4}	22	27	51				(1961SP04, 1964HO02, 1965WA1P)
3.59	6.9×10^{-3}	15	65	< 3	20			(1958ME81, 1964BR06, 1964HO02, 1964SI03, 1965WA1P)
4.77	0.03	8	92					Table 10.8, (1963WA17)
5.11	0.07	96	4					Table 10.8, (1963WA17)
5.17	0.6	5.5	29.5		65			Tables 10.8 and 10.19, (1963WA17)
5.18	0.06			100				Table 10.8
5.92		100						Table 10.8
6.03		100						Table 10.8
6.4	0.75 [c]							(1964JA03)
6.88	(4.8)	< 3	24	56	17	4	< 11	Table 10.13
7.43	2.4	< 2	1.3	< 0.1	0.62	0.5	< 1	Table 10.13 [d]
7.47	11							(1965SP04)
7.48	25.8	25	0.3	< 0.1	0.49	0	< 1	Table 10.13 [d]
7.56	8.5	< 0.2	6.7	< 0.3	0.8	< 0.2	1.0	Table 10.13 [d]
7.77	8.5	6.6	0.9	< 0.1	0.3	0.3	0.4	Table 10.13 [d]
8.89	0.6							(1964GR40)
11.8 [a]								
14 [a]								
18.6 [b]								
18.8 [b]								
19.3 [b]								

[a] See (1962ED02).
[b] See Table 10.10.
[c] $B(\mathrm{E2}\uparrow) = 29$ fm^4.
[d] Partial Γ_γ in eV (1964HO02).

Table 10.8: Levels of ^{10}B from ^{6}Li(α, γ)^{10}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): $E2/M1 = 0.64$, γ(g.s.) $< 3\%$; $\Gamma_\gamma/\Gamma < 4 \times 10^{-4}$ (1965RO01).

[e] See (1958ME81) and ^{9}Be(d, n)^{10}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 ^{6}Li) particles (1963BL20: $E_\alpha = 9.50$ to 12.50 MeV), d_0 particles (to the ground state of ^{8}Be) (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}Li(^{6}Li, d)^{10}B — $Q_m = 2.989$
   (b) ^{6}Li(^{7}Li, t)^{10}B — $Q_m = 1.994$
   (c) ^{6}Li(^{9}Be, ^{5}He)^{10}B — $Q_m = 1.933$

Table 10.9: ^{10}B levels from ^{6}Li(α, α)^{6}Li

E_α (MeV)	E_α (MeV)	E_x (MeV)	Γ_{lab} (keV)	$J^\pi; T$	θ^2_α	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}Li(^{3}He, n)^{9}B $Q_m = 9.349$ $E_b = 17.786$
(b) ^{7}Li(^{3}He, p)^{9}Be $Q_m = 11.199$
(c) ^{7}Li(^{3}He, d)^{8}Be $Q_m = 11.759$
(d) ^{7}Li(^{3}He, α)^{6}Li $Q_m = 13.325$
(e) ^{7}Li(^{3}He, γ)^{10}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}Li + ^{3}He

E_{res} (MeV)	$\Gamma_{c.m.}$ (keV)	E_x (MeV)	$\omega\Gamma$ [a] for transition to				Γ_α	References
			g.s.	0.72	3.59	4.77		
1.1	< 500	18.6	35			140		(1965PA02)
1.4	< 600	18.8		100	100		< 80	(1965PA02, 1965PA03)
2.2	$280 - 420$	19.3	85			200	< 20	[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}Li(α, n)^{10}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}Be(p, γ)^{10}B

E_p (MeV $\pm$ keV)	E_x (MeV)	$\Gamma_{c.m.}$ (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	7.43	140 ± 30	$(2^-); 0$	0.7	2.4	(1962EL06, 1964HO02)
(0.98)	(7.47)		(2^+)			(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: se 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}Li(^{3}He, γ): $J^\pi = 2^+$ or 1^-; $T = (1)$ for both: Γ_α is small (1965PA03).

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

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}Be(p, γ)^{10}B $\qquad$ $Q_m = 6.587$

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}B*(6.88)) is ascribed to s-wave protons because of its comparatively large proton width [see ^{9}Be(p, p)] and because of the isotropy of the γ-radiation. The strong transition to ^{10}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}B*(0.7, 2.1) indicate a $T = 1$ admixture of 20% or more (1956WI16, 1959ME85). A small P_2 term in

Table 10.13: Radiative transitions in ^{9}Be(p, γ)^{10}B

Initial state (MeV)	Γ_γ(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		2.4	6	15	3	5	3.6		(1957BI75)
$E_p = 0.33$	[10]	15	40	100	45				(1955CA25)
	4.8		1.0	2.6	0.5		0.65		(1956CL69)
		< 0.7	6.4	15	4.5	≈ 1	< 2.9		(1959ME85)
$1^-; 0$			0.006	0.025	0.009	≈ 0.005		$\|M\|^2$E1	(1959ME85)
7.43			(res)						(1962EL06)
$E_p = 0.94$	[2.4]	< 2	1.3	[< 0.14]	0.62	0.5	[< 1]		(1964HO02)
$2^-; 0$			0.013		0.013	0.03		$\|M\|^2$E1	(1964HO02)
7.48		400	< 10	19	22	< 7	< 13		(1959ME85)
$E_p = 0.99$	[25.8]	25	0.3	[< 0.14]	0.49	0	[< 1]		(1964HO02)
$2^-; 1$		0.19	0.003		0.10			$\|M\|^2$E1	(1964HO02)
7.56	4.8		1.0	2.6	0.5		0.65		(1956CL69)
$E_p = 1.08$		< 3	100	< 8	< 8	< 4	23		(1959ME85)
			76		9		15		(1961SP04)
	6.6		100	< 2	10		40		(1962ME1A)
	[8.5]	< 0.2	6.7	< 0.3	0.8	< 0.2	1.0		(1964HO02)
$0^+; 1$			1.0		0.24		3.5	$\|M\|^2$M1	(1964HO02)
7.75	14.6	83%							(1963FU11)
$E_p = 1.29$	[8.5]	6.6	0.9	< 0.08	0.3	0.3	0.4		(1964HO02)
$2^-; 1$		0.044	0.008		0.006	0.013	0.08	$\|M\|^2$E1	(1964HO02)

the angular distribution at resonance suggests a d-wave admixture. The angular correlation of $6.88 \rightarrow 0.72 \rightarrow$ 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}B*(7.56)) is formed by p-wave protons, $J^\pi = 0^+$ [see ^{9}Be(p, p) and ^{9}Be(p, α)]. 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}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}B*(0.7) (1953MA1A). It appears from the width that this resonance corresponds to that observed in ^{9}Be(p, α), $J = 2^+$; $T = 1$ and not to the ^{9}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}Be(p, n)^{9}B $\qquad Q_m = -1.851 \qquad E_b = 6.587$

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 ^{9}B 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}Be(p, α) and ^{9}Be(p, γ) 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}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}Be(p, p)^{9}Be $\qquad E_b = 6.587$

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}Be(p, n)^{9}B

E_{res} (MeV $\pm$ keV)	Γ_{lab} (keV)	E_x (MeV)	$J^\pi; T$	σ_{max} (mb)	References
2.562 ± 6	85 ± 10	8.892	$3^{(-)}$; (1)		(1956MA55, 1962AL1A)
	100 ± 10			160	(1959GI47)
3.5	≈ 700	9.7			(1956MA55, 1959MA20)
				240	(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: posibly 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}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 (1964BI19) 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, 1963WI12, 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}Be(p, p)^{9}Be

E_{res} (keV)	E_x (MeV)	Γ_{lab} (keV)	J^{π}	Γ_p/Γ	θ^2_p	References
330	6.88		1^-	0.30	0.5	(1956MO90)
(980 ± 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}Be(p, d)^{8}Be and ^{9}Be(p, α)^{6}Li

E_p (MeV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	$J^{\pi}; T$	Γ_p/Γ	θ^2_p	θ^2_d	θ^2_α	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, 1965MO27)
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}Li*(3.56), $0^+; T = 1$.

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

$^{10}B^*$ (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. $^{9}Be(p, t)^{7}Be$ $\quad Q_m = -12.079 \quad E_b = 6.587$

See ^{7}Be.

10. (a) $^{9}Be(p, d)^{8}Be$ $\quad Q_m = 0.559 \quad E_b = 6.587$
(b) $^{9}Be(p, \alpha)^{6}Li$ $\quad Q_m = 2.126$

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 (1965MO27) and for $E_p = 3.5$ to 12.5 MeV by (1963BL20); the (p, α_2) reaction, leading to $^{6}Li^*(3.56)$, 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^2_α 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, 1965MO27). 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}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}Be*(7.55, 9.26, 9.4) (1959MA20). See also (1959LE27, 1961BE1E, 1961ST1D).

11. ^{9}Be(d, n)^{10}B $\qquad$ $Q_m = 4.363$

Neutron groups are observed corresponding to ^{10}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}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}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}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}Be and ^{10}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 $E_x = 3.59 \rightarrow 0.7 \rightarrow$ 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}Be(d, n)^{10}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}Be(d, n)^{10}B

Transition	E_γ (keV)	Branching ratio [d] (%)
$0.7 \to$ g.s.	716.6 ± 1 [a]	100
$1.7 \to$ g.s.		< 2
$1.7 \to 0.7$	1022 ± 2 [a]	100
$2.15 \to$ g.s.	2152 ± 15 [a]	22
$2.15 \to 0.7$	1433 ± 5 [a]	27
$2.15 \to 1.7$	413.5 ± 1 [a]	51
$3.59 \to$ g.s.	3583 ± 13 [b,c]	15 [e]
$3.59 \to 0.7$	2872 ± 15 [b,c]	65 [e]
$3.59 \to 2.15$		20
$5.17 \to$ g.s.	5159 ± 16 [b]	5.5 ± 0.7 [b]
$5.17 \to 0.7$	4461 ± 13 [b,c]	29.5 ± 2 [b]
$5.17 \to 2.15$	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}B*(0.72)

τ_m (nsec)	Reaction	References
0.7 ± 0.2	^{9}Be(d, n)^{10}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}B(p, p′)^{10}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 (1958GO47, 1958KN1B, 1960GO23, 1961RI08, 1962LO02).

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}Li(α, γ)]. 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}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}Be(^{3}He, d)^{10}B $\qquad Q_m = 1.094$

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}Be(^{3}He, d)^{10}B (1960HI08) [a]

E_x (MeV ± 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}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}Be(α, t)^{10}B $\quad Q_m = -13.227$

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

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

See (1964BO1M).

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

See ^{10}Be.

16. (a) ^{10}B(γ, n)^{9}B $\quad Q_m = -8.438$
(b) ^{10}B(γ, p)^{9}Be $\quad Q_m = -6.587$
(c) ^{10}B(γ, d)^{8}Be $\quad Q_m = -6.028$
(d) ^{10}B(γ, α)^{6}Li $\quad Q_m = -4.461$

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 ^{9}B. 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) (1964GR40). For reactions (b), (c), (d), see (1959AJ76) and (1962CH26, 1962VO1D).

17. ^{10}B(γ, γ)^{10}B

See (1964LO1C).

18. ^{10}B(e, e)^{10}B

Elastic scattering at $\theta = 180°$ gives evidence of an M3 contribution (1965GO1K: see also (1965RA1D)). At $E_e = 41.5$ MeV $(\theta = 180°)$ 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}B*(6.02 ± 0.02 and 7.48 ± 0.02 MeV), the latter with $\Gamma = 40$ keV, Γ_γ(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}B(n, n′)^{10}B*

See (1956DA23, 1960AN14, 1963GL1F).

20. ^{10}B(p, p′)^{10}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}Be(d, n)^{10}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}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 σ(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(E2) $= 29$ 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}Li (1965HA17). Inelastic cross sections at $E_p = 153$ MeV yield $|M|^2 = 11$, 0.02, and 0.66 for γ-transitions from ^{10}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 ± 5, 1438 ± 5, 2120 ± 60, 2880 ± 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}B(p, 2p)^{9}Be $\qquad Q_m = -6.587$

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}Be.

22. ^{10}B(d, d′)^{10}B*

Deuteron groups have been observed corresponding to eleven excited states of ^{10}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}B(t, t)^{10}B

See (1963HO19).

24. ^{10}B(α, α')^{10}B*

See (1956BO25, 1964ST1K).

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

See (1961AN07).

Table 10.22: ^{10}B levels from ^{10}B(p, p′) [a], ^{10}B(d, d′) and ^{12}C(d, α)^{10}B

E_x [b] (MeV)	Relative Intensities [b] (p, p′)	(d, d′)	E_x [c] (p, p′)	E_x [d] (d, d′)	E_x [d] ^{12}C(d, α)	E_x [e] (MeV)	Γ [e] (keV)
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 ± 10 [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 $\theta = 90°$, $E = 7.6$ MeV.
[c] (1962AR02): energies ± 10 keV. $E_p = 10.0$ MeV, $\theta_L = 90°$, $120°$.
[d] (1962AR02): energies ± 10 keV. $E_d = 10.0$ MeV, $\theta_L = 60°$, $90°$.
[e] (1964AR04): E_p and $E_d = 11$ MeV, $\theta_L = 45°$, $60°$; 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}C(β^+)^{10}B $\qquad Q_{\rm m} = 3.606$

The half life is 19.48 ± 0.05 sec (1962EA02), 19.27 ± 0.08 sec (1963BA52): E_{β^+}(max) $=$ 1.865 ± 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 ± 0.2/< 0.1 (1953SH38): ft (from $\tau_{1/2} = 19.41$ sec, $Q_{\rm m}$ above) are 1.0×10^3 and 2.2×10^3 to the 0.72 and 1.74 MeV states, respectively (1966BA1A).

27. ^{11}B(γ, n)^{10}B $\qquad Q_{\rm m} = -11.456$

See (1951SH63).

28. ^{11}B(p, d)^{10}B $\qquad Q_{\rm m} = -9.231$

At $E_{\rm p} = 19$ MeV, the ground state and the first four excited states have been observed. From the angular distributions, analyzed by PWBA, $l_{\rm n} = 1$, $\theta^2 = 0.011$, 0.029, 0.011 and 0.0031 (1961LE1A, 1963LE03). At $E_{\rm p} = 155$ 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}B(d, t)^{10}B $\qquad Q_{\rm m} = -5.199$

See (1960VL05, 1963OG1A).

30. ^{11}B(^{3}He, α)^{10}B $\qquad Q_{\rm m} = 9.122$

Reported levels are listed in Table 10.23. No evidence is found for previously reported levels at $E_{\rm x} = 2.86$, 5.58 and 6.40 MeV (1963GA03, 1965GO05). See also (1965RO01). The apparent absence of the $E_{\rm x} = 5.18$ 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}He) $= 2.3$ to 5.5 MeV (1960TA12, 1965FO06: see also (1965GO05)); the distributions of α_2 ($E_{\rm x} = 1.74$ MeV) vary strongly with energy (1965FO06). Alpha-gamma coincidence studies yield $\Gamma_\gamma/\Gamma < 4 \times 10^{-4}$ for ^{10}B*(4.77), ≈ 1 for ^{10}B*(5.17) (1965RO01). See also (1961BO33, 1964EL1B, 1964GA1B). The $\tau_{\rm m}$ of the 1.74 MeV state is 0.15 ± 0.02 psec (1965LO04).

Table 10.23: ^{10}B levels from ^{11}B(^{3}He, α)^{10}B

E_x [a] (MeV ± keV)	$d\sigma/d\Omega$ [b] (mb/sr)	E_x [c] (MeV ± 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): $E(^{3}\mathrm{He}) = 5.2$ MeV.
[b] At $\theta_{\max}$ (1960TA12).
[c] (1965GO05).
[d] $E(^{3}\mathrm{He}) = 4.96$ MeV, $\theta = 60°$: see (1965GO05) for other angles.

31. ^{12}C(n, t)^{10}B $\quad Q_m = -18.931$

Not reported.

32. (a) ^{12}C(p, ^{3}He)^{10}B $\quad Q_m = -19.695$
(b) ^{12}C(p, pd)^{10}B $\quad Q_m = -25.188$

See (1961CL09, 1964BA1C).

33. ^{12}C(d, α)^{10}B $Q_{\rm m} = -1.341$

$Q_0 = -1.3401 \pm 0.0012$ (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, 1965VO1B, 1966HA09); 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 $E_{\rm d} = 10$ MeV (1962AR02). See Table 10.22. Angular distributions of the α_0-, α_1-, α_3- and α_4-groups have been determined for $E_{\rm d} = 9.2$ to 19.7 MeV (1961YA08, 1963YA1B, 1965BA06). See also (1958CA1F, 1959HE1C, 1961GA13, 1963JA03, 1963PE07, 1964BA54).

34. ^{12}C(α, ^{6}Li)^{10}B $Q_{\rm m} = -23.716$

See (1962ZA01, 1964BR1L).

35. ^{13}C(p, α)^{10}B $Q_{\rm m} = -4.063$

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

36. (a) ^{14}N(γ, α)^{10}B $Q_{\rm m} = -11.613$

(b) ^{14}N(p, αp)^{10}B $Q_{\rm m} = -11.613$

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

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

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

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

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 (1965VA23) and ^{11}C.

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

See (1964OS1A).

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

See (1959OC07).

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

At $E_{\rm p} = 155$ 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 Eggler, Hughes and Huddleston, Phys. Rev. 74 (1948) 1238

1949HU19 D.J. Hughes, C. Eggler 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, Rev. Mod. Phys. 22 (1950) 386

1951BO45 C.K. Bockelman, D.W. Miller, R.K. Adair and H.H. Barschall, Phys. Rev. 84 (1951) 69

1951CR01 R.W. Crews, Phys. Rev. 82 (1951) 100

1951FE1A A.M. Feingold, Rev. 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, Phy. 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

1958ZE01 B. Zeidman and J.M. 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

1959ME24 U. Meyer-Berkhout, K.W. Ford and A.E.S. Green, Ann. Phys. (N.Y.) 8 (1959) 119

1959ME85 W.E. Meyerhof, N.W. Tanner and C.M. Hudson, Phys. Rev. 115 (1959) 1227

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

1960AN14 A.L. Androsenko, D.L. Broder and A.I. Lashuk, At. Energ. 9 (1960) 403; Sov. J. At. Energy 9 (1961) 945

1960BA01 W.D. Barfield, 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, Atomnaya Energiya 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. Slatis, 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, Rev. 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

1960PE25 J.M. Peterson, A. Bratenahl and J.P. 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. Rev. 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

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

1961CA23 H.C. Catron, M.D. Goldberg, R.W. Hill, J.M. Le Blanc, J.P. Stoering, C.J. Taylor and M.A. Williamson, 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. Perelygin, 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. Vatset, 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, MacDonald 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

1962CH26 V.P. 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. Otstavnov 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)

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 Gusakow, 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

1963WI12 B.D. Wilkins and G. Igo, Phys. Rev. 129 (1963) 2198

1963WI1D Wilkins, UCR-10783 (1963)

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

1964BA54 S. Barshay and G.M. 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

1964BI19 F.W. Bingham, M.K. Brussel and J.D. 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

1964GO1L Gorlov, Lebedeva and Morozov, Dokl. Akad. Nauk SSSR 158 (1964) 574

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

1964GR40 L. Green and D.J. Donahue, Phys. Rev. 135 (1964) B701

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, Atomnaya Energ. 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. Klabes, 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

1965MO27 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

1965RA1D Rand, Frosch and Yearian, Bull. Amer. Phys. Soc. 10 (1965) 542

1965RI1A Riou, Rev. 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

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

1965VA23 L. 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. Isacsson and T. Berggren, Nucl. Phys. 79 (1966) 321; Erratum Nucl. Phys. A119 (1968) 692