Energy Levels of Light Nuclei
$A = 11$

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Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), p. 1. This version of $A = 11$ 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.

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^{11}Be

(Not illustrated)

GENERAL:

Mass of ^{11}*Be:* From the decay energy, ^{11}Be(β^-)^{11}B, and using the Wapstra mass (1955WA1A) for ^{11}B, the mass excess of ^{11}Be, $M - A = 23.39 \pm 0.15$ MeV (1959WI49). The binding energies of a neutron, deuteron and triton in ^{11}Be are, respectively, 0.54, 18.4 and 15.76 MeV.

1. ^{11}Be(β^-)^{11}B $\qquad Q_{\rm m} = 11.48$

The decay proceeds to ^{11}B$_{\rm g.s.}$ and to several excited states. For the ground-state transition, E_β(max) $= 11.48 \pm 0.15$ MeV; $\tau_{1/2} = 13.57 \pm 0.15$ sec, $\log ft = 6.77$ (1958AL96, 1959WI49); see ^{11}B.

2. ^{9}Be(t, p)^{11}Be $\qquad Q_{\rm m} = -1.13$

Not reported.

3. ^{11}B(n, p)^{11}Be $\qquad Q_{\rm m} = -10.69$

At $E_{\rm n} = 14.8$ MeV, an activity with a 14.1 ± 0.3 sec half-life is observed which is attributed to the β-decay of ^{11}Be formed in this reaction (1958NU40).

^{11}B

(Figs. 16)

GENERAL:

Theory: See (1956KU1A, 1957KU58, 1958FR1C).

1. ^{7}Li(α, γ)^{11}B $\qquad Q_{\rm m} = 8.670$

Table 11.1: Energy levels of ^{11}B

E_x (Mev $\pm$ keV)	J^π	τ_m (sec) or Γ (keV)	Decay	Reactions
0	$\frac{3}{2}^-$	stable	–	1, 10, 11, 12, 19, 22, 29, 30, 31, 34, 36, 38
2.127 ± 6	$\frac{1}{2}^-$	$\tau_m = (4.6 \pm 0.6) \times 10^{-15}$	γ	10, 11, 19, 22, 23, 27, 28, 36, 38
4.459 ± 8	$(\frac{5}{2}^-)$	$\tau_m = (1.17 \pm 0.17) \times 10^{-15}$	γ	1, 10, 12, 13, 19, 23, 28, 36, 38
5.035 ± 8	$(\frac{3}{2}^-)$	< 13	γ	1, 10, 19, 38
6.758 ± 7	$(\frac{7}{2}^-)$	< 13	γ	1, 10, (12), 13, 19, 22, 28, 38
6.808 ± 7	$(\frac{3}{2})^-$	< 13	γ	1, 10, (12), 19, 22, 36
7.298 ± 6	$(\frac{5}{2}^-)$	< 13	γ	1, 10, 19, 38
7.987 ± 9		< 8	γ	10, 19, 22, 28, 38
8.568 ± 5	$(\frac{1}{2}^+, \frac{3}{2}^+)$	< 8	γ	10, 19, 28, 38
8.927 ± 5	$(\frac{5}{2}^+)$	< 0.7	γ, α	1, 10, 12, 13, 19, 38
9.191 ± 5	$(\frac{7}{2}^+)$	< 0.1	γ, α	1, 10, 13, 19, 26
9.276 ± 5	$(\frac{5}{2}^+)$	5	γ, α	1, 10, 19
9.88 ± 20	$(\leq \frac{5}{2})$	160	α	4, 10
10.26	$(\leq \frac{7}{2})$	220	α	4
10.32 ± 20		45 ± 14		19
10.62		100	α	4
11.0		670	α	4
11.46		70	α, (n)	4, 18
11.68 ± 100	$(\frac{5}{2}^+, \frac{7}{2}^+)$	140	α, n	2, 4, 12, 18
11.95 ± 80	$(\frac{3}{2}^-, \frac{5}{2}^+)$	320	α, n	2, 4, 13, 18, 38
13.16		450	α, n	2, 13, 18
14.0		300	α, n	13, 18
15.1		500	α, n	13, 18
16.77		60	d, (n), p, t	6, 7, 8, 18
16.93		100	d, p, t	7, 8
17.5			d, p	8

Three resonances are reported below $E_\alpha = 2.5$ MeV (1951BE13, 1954HE22): see Table 11.2. Study of α-γ and γ-γ angular correlations, taken together with the relative γ-intensities, leads to the following assignments: 9.28 MeV level, $J = \frac{5}{2}^+$; 9.19 MeV, $J = \frac{5}{2}^-$; 8.93 MeV, $J = \frac{3}{2}$ or $\frac{5}{2}$; 6.81 MeV, $J = \frac{3}{2}^-$; 4.46 MeV, $J = \frac{5}{2}^-$ ((1952JO1B) and D.H. Wilkinson, private communication). The strength of the transition ($8.92 \to$ g.s.) implies E1 radiation (1958BI31). Angular distributions of

Table 11.2: Resonances in ^{7}Li(α, γ)^{11}B

E_r [a] (MeV ± keV)	Γ_{lab} [a] (keV)	^{11}B* (MeV)	Partial widths [b], $\omega\Gamma_\gamma$ (eV) to states of ^{11}B at 0	2.14	4.46	5.03	6.81 [d]
0.401	< 1	8.925	0.15 [c]	< 0.003	< 0.003	≈ 0.005	< 0.003
0.819 ± 1	≈ 4	9.191	< 0.05	< 0.02	2.0	< 0.1	≈ 0.35
0.958 ± 1 [d]	7	9.280	3.5 [e]	< 0.17	8.1	< 0.4	2.4

[a] (1951BE13). See also (1954HE22).

[b] (1952JO1B) and D.H. Wilkinson, private communication: compare ^{9}Be(^{3}He, p)^{11}B and Fig. 17. (1951BE13) report total gamma widths of 0.04, 0.6 and 4.7 eV for the three resonances.

[c] (1957WA07) finds $\omega\Gamma = 9 \times 10^{-3}$ eV for the 8.9-MeV state.

[d] (1957BR18) find 957.2 ± 2 keV. According to (1958FE70) the transition from ^{11}B*(9.28) is to the 6.76-MeV level and not that at 6.81 MeV.

[e] (1958ME77) report $\omega\Gamma = 0.8$ eV: see ^{11}B(γ, α)^{7}Li.

several gamma rays at each resonance are tabulated by (1957ME1D); no terms higher than $\cos^2\theta$ are indicated. The absence of the transition $(9.28 \rightarrow 2.14)$ speaks for $J = \frac{1}{2}^-$ for the latter (1957WI26). Angular distributions of γ-rays from the 9.28 MeV level have been measured by (1958FE70). The results are in agreement with assignments $J = \frac{5}{2}^+$ and $\frac{5}{2}^-$ for ^{11}B*(9.28, 4.46), respectively. The angular distribution of the transition $9.28 \rightarrow 6.76$ strongly favors $J = \frac{7}{2}^-$ for the latter. See also (1958ME77): ^{11}B(γ, α)^{7}Li, and ^{10}B(d, p)^{11}B.

2. ^{7}Li(α, n)^{10}B $\quad Q_m = -2.793 \quad E_b = 8.670$

For $E_\alpha < 5.8$ MeV, two resonances are observed; at $E_\alpha = 4.7$ MeV (broad), and 5.15 ± 0.08 MeV ($\Gamma = 0.22$ MeV) corresponding to ^{11}B*(11.68 ± 0.10, 11.95 ± 0.08) (1957BI84). A further resonance at $E_\alpha = 7.15$ MeV, ^{11}B*(13.22), is reported by (1958MA1J, 1959GI47). Calculation of σ(^{10}B(n, α)^{7}Li) from the observed yield of ^{7}Li(α, n)^{10}B gives good agreement for $E_n = 0$ to 0.8 MeV. The 5.15 MeV resonance corresponds to that reported in σ(n, α) at 0.52 MeV: $E_x = 11.95$ MeV. It is concluded that the resonance is formed by s or p-wave neutrons, $J = \frac{5}{2}^+$ or $\frac{3}{2}^-$, $\Gamma_n \approx 20$ keV and $\Gamma_\alpha \approx 300$ keV (1959GI47). See also (1950HO80).

3. ^{7}Li(α, p)^{10}Be $\quad Q_m = -2.566 \quad E_b = 8.670$

See (1937EC1A).

Table 11.3: Resonances in ^{7}Li(α, $\alpha'\gamma$)^{7}Li [a]

E_α (MeV)	^{11}B* (MeV)	$\Gamma_{\rm c.m.}$ (MeV)
1.90 ± 0.01 [b]	9.88	0.16 [d]
2.50 ± 0.03 [b]	10.26	0.22 [d]
3.06 ± 0.03 [c]	10.62	0.10
3.6 ± 0.1	11.0	0.67
4.39 ± 0.01	11.46	0.07
4.6 ± 0.1	11.6	0.14
5.0 ± 0.1	11.9	0.17

[a] (1957BI84): no correction for barrier penetration effects.
[b] (1954LI48) and (1957BI84). See also (1954HE22).
[c] (1954HE22) and (1957BI84).
[d] (1954LI48) find $\Gamma_{\rm c.m.} = 125 \pm 10$ and ≈ 155 keV for the first two levels.

4. ^{7}Li(α, α')^{7}Li* $E_{\rm b} = 8.670$

Observed resonances in the yield of 0.48 MeV γ-radiation are exhibited in Table 11.3 (1954HE22, 1954LI48, 1957BI84). Sum rule limits give $J \leq \frac{5}{2}$ for the 9.88 MeV level and $J \leq \frac{7}{2}$ for the 10.26 MeV level (1954LI48).

5. ^{9}Be(d, γ)^{11}B $Q_{\rm m} = 15.822$

This reaction has not been observed: at $E_{\rm d} = 0.9$ MeV, $\sigma < 1.8$ μb; at $E_{\rm d} = 1.5$ MeV, $\sigma < 20$ μb (1955AL16).

6. ^{9}Be(d, n)^{10}B $Q_{\rm m} = 4.358$ $E_{\rm b} = 15.822$

The cross section follows the Gamow function for $E_{\rm d} = 70$ to 110 keV (1955RA14). The fast neutron and γ-ray yield rise smoothly to $E_{\rm d} = 1.8$ MeV except for a broad resonance at $E_{\rm d} = 1$ MeV (1949EV1A, 1955BO1A, 1957SH65). This resonance is observed in the total neutron yield and in the yield of the fast neutrons to each of the first five states of ^{10}B. Angular distributions change markedly through the resonance except for that corresponding to ^{10}B*(3.58), which is dominated by stripping throughout (1957SH65). On the other hand, (1958NE38, 1959NE1A) have obtained integrated cross sections for three separate neutron groups from $E_{\rm d} = 0.5$ to 2.0 MeV and find no evidence of a resonance near 1 MeV. See also ^{10}B.

7. ^{9}Be(d, d)^{9}Be $E_{\rm b} = 15.822$

In the range $E_{\rm d} = 1.02$ to 1.44 MeV, two resonance anomalies are reported by (1956JU17) at $E_{\rm d} = 1.162$ and 1.348 MeV corresponding to ^{11}B*(16.77, 16.93) ($\Gamma \approx 70$ and 120 keV, respectively). See also ^{9}Be.

8. (a) ^{9}Be(d, p)^{10}Be	$Q_{\rm m} = 4.585$	$E_{\rm b} = 15.822$
(b) ^{9}Be(d, α)^{7}Li	$Q_{\rm m} = 7.152$	
(c) ^{9}Be(d, t)^{8}Be	$Q_{\rm m} = 4.592$	
(d) ^{9}Be(d, 2α)^{3}H	$Q_{\rm m} = 4.686$	
(e) ^{9}Be(d, tn)^{7}Be	$Q_{\rm m} = -14.307$	

Reaction (a) exhibits a simple Gamow dependence to 250 keV (1953SA1A). Angular distributions for $E_{\rm d} < 1.5$ MeV are reported by (1952DE24, 1955JU10, 1955JU1B, 1957HY1A, 1957SM78, 1958JU38). The distributions of long-range protons for $E_{\rm d} = 0.1$ to 0.2 MeV are analyzed in terms of two ^{11}B states with $J = \frac{1}{2}^-$ and $\frac{1}{2}^+$ or $J = \frac{3}{2}^-$ and $\frac{1}{2}^+$ (1957SM78). (1952CA19) reports broad maxima in the $90°$ yield of ground-state protons at $E_{\rm d} \approx 0.9$, (1.3) and 2.1 MeV. (1957MC35) observe broad resonances at 1.3 and possibly at 1.8 MeV in the yield of 3.37 MeV γ-rays, in the range $E_{\rm d} = 1.0$ to 5.6 MeV. No resonances are observed in the yield of 6 MeV γ-rays for $E_{\rm d} = 2.0$ to 5.6 MeV. The cross section for production of ^{10}Be (reaction (a)) rises to a peak value of ≈ 0.34 b at ≈ 4 MeV and then falls almost linearly to ≈ 0.08 b at ≈ 21.5 MeV (1955HE83). See also (1957CO54).

The cross section for reaction (b) shows a simple Gamow rise to $E_{\rm d} = 250$ keV (1953SA1A). Angular distributions have been measured for $E_{\rm d} = 0.3$ to 0.7 MeV by (1951RE01): see also ^{7}Li. The cross section for reaction (c) has been measured for $E_{\rm d} = 0.15$ to 0.62 MeV by (1952DE24), for $E_{\rm d} = 0.6$ to 1.5 MeV by (1955JU10, 1955JU1B), and at several energies in the range $E_{\rm d} = 3$ to 19 MeV by (1955HE83). The forward yield of tritons shows a peak at $E_{\rm d} = 1.38$ MeV (1955JU10, 1955JU1B). There seems also the possibility of a resonance at $E_{\rm d} = 0.87$ MeV (1958JU38). Triton angular distributions for $E_{\rm d} = 0.1$ to 0.2 MeV are analyzed in terms of two ^{11}B states with $J = \frac{5}{2}^-$ and $\frac{3}{2}^+$ (1957SM78). See also (1957HY1A) and ^{8}Be.

Relative yields for the various groups from reactions (a), (b) and (c) are given by (1953GE01). See also (1957JA37).

The direct three-body reaction (d) does not appear to occur (1953GE01). The cross section for reaction (e) has been measured from threshold to $E_{\rm d} \approx 21.5$ MeV ($\sigma \approx 80$ μb) (1955HE83).

9. ^{9}Be(t, n)^{11}B $\qquad Q_{\rm m} = 9.564$

Not reported.

10. ^{9}Be(^{3}He, p)^{11}B $\qquad Q_{\rm m} = 10.329$

Angular distributions of the protons to the ground state and several excited states of ^{11}B have been determined at various bombarding energies from 2 to 6 MeV: see ^{12}C. See also (1956HL01, 1956WO1A, 1957JO1B).

Gamma rays from the first nine excited states have been observed at $E(^{3}\text{He}) = 2.1$ MeV in coincidence with proton groups. The direct ground state gamma-transition is observed for all the levels. In addition the cascade through the 2.14 MeV state is observed from the 5.03, 6.81, 7.99 and 8.57 MeV states and, possibly, from the 6.76 and 8.92 MeV states, generally with an intensity comparable with that of the corresponding ground state transition. The gamma-ray width, Γ_γ, of the 8.92 MeV level is found to be comparable with its Γ_α. The decay scheme derived from this work is shown in Fig. 17 (1957FE1B, 1958FE70). The branching of the 5.03 and 7.30 MeV levels agrees with the shell-model assignments $\frac{3}{2}^-$ and $\frac{5}{2}^-$ (1957KU58, 1958FE70). At $E(^{3}\text{He}) = 5.7$ MeV, proton groups are reported to levels at 2.126 ± 0.010, 4.459 ± 0.010, 5.037 ± 0.010, 6.756 ± 0.010, 6.807 ± 0.010, 7.296 ± 0.010, 7.987 ± 0.010, 8.569 ± 0.010, 8.927 ± 0.010, 9.191 ± 0.010, 9.278 ± 0.010 and 9.87 ± 0.02 MeV. The 9.87 MeV state is broad, $\Gamma \approx 150$ keV (S. Hinds and R. Middleton, private communication). See also (1954MO1E, 1958BR1D, 1958SW63) and ^{7}Li(α, γ)^{11}B.

11. ^{9}Be(α, d)^{11}B $\qquad Q_{\rm m} = -8.022$

Deuteron groups have been observed at $E_\alpha = 21.6$ MeV to the ground and 2.14 MeV states of ^{11}B. A search in the region $E_{\rm x} = 0.4$ to 1.0 MeV showed no deuteron groups with intensity greater than 0.1 of the intensity of the two observed groups (1955RA41).

12. ^{10}B(n, γ)^{11}B $\qquad Q_{\rm m} = 11.464$

The thermal neutron capture cross section is 0.5 ± 0.2 b. Observed capture γ-rays are listed in Table 11.4. The relative weakness of the ground state transition suggests $J = \frac{7}{2}^+$ for the capturing level.

13. ^{10}B(n, n)^{10}B $\qquad E_{\rm b} = 11.464$

Table 11.4: Capture γ-rays in ^{10}B(n, γ)^{11}B (1957BA18)

E_γ [a] (MeV)	Intensity [b] (%)	Γ_γ (eV)	assignment [c]
11.43 ± 0.04	0.8	0.01	C $\rightarrow$ 0
8.91 ± 0.03	6		$8.93 \rightarrow 0$
6.98 ± 0.03	18	0.2	C $\rightarrow$ 4.46
6.74 ± 0.03	10		$6.76 \rightarrow 0$
4.73 ± 0.03	30	0.1	{ C $\rightarrow$ 6.76 9.19 $\rightarrow$ 4.46 ?
4.47 ± 0.02	80		$4.46 \rightarrow 0$

[a] Corrected for recoil.

[b] γ-rays per 100 radiative captures (1958BA52). $\sigma_{\mathrm{n},\gamma}$(total) $= 0.5 \pm 0.2$ b.

[c] C = capturing level: $Q_{\mathrm{m}} = 11.464$.

The epithermal scattering cross section (free) is 3.6 ± 0.2 b (1958HU18). Broad maxima appear in the total cross section at $E_{\mathrm{n}} = 1.9$ and 2.8 MeV (1951BO45) and at 4 MeV (1957HU1D); additional peaks near 0.2 and 0.4 MeV may be indicated (1951BO45). Differential cross sections have been measured at $E_{\mathrm{n}} = 0.55$, 1.00 and 1.50 MeV: derived phase shifts are $\delta_0 = -53.5°$ at $E_{\mathrm{n}} = 0.55$ MeV, $\delta_0 = -60.7°$, $\delta_1 = -4.0°$ at $E_{\mathrm{n}} = 1.00$ MeV, and $\delta_0 = -66.9°$, $\delta_1 = -10.3°$, $\delta_2 = -2.9°$ at $E_{\mathrm{n}} = 1.50$ MeV (1955WI25). The total cross section decreases from ≈ 1.9 b at 4.4 MeV to 1.6 b at 5.6 MeV and then remains approximately constant at ≈ 1.5 b from 6 to 9.7 MeV (1954NE1A, 1956BE98). At $E_{\mathrm{n}} = 14$ MeV it is 1.47 ± 0.03 b (1952CO41) and it remains nearly constant to 18 MeV (1954CO16: $\sigma = 1.45 \pm 0.02$ b). See (1957HU1D).

14. ^{10}B(n, n$'$)^{10}B* $\qquad E_{\mathrm{b}} = 11.456$

See (1952PH01) and (1956DA23).

15. ^{10}B(n, p)^{10}Be $\qquad Q_{\mathrm{m}} = 0.227 \qquad E_{\mathrm{b}} = 11.464$

The thermal cross section is < 0.2 b (1958HU18); the cross section for fast pile neutrons is 3 mb (1948EG1A).

16. ^{10}B(n, d)^{9}Be $\qquad Q_{\mathrm{m}} = -4.358 \qquad E_{\mathrm{b}} = 11.464$

At $E_n = 14$ MeV, the integrated cross sections ($0°$ to $90°$, c.m.) for the transitions to the ground and the 2.4 MeV states of ^{9}Be are 21 ± 3 mb and 16 ± 2 mb, respectively (1954RI15). See also (1956FR18).

17. ^{10}B(n, t)^{8}Be $\qquad Q_m = 0.234 \qquad E_b = 11.464$

For $E_n = 5.20$ MeV, production of tritons appears to be mainly via ^{10}B(n, α)^{7}Li*(4.7) and direct three-body breakup (1956FR18). Cross sections at $E_n = 4$, 5.6, 9.6 and 14.1 MeV are 95 ± 10, 230 ± 25, 125 ± 15 and 85 ± 6 mb, respectively (1958WY67).

18. ^{10}B(n, α)^{7}Li $\qquad Q_m = 2.793 \qquad E_b = 11.464$

Recent values for the thermal neutron absorption cross section in natural boron are 749 ± 4 b (1953CA45), 755 ± 3 b (1953HA1C), 744 ± 20 b (1954SC87), 764 ± 3 b (1954VO1A) and 760 ± 3 b (1956CO1E). (1958HU18) give 755 ± 2 b for the thermal absorption cross section in "U. S. standard" boron and 3813 b for the thermal isotropic cross section; see also (1957HU1D). The cross section follows the $1/v$ law from 7×10^{-4} eV to 100 keV (1955HU1B, 1957BI84). (1957BI1F) report $\sigma_{\text{total}} = 642/\sqrt{E_n} + 2.45$ b for $E_n = 3$ to 70 keV. The data from $E_n = 0$ to 250 keV can be satisfactorily interpreted in terms of the ^{11}B levels at 11.46 and 11.68 MeV ($E_n = 0$ and 140 keV) observed in ^{7}Li(α, α')^{7}Li* (1957BI84). (1957BE71) find, on the other hand, that deviations from the $1/v$ law for $E_n < 1$ MeV indicate a single broad level at $E_n \approx 250$ keV with $J = \frac{5}{2}^+$ or $\frac{7}{2}^+$, $\Gamma_\alpha \approx 400$ keV, $\Gamma_n \approx 200$ keV. A pronounced resonance is observed at $E_n = 1.86$ MeV: $\Gamma_{\text{c.m.}} = 0.45$ MeV ((1957BI84) and (1951PE18); see also (1950ST1A) and (1952BI1A)). There are indications of less pronounced resonances at 0.53, 2.8 and 4.1 MeV (with $\Gamma_{\text{c.m.}} = 0.10$, 0.3 and 0.5 MeV) in the energy range to $E_n = 4.8$ MeV (1957BI84). The ratio of ground state to excited state transition varies strongly with energy: see (1952AJ38, 1954DE38, 1958BU02).

Cross sections for production of $2\alpha + $t either through the 4.6 MeV level of ^{7}Li or via three-body breakup have been determined for $E_n = 4$ to 19.5 MeV. A strong maximum near $E_n = 5.6$ MeV may indicate a resonance near ^{11}B*(16.6) (1956FR18, 1958WY66). See also (1955AJ61).

19. ^{10}B(d, p)^{11}B $\qquad Q_m = 9.237$

Proton groups reported by (1951VA1A) and (1953EL12) are listed in Table 11.5. No other levels are observed below $E_x = 11.46$ MeV: the known levels observed in ^{7}Li(α, α')^{7}Li are presumably too wide to be seen here. See also (1954KH1A, 1955KH35).

The angular distribution of protons leading to the ground state ($J = \frac{3}{2}^-$) shows a well-developed $l_n = 1$ stripping pattern at all energies $\gtrsim 2.0$ MeV (1954EV1A, 1958EV01: 7.7 MeV), (1953HO48: 8 MeV), (1956ZE1A: 10 MeV), (1957LE1F: 15.1 MeV), (1956MA69: 1.0 to 3.0

Table 11.5: Proton groups from ^{10}B(d, p)^{11}B

^{11}B* [a] (MeV $\pm$ keV)	Γ (keV)	dσ/dΩ [b] (mb/sr)	l_n	J^π	Λ_n [c]
0 ± 11		2	1 [d]	$\frac{3}{2}^-$	5.0
2.138 ± 9	< 15	0.4	1 [e]	$\frac{1}{2}^-$ [e]	0.9
4.459 ± 8	< 15	1.2	1 [d]	$\frac{3}{2}^-, \frac{5}{2}^-$ [f]	1.6
5.034 ± 8	< 15	1.0	1 [d]		0.5
6.758 ± 7	< 15	2	1 [g]	$\frac{5}{2}^-, \frac{7}{2}^-$ [f]	5.7
6.808 ± 7	< 15	0.2			weak [g]
7.298 ± 6	< 15	1.2			weak [g]
7.987 ± 9	< 10				weak [g]
8.568 ± 5	< 10	0.3	(2) [g]	$(\frac{1}{2}^+, \frac{3}{2}^+)$	weak [g]
8.927 ± 5	< 4	5	2, 0 [g]	$\frac{5}{2}^+, (\frac{7}{2}^+)$	
9.191 ± 5	< 10	8	0 [g]	$(\frac{5}{2}^+), \frac{7}{2}^+$	
9.276 ± 5	< 10	4	0 [g]	$\frac{5}{2}^+, (\frac{7}{2}^+)$	
10.32 ± 20	54 ± 17 [h]				

[a] (1951VA1A, 1953EL12): stated errors refer to Q-values.

[b] Approximate differential cross sections in mb/sr at $\theta = 90°$, $E_d = 1.51$ MeV (1951VA1A).

[c] Relative neutron capture probability (1954EV1A: $E_d = 7.7$ MeV).

[d] (1954EV1A: $E_d = 7.7$ MeV).

[e] See text.

[f] From p-γ correlation (1957CO54).

[g] (1958BI31).

[h] The width of this state suggests that it is not to be identified with that observed at 10.26 MeV in ^{7}Li(α, α')^{7}Li.

MeV); see, however, (1957CO54). Even below $E_d = 1$ MeV, stripping appears to play an important role in formation of this level (1954BU06, 1954PA28, 1957HA1H). The relatively large neutron capture probability suggests a single-particle character (1953HO48, 1954EV1A). See also (1957CO54, 1957HA1H). The polarization has been studied by (1958HE47, 1958HI74).

For the 2.1 MeV state, the evidence is not so clear: the pattern though generally of an $l_n = 1$ shape (see, however, (1954PA28, 1957LE1F)) shows strong variations with energy (1954EV1A, 1956MA69, 1956ZE1A, 1957CO54, 1957LE1F, 1958EV01). An $l_n = 1$ formation implies $\frac{3}{2}^- \leq J \leq \frac{9}{2}^-$, in contradiction to the shell-model expectation that the state should have $J = \frac{1}{2}^-$; however to form such a state requires $l_n = 3$, involving rearrangement of several nucleons and hence a low probability (1956MA69, 1958EV01). The more probable mode of formation would appear to involve a nucleon exchange (1958EV01) or a spin reversal of the outgoing proton (1957WI26). The observation that the polarization of protons for this state is opposite to those corresponding to the ground state is consistent with either point of view, and permits $\frac{1}{2}^- \leq J \leq \frac{11}{2}^-$ (1958HE47). Support for the assignment $J = \frac{1}{2}$ is found in the observed isotropy of the p-γ correlation (see below): see also ^{11}B(p, p$'$)^{11}B* and (1957WI26, 1958BO1C).

The 4.46, 5.03 and 6.76 MeV states are also formed by $l_n = 1$. The large neutron capture probability for the 6.76 MeV state indicates that it has a single-particle character (1954EV1A, 1958BI31). See also (1957CO54, 1957SJ1C). The next four states appear only weakly and probably arise from configuration mixing (1958BI31).

For the 8.92 MeV state, $l_n = 2$ with a small admixture of $l_n = 0$ is indicated; $J = \frac{5}{2}^+, \frac{7}{2}^+$. The large γ-width suggests $J = \frac{5}{2}^+$. The 9.19 and 9.28 MeV state are formed with $l_n = 0$, $J = \frac{5}{2}^+$ or $\frac{7}{2}^+$; the intensity ratio is consistent with $J(9.19) = \frac{7}{2}^+$, $J(9.28) = \frac{5}{2}^+$. Again, the high relative intensities suggest that these three are single-particle states, formed by direct capture into the 1d, 2s, shell (1958BI31); see also ^{7}Li(α, γ)^{11}B.

Gamma rays reported by (1955BE81) and (1955SA1B) are listed in Table 11.6. The p-γ angular correlation through the 2.14 MeV state is isotropic to $\approx 4\%$, consistent with $J = \frac{1}{2}$: see (1953TH1B, 1955GO1D, 1956GO1L, 1956GO1M, 1956GO39, 1957GA1B). The angular correlation through 4.46 MeV state is consistent with $J = \frac{3}{2}^-$ or $\frac{5}{2}^-$; that through the 6.76 MeV state rules out $J = \frac{3}{2}$ and suggest $J = \frac{9}{2}$ is unlikely for that state (1957CO54). See also (1956VA17).

20. ^{10}B(t, d)^{11}B $\qquad Q_m = 5.205$

Not reported.

21. ^{10}B(α, ^{3}He)^{11}B $\qquad Q_m = -9.114$

Not reported.

Table 11.6: γ-rays from ^{10}B(d, p)^{11}B

E_γ [a] (MeV)	σ(total) [b] (mb)	E_γ [c] (MeV)	I [d] (relative)	Assignment ^{11}B*
4.49 ± 0.05	5.0	4.46 ± 0.04	14	$4.46 \rightarrow 0$
5.03 ± 0.03	3.0	5.03 ± 0.09	6	$5.03 \rightarrow 0$
6.75 ± 0.03	5.4	6.78 ± 0.07	6	$6.76 \rightarrow 0$
7.30 ± 0.03	6.0	7.29 ± 0.04	5	$7.30 \rightarrow 0$
		8.27 ± 0.09	4	
8.57 ± 0.04	1.8			$8.57 \rightarrow 0$
8.93 ± 0.04	8.1	8.87 ± 0.02	11	$8.93 \rightarrow 0$
4.73 ± 0.03	6.3	4.75 ± 0.03	6	$9.19 \rightarrow 4.46$

[a] (1955BE81): Doppler corrected.
[b] Average value $E_{\rm d} = 0$ to 2.0 MeV (1955BE81).
[c] (1955SA1B): no Doppler correction.
[d] Relative intensity (1955SA1B): ($E_{\rm d} = 1.4$ MeV).

22. ^{11}Be(β^-)^{11}B $\qquad Q_{\rm m} = 11.48$

The decay properties of ^{11}Be are exhibited in Table 11.7. The transition energy to the ground state is $E_\beta(\max) = 11.48 \pm 0.15$ MeV; $\tau_{1/2} = 13.57 \pm 0.15$ sec, $\log ft = 6.77$ (1958AL96, 1959WI49), $\tau_{1/2} = 14.1 \pm 0.3$ sec (1958NU40). The transition probabilities to ^{11}B$_{\rm g.s.}$, $J = \frac{3}{2}^-$, and ^{11}B*(2.1), $J = \frac{1}{2}^-$, suggest $J = \frac{1}{2}^-$ for ^{11}Be, but it is not clear why the transition should be so much inhibited as compared with other allowed transitions (1959WI49).

23. ^{11}B(γ, γ)^{11}B

The mean life of the 4.46 MeV level, determined by resonance absorption and scattering is $\tau_{\rm m} = 1.17 \pm 0.17 \times 10^{-15}$ sec, assuming $J = \frac{5}{2}$. On the same assumption, the intensity ratio of quadrupole to dipole transitions is ≤ 0.2 (1958RA14). A mean life of $\approx 1.5 \times 10^{-15}$ sec is calculated by (1957KU58).

A similar experiment yields $\tau_{\rm m} = (4.6 \pm 0.6) \times 10^{-15}$ sec for the 2.1 MeV state, assuming $J = \frac{1}{2}$. The result does not distinguish $J = \frac{1}{2}^-$ from $J = \frac{1}{2}^+$, but the shortness of the lifetime excludes $J > \frac{1}{2}$ (1958ME79): see (1957WI26: ^{11}B(p, p$'$)^{11}B*). A calculation in intermediate coupling, assuming an M1 transition yields $\tau_{\rm m} = (2.5 \text{ to } 5) \times 10^{-15}$ sec (1957KU58). See also (1958MC1D).

Table 11.7: Beta decay of ^{11}Be (1958AL96, 1959WI49)

^{11}B* (MeV)	J^{π}	% betas	log ft	E_{γ} (MeV $\pm$ keV)	% gammas [a]
0	$\frac{3}{2}^-$	61	6.77		
2.138	$\frac{1}{2}^-$	29	6.63	2.121 ± 10	32
4.459	$(\frac{5}{2}^-)$	≤ 0.2	≥ 8.2		
5.034		≤ 0.2	≥ 8.2		
6.758 } 6.808 }		6.5	5.93	6.76 ± 30	4.4
				4.64 ± 20	2.1
7.298		≤ 1.5	≥ 6.4		
7.987		4.1	5.53	7.97 ± 30	1.7
				5.86 ± 40	2.4
8.568		≤ 0.3	≥ 6.3		
8.927		≤ 0.15	≥ 6.3		

[a] Relative to all β-transitions.

24. ^{11}B(γ, n)^{10}B $\qquad Q_{\rm m} = -11.464$

See (1951SH63) and (1955TI1A).

25. ^{11}B(γ, t)^{4}He + ^{4}He $\qquad Q_{\rm m} = -11.136$

See (1955AJ61).

26. ^{11}B(γ, α)^{7}Li $\qquad Q_{\rm m} = -8.670$

Resonance absorption of 9.19 MeV radiation yields $\Gamma < 100$ eV, $(2J+1)\Gamma_{\gamma} \approx 0.8$ eV for ^{11}B*(9.19) (1958ME77).

27. ^{11}B(n, n′)^{11}B*

At $E_{\rm n} = 4.5$ MeV, a 2.2 MeV γ-ray is reported (1955GR18, 1956DA01). See also (1954SC85).

28. ^{11}B(p, p′)^{11}B*

At $E_p = 3.58$ MeV, a 2.134 ± 0.005 MeV γ-ray is observed (1957MC35); see also (1953HU29). The mean lifetime of the 2.14 MeV state has been determined by a Doppler shift measurement to be $< 4 \times 10^{-14}$ sec (1957WI26): see ^{11}B(γ, γ)^{11}B. It is pointed out that the observed isotropy in ^{10}B(d, pγ)^{11}B requires a nearly pure E2 transition if $J = \frac{3}{2}^-$ and the present lifetime value excludes E2. On the other hand, the lifetime is quite consistent with M1 (1957WI26). The 2.14 MeV γ-ray exhibits $< 2.0 \times 10^{-3}$ part of circular polarization; this observation places an upper limit of $F^2 \lesssim 1 \times 10^{-7}$ for the intensity of the parity non-conserving part of the wave function (1958WI41).

At $E_p = 185$ MeV, inelastic groups with $Q = -4.7$, -6.6 and -8.5 MeV are observed; the latter shows strong forward peaking and is attributed to a spin flip of a target nucleon, indicating $J = \frac{1}{2}^-$, $\frac{3}{2}^-$ or $\frac{5}{2}^-$ (1958TY46). See also (1955AJ61, 1956ST1D) and ^{12}C.

29. ^{11}B(d, d′)^{11}B*

Ground state deuterons have been observed at $E_d = 4.2$ MeV (1955KH35).

30. ^{11}C(β^+)^{11}B $\qquad Q_m = 1.981$

See ^{11}C.

31. ^{12}C(γ, p)^{11}B $\qquad Q_m = -15.958$

See ^{12}C.

32. ^{12}C(p, 2p)^{11}B $\qquad Q_m = -15.958$

At $E_p = 185$ MeV, the summed proton spectrum shows peaks attributed to removal of p- and s-protons (1958MA1B, 1958TY47).

33. (a) ^{12}C(n, d)^{11}B $\qquad Q_m = -13.731$
(b) ^{12}C(d, ^{3}He)^{11}B $\qquad Q_m = -10.465$

Not reported.

34. ^{12}C(t, α)^{11}B $Q_{\rm m} = 3.855$

This reaction has been observed at $E_{\rm t} = 1.4$ MeV (1955CU17). See also (1958JA06).

35. (a) ^{13}C(n, t)^{11}B $Q_{\rm m} = -12.419$
(b) ^{13}C(p, ^{3}He)^{11}B $Q_{\rm m} = -13.184$

Not reported.

36. ^{13}C(d, α)^{11}B $Q_{\rm m} = 5.167$

Alpha-particle groups have been observed corresponding to ^{11}B*(2.107 ± 0.017) (1951LI29) and ^{11}B*(4.45, 6.83) (1953SP1A). A 4.46 MeV γ-ray observed by (1955BE62) in (^{13}C + d) is definitely assigned to the present reaction by (1958RA13). See also (1955AJ61).

37. ^{14}C(p, α)^{11}B $Q_{\rm m} = -0.780$

Not reported.

38. ^{14}N(n, α)^{11}B $Q_{\rm m} = -0.152$

Q_0-values of -0.12 ± 0.06 and -0.18 ± 0.05 MeV are reported by (1958DO63). See also (1952LI24).

^{11}C

(Fig. 18)

GENERAL:

Theory: See (1956KU1A, 1957KU58, 1958FR1C).

1. ^{11}C(β^+)^{11}B $\qquad Q_m = 1.981$

The spectrum is simple; $E_{\beta^+}(\max) = 968 \pm 8$ keV (1954WO23). The mean of half-lives reported in (1955AJ61) is 20.36 ± 0.05 min. Recent values of the half-lives are 20.26 ± 0.1 min (1955BA63), 20.8 ± 0.2 min (1957PR53) and 20.11 ± 0.13 min (1958AR15); $\log ft = 3.62$ (1954WO23). The ratio of K-capture to positron emission is 0.19 ± 0.03 % (1957SC29). See also (1957BR18, 1957KA1C).

2. (a) ^{6}Li(^{6}Li, n)^{11}C $\qquad Q_m = 9.462$
   (b) ^{7}Li(^{6}Li, 2n)^{11}C $\qquad Q_m = 2.209$

See (1957NO17).

3. ^{9}Be(^{3}He, n)^{11}C $\qquad Q_m = 7.565$

See (1952PO27, 1953KU08, 1954MO1E).

4. ^{10}B(p, γ)^{11}C $\qquad Q_m = 8.700$

For $E_p = 0.7$ to 3 MeV, the main capture radiation is to the ground state. Weaker radiations, $\approx 5\%$, with $E_\gamma \approx 4.2$ and 5.8 MeV suggest a cascade through the 4.23 MeV level (1956CH20, 1957HU79). Two broad resonances are reported at 1.14 and ≈ 4.4 MeV: see Table 11.9 (1954DA20, 1955BA22, 1955HA01, 1956CH20, 1957HU79). The angular distribution at the first resonance is $1 + 0.5\cos^2\theta$. Using $\sigma_\alpha = 16$ mb/sr, (1956CH20) find $\omega\Gamma_p \approx 40$ keV, $\Gamma_\alpha \approx 500$ keV, $\omega\Gamma_\gamma = 10$ eV, consistent with M1 radiation. The angular distribution and the gamma-ray width appear to rule out all $J \leq \frac{7}{2}$ except $J = \frac{5}{2}^-$ (1956CH20); see, however, ^{10}B(p, α)^{7}Be (1956CR07). The cross section increases rapidly in the range $E_p = 2.2$ to 2.7 MeV, but there is no indication of a previously reported 2.4 MeV resonance (see (1954DA20, 1955BA22, 1957HU79)). See also (1955AJ61, 1955WI1E) and (1957JA37).

Table 11.8: Energy levels of ^{11}C

E_x (MeV $\pm$ keV)	J^π	τ (min) or Γ (keV)	Decay	Reactions
0	$(\frac{3}{2}^-)$	$\tau_{1/2} = 20.45 \pm 0.06$	β^+	1, 2, 3, 4, 11, 14, 15, 17, 18, 19, 20, 21, 23, 24
1.99 ± 20	$(\frac{3}{2}^- \rightarrow \frac{9}{2}^-)$		γ	11, 12, 15, 21
4.26 ± 30	$(\frac{3}{2}^- \rightarrow \frac{9}{2}^-)$		γ	4, 11
4.75 ± 30	$(\frac{3}{2}^- \rightarrow \frac{9}{2}^-)$		γ	11
6.50 ± 20			γ	11
6.77 ± 40			(γ)	11
7.40 ± 40			γ	11
8.108 ± 8				11
8.431 ± 8				11
8.661 ± 8				11
8.98 ± 30				11
(9.13 ± 20)				11
(9.28 ± 30)				11
9.74 ± 10	$(\frac{3}{2}^-)$	450	γ, p, α	4, 6, 10, 11
10.09 ± 10	$(\frac{7}{2}^+)$	200	p, α	6, 10, 11
$(10.69 \pm 20\ )$				11
10.89 ± 20				11
(11.26 ± 20)				11
(11.52 ± 20)				11
12.3		≈ 500	γ, p, α	4, 10
13.8 ± 200			p, α	10
(15.7 ± 200)			(p, α)	10

5. ^{10}B(p, n)^{10}C $\qquad Q_m = -4.56 \qquad E_b = 8.700$

The cross section is ≤ 1.4 mb at $E_p = 5.35$ MeV, ≤ 2 mb at $E_p = 5.51$ MeV (1959GI47). See (1958MA1F, 1958TA03) and ^{10}C.

Table 11.9: Resonances in ^{10}B(p, γ)^{11}C, ^{10}B(p, p)^{10}B, ^{10}B(p, α_0)^{7}Be and ^{10}B(p, $\alpha_1\gamma$)^{7}Be

Reaction	$E_{\rm res}$ (MeV)	$\Gamma_{\rm lab}$ (keV)	σ	$E_{\rm x}$ (MeV)	J^{π}	Refs.
^{10}B(p, γ)^{11}C	1.146 ± 0.005	414 ± 20	5.5 ± 2.8 μb	9.74		(1957HU79)
^{10}B(p, γ)^{11}C	1.135 ± 0.015	540 ± 40	3.5 ± 1.0 μb		$(\frac{5}{2}^-)$	(1956CH20)
^{10}B(p, γ)^{11}C	1.21		7.5 ± 3.8 μb			(1954DA20)
^{10}B(p, γ)^{11}C	1.18 ± 0.04	570 ± 20				(1955HA01)
^{10}B(p, α_0)^{7}Be	1.15		205 ± 40 mb			(1951BR10)
^{10}B(p, p)^{10}B	(1.15)					(1951BR10)
^{10}B(p, α_0)^{7}Be	1.1	> 330			$(\frac{5}{2}^+)$	(1956AL23)
^{10}B(p, α_0)^{7}Be	1.17	300	210 ± 40 mb		$\frac{3}{2}^-$	(1956CR07)
^{10}B(p, $\alpha_1\gamma$)^{7}Be	1.533 ± 0.005	220	80 ± 40 mb	10.09		(1957HU79)
^{10}B(p, $\alpha_1\gamma$)^{7}Be	1.5	250	100 ± 20 mb		$\frac{7}{2}^+$	(1956CR07)
^{10}B(p, α_0)^{7}Be	1.5	250	230 ± 40 mb		$\frac{7}{2}^+$	(1956CR07)
^{10}B(p, $\alpha_1\gamma$)^{7}Be	1.52	250	140 ± 30 mb			(1951BR10,
			210 ± 70 mb			1954DA20)
^{10}B(p, α_0)^{7}Be	1.5		140 ± 30 mb			(1951BR10)
^{10}B(p, p)^{10}B	(1.5)					(1951BR10)
^{10}B(p, $\alpha_1\gamma$)^{7}Be	1.53		210 ± 50 mb			(1956CH20)
^{10}B(p, α_0)^{7}Be	1.5	≈ 230			$(\frac{5}{2}^-)$	(1956AL23)
^{10}B(p, γ)^{11}C	≈ 4	≈ 500		12.3		(1955BA22)
^{10}B(p, α)^{7}Be	≈ 4					(1957KA1C)
^{10}B(p, α)^{7}Be	5.6			13.8		(1957KA1C)
^{10}B(p, α)^{7}Be	(7.8)			(15.7)		(1957KA1C)

6. ^{10}B(p, p)^{10}B $\qquad E_{\rm b} = 8.700$

The elastic scattering cross section at $\theta = 138°$ rises from nearly the Rutherford value for $E_{\rm p} < 0.9$ MeV to 4 times Rutherford at $E_{\rm p} = 1.6$ MeV. Anomalies are observed at $E_{\rm p} = 1.15$ and 1.5 MeV (1951BR10). See Table 11.9.

7. ^{10}B(p, p$'$)^{10}B* $\qquad E_{\rm b} = 8.700$

The yield of 0.71 MeV radiation, from the first excited state of ^{10}B, rises monotonically from $E_{\rm p} = 1.5$ to 2.7 MeV (1952DA05, 1954DA20, 1957HU79). At $E_{\rm p} = 2.7$ MeV the cross section is 11 ± 5 mb (1957HU79). Above $E_{\rm p} = 2.4$ MeV, weak ($\approx$ 1%) γ-rays of 1.00 ± 0.04 MeV ($1.74 \rightarrow 0.71$ transition in ^{10}B) and 2.12 ± 0.06 MeV ($2.14 \rightarrow$ g.s. transition) are observed (1957HU79). See also (1952CR30), (1956CH20) and (1957JA37).

8. ^{10}B(p, d)^{9}B $\qquad Q_{\rm m} = -6.212 \qquad E_{\rm b} = 8.700$

See ^{9}B.

9. ^{10}B(p, ^{3}He)^{8}Be $\qquad Q_{\rm m} = -0.532 \qquad E_{\rm b} = 8.700$

See ^{8}Be.

10. ^{10}B(p, α)^{7}Be $\qquad Q_{\rm m} = 1.147 \qquad E_{\rm b} = 8.700$

The excitation function is a smooth exponential from $E_{\rm p} = 60$ to 200 keV (1955BA1M). Excitation functions have been studied up to 3 MeV (see (1957JA37)). Using the stacked foil method, (1957KA1C) report structure in the excitation function corresponding to ^{11}C levels at 12.3, 13.8 ± 0.2 and 15.7 ± 0.2 MeV. The ground state α-particles (α_0) exhibit broad resonances at $E_{\rm p} = 1.17$ and 1.53 MeV superposed on a continuous isotropic background (1951BR10, 1956AL23, 1956CR07). Alpha particles to the 0.43 MeV ^{7}Be state (α_1) and 0.43 MeV γ-rays show only the resonance at $E_{\rm p} = 1.53$ MeV (1951BR10, 1954DA20, 1956CH20, 1956CR07, 1957HU79). A summary of the evidence on the (^{10}B + p) resonances is given in Tables 11.9 and 11.10.

The reaction cross section for α_0 at the $E_{\rm p} = 1.17$ MeV resonance requires $J \geq \frac{3}{2}$. The angular distribution is isotropic, except for small terms attributed to interference, restricting the choice to $\frac{5}{2}^+$, $\frac{7}{2}^+$, $\frac{3}{2}^-$. The absence of α_1 suggests $\frac{3}{2}^-$, $\frac{5}{2}^+$ as most likely; $\frac{3}{2}^-$ would agree with the mirror level in ^{11}B (1956CR07: see Table 11.10).

At the $E_{\rm p} = 1.5$ MeV resonance, the angular distribution of α_0 has the form $1 - 0.53 \cos^2\theta$. Between resonances, coefficient of odd order Legendre polynomials show a sharp peak, indicating that the two levels have opposite parity. The α_1 distribution at $E_{\rm p} = 1.5$ MeV also shows interference effects. From the reaction cross section at $E_{\rm p} = 1.5$ MeV, $J \geq \frac{5}{2}$. The most satisfactory account of the α_0 and α_1 angular distributions is given with the assumption of $J = \frac{7}{2}^+$, formed by s- and d-waves. The assumption $J = \frac{5}{2}^+$, $\frac{5}{2}^-$ for the 1.17 and 1.5 MeV resonances is excluded (1956CR07: see Table 11.10).

At $E_{\rm p} = 1.2$ MeV the (non-resonant) 430 keV γ-rays are isotropic ± 2% (1956CH20). See also (1955WI1E).

Table 11.10: Resonance parameters for ^{10}B(p, α)^{7}Be (1956CR07)

E_{res} (MeV)	J^{π}	Γ (keV)	Γ_p (keV)	$\Gamma_{\alpha 0}$ (keV)	$\Gamma_{\alpha 1}$ (keV)	θ^2_p (%)	$\theta^2_{\alpha 0}$ (%)	$\theta^2_{\alpha 1}$ (%)
1.17	$\frac{3}{2}^-$	300	75 [a,c]	225	non res	0.8	8	
			225 [a]	75		2.5	2.7	
1.53 [b]	$\frac{7}{2}^+$	250	1600 [a]	56	34	13	15.7	20.3
			90 [a]	100	60	9	32	42

[a] Alternative solutions.
[b] (1957HU79).
[c] Compare ^{10}B(p, γ)^{11}C.

11. ^{10}B(d, n)^{11}C $\qquad$ $Q_m = 6.473$

Level information derived from studies of the neutron groups is displayed in Table 11.11 (1952JO10, 1954PA29, 1956CE1B, 1956CE73, 1956GR54, 1956MA83, 1957GR50, 1958MC1E, 1959NE1A). See also (1953GI05, 1954BU06, 1956BO1F). A search for possible doublet structure at $E_x = 6.50$ MeV revealed no other level in this neighborhood. A group with relative intensity $\frac{1}{10}$ would have been seen if the separation were as much as 40 keV (1959NE1A: $E_d = 1.5$ MeV, $\theta = 60°$).

Neutron threshold measurements indicate levels in ^{11}C at 8.108, 8.431, and 8.661 MeV (1955MA76: ± 0.008 MeV). Gamma-ray measurements indicate lines with $E_\gamma = 4.75 \pm 0.03$ MeV (1955SA1B), 5.35 ± 0.05 MeV (1955SA1B: from ^{11}C*($7.4 \rightarrow 2.0$)), and 6.50 ± 0.03 (1955BE81: Doppler corrected), 6.52 ± 0.05 MeV (1955SA1B). Gamma rays of energy 6.5, 4.3, and ≈ 2.0 MeV are observed in coincidence with neutrons leading to ^{11}C*(6.50). In coincidence with neutrons to ^{11}C*(4.26 and 4.75, unresolved) are $E_\gamma = 4.28$, ≈ 2.3, ≈ 2.0 MeV (1958MC1E). See also (1957BI78).

12. ^{10}B(^{3}He, d)^{11}C $\qquad$ $Q_m = 3.206$

At $E(^{3}\text{He}) = 2$ MeV, deuterons have been observed in coincidence with a 2.0 ± 0.1 MeV γ-ray (1957GO1B).

13. ^{10}B(α, t)^{11}C $\qquad$ $Q_m = -11.113$

Not reported.

Table 11.11: Levels of ^{11}C from ^{10}B(d, n)^{11}C

E_x (MeV ± keV)	l_p	J^π	References
0	1	$\frac{3}{2}^- \rightarrow \frac{9}{2}^-$ [a]	(1954PA29, 1956CE1B, 1956CE73, 1956MA83)
1.94 ± 50	1	$\frac{3}{2}^- \rightarrow \frac{9}{2}^-$ [a,b]	(1952JO10, 1954PA29, 1956CE1B, 1956CE73, 1956GR54, 1956MA83)
4.26 ± 30	1	$\frac{3}{2}^- \rightarrow \frac{9}{2}^-$	(1952JO10, 1954PA29, 1956CE1B, 1956CE73, 1956GR54, 1958MC1E, 1959NE1A)
4.75 ± 30	1	$\frac{3}{2}^- \rightarrow \frac{9}{2}^-$	(1952JO10, 1955SA1B, 1956CE1B, 1956CE73, 1956GR54, 1959NE1A)
6.50 ± 20	[c]		(1952JO10, 1955BE81, 1955SA1B, 1956CE1B, 1956CE73, 1958MC1E, 1959NE1A)
6.77 ± 40	[c]		(1952JO10, 1956CE1B, 1956CE73)
7.40 ± 40			(1952JO10, 1956CE1B, 1956CE73)
8.108 ± 8			(1952JO10, 1955MA76, 1956CE1B, 1956CE73)
8.431 ± 10	[d]		(1952JO10, 1955MA76, 1956CE1B, 1956CE73)
8.661 ± 10	[d]		(1952JO10, 1955MA76, 1956CE1B, 1956CE73)
8.97 ± 20			(1952JO10, 1956CE1B, 1956CE73, 1957GR50)
(9.13 ± 20)			(1952JO10)
(9.28 ± 30)			(1956CE1B, 1956CE73)
9.69 ± 30			(1956CE1B, 1956CE73)
10.09 ± 20			(1956CE1B, 1956CE73, 1957GR50)
(10.69 ± 20)			(1956CE1B, 1956CE73, 1957GR50)
10.89 ± 20 [e]			(1956CE1B, 1956CE73, 1957GR50)

[a] $(2J+1)\gamma^2 = 2.1 \times 10^{-19}$ and 0.8×10^{-19} erg · cm for ^{11}B*(0, 2.1), respectively (1956MA83): $\theta_n^2 = 0.02$ and 0.016.
[b] J probably $\frac{1}{2}^-$: see ^{10}B(d, p)^{11}B.
[c] $l_p = 1$ for unresolved groups at $E_x \approx 6.6$ MeV (1956MA83).
[d] $l_p = 1$ for unresolved groups at $E_x \approx 8.5$ MeV (1956MA83). (1957GR50) reports $l_n = 0$.
[e] Neutron groups are also reported to $E_x = (11.26 \pm 0.02)$ and (11.52 ± 0.02) MeV (1956CE1B, 1956CE73).

14. ^{10}B(^{6}Li, ^{5}He)^{11}C $\qquad Q_m = 4.045$

See (1957NO17).

15. ^{11}B(p, n)^{11}C $\qquad Q_m = -2.764$

$Q_0 = -2.83^{+0.08}_{-0.05}$ (1956AJ22).

At $E_p = 7.03$ MeV, groups are observed corresponding to the ground state and to a state at 2.01 ± 0.06 MeV. The intensity of the ground-state group is ≈ 2.5 times that of the ^{11}C*(2.0) group at the four angles studied; $I(0°)/I(20°) \approx 2.5$ for both groups. An appreciable number of low-energy (< 1.5 MeV) neutrons of undetermined origin is reported (1956AJ22). See also (1955MA84, 1958GO77).

16. ^{11}B(^{3}He, t)^{11}C $\qquad Q_{\rm m} = -1.999$

Not reported.

17. ^{12}C(n, 2n)^{11}C $\qquad Q_{\rm m} = -18.722$

See ^{13}C.

18. ^{12}C(γ, n)^{11}C $\qquad Q_{\rm m} = -18.722$

See ^{12}C.

19. ^{12}C(p, d)^{11}C $\qquad Q_{\rm m} = -16.495$

See (1952BR52, 1956GR1E, 1956WE1B).

20. ^{12}C(d, t)^{11}C $\qquad Q_{\rm m} = -12.463$

See (1956WE1B) and ^{14}N.

21. ^{12}C(^{3}He, α)^{11}C $\qquad Q_{\rm m} = 1.856$

At E(^{3}He) $= 1.3$ and 2.0 MeV, no 1.9 MeV γ-radiation (from ^{11}C*(2.0)) is observed by (1957BR18). The energy of the first excited state is 1.990 ± 0.010 MeV (1959PO61). See also (1952FR1A, 1952PO27, 1953KU08, 1958WE1E).

22. ^{13}C(p, t)^{11}C $\qquad Q_{\rm m} = -15.183$

Not reported.

23. ^{14}N(p, α)^{11}C $\qquad Q_{\rm m} = -2.916$

See ^{15}O.

24. ^{16}O(γ, nα)^{11}C $\qquad Q_{\rm m} = -25.870$

See (1955AJ61).

References

(Closed 1 December 1958)

References are arranged and designated by the year of publication followed by the first two letters of the first-mentioned author's name and then by two additional characters. Most of the references appear in the National Nuclear Data Center files (Nuclear Science References Database) and have NNDC key numbers. Otherwise, TUNL key numbers were assigned with the last two characters of the form 1A, 1B, etc. In response to many requests for more informative citations, we have, when possible, included up to ten authors per paper and added the authors' initials.

1937EC1A Eckardt, Ann. Phys. 29 (1937) 497

1948EG1A Eggler, Hughes and Huddleston, Phys. Rev. 74 (1948) 1238

1949EV1A Evans, Malich and Risser, Phys. Rev. 75 (1949) 1161

1950HO80 W.F. Hornyak, T. Lauritsen, P. Morrison and W.A. Fowler, Rev. Mod. Phys. 22 (1950) 291

1950ST1A Stebler, Bichsel and Huber, Helv. Phys. Acta 23 (1950) 511

1951BE13 W.E. Bennett, P.A. Roys and B.J. Toppel, Phys. Rev. 82 (1951) 20

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

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

1951LI29 C.W. Li and W. Whaling, Phys. Rev. 82 (1951) 122

1951PE18 B. Petree, C.H. Johnson and D.W. Miller, Phys. Rev. 83 (1951) 1148

1951RE01 I. Resnick and S.S. Hanna, Phys. Rev. 82 (1951) 463

1951SH63 R. Sher, J. Halpern and A.K. Mann, Phys. Rev. 84 (1951) 387

1951VA1A Van Patter, Buechner and Sperduto, Phys. Rev. 82 (1951) 248

1952AJ38 F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys. 24 (1952) 321

1952BI1A Bichsel, Halg, Huber and Stebler, Helv. Phys. Acta 25 (1952) 119

1952BR52 R. Britten, Phys. Rev. 88 (1952) 283

1952CA19 F.L. Canavan, Phys. Rev. 87 (1952) 136

1952CO41 J.H. Coon, E.R. Graves and H.H. Barschall, Phys. Rev. 88 (1952) 562

1952CR30 D.S. Craig, D.J. Donahue and K.W. Jones, Phys. Rev. 88 (1952) 808

1952DA05 R.B. Day and R.L. Walker, Phys. Rev. 85 (1952) 582

1952DE24 D. deJong, P.M. Endt and L.J.G. Simons, Physica 18 (1952) 676

1952FR1A Fremlin, Proc. Phys. Soc. (London) A65 (1952) 762

1952JO10 V.R. Johnson, Phys. Rev. 86 (1952) 302

1952JO1B Jones and Wilkinson, Phys. Rev. 88 (1952) 423
1952LI24 A.B. Lillie, Phys. Rev. 87 (1952) 716
1952PH01 D.D. Phillips, R.W. Davis and E.R. Graves, Phys. Rev. 88 (1952) 600
1952PO27 M.L. Pool, Physica 18 (1952) 1304
1953CA45 R.S. Carter, H. Palevsky, V.W. Myers and D.J. Hughes, Phys. Rev. 92 (1953) 716
1953EL12 M.M. Elkind, Phys. Rev. 92 (1953) 127
1953GE01 R.W. Gelinas and S.S. Hanna, Phys. Rev. 89 (1953) 483
1953GI05 W.M. Gibson, Phil. Mag. 44 (1953) 297
1953HA1C Hamermesh, Ringo and Wexler, Phys. Rev. 90 (1953) 603
1953HO48 J.R. Holt and T.N. Marsham, Prog. Phys. Soc. A66 (1953) 1032
1953HU29 T. Huus and R.B. Day, Phys. Rev. 91 (1953) 599
1953KU08 D.N. Kundu, T.W. Donaven, M.L. Pool and J.K. Long, Phys. Rev. 89 (1953) 1200
1953SA1A Sawyer and Phillips, Los Alamos Rept.1578 (1953)
1953SP1A Sperduto and Fader, M.I.T. Prog. Rept. (May, 1953)
1953TH1B Thirion, Ann. Phys. 8 (1953) 489
1954BU06 W.H. Burke, J.R. Risser and G.C. Phillips, Phys. Rev. 93 (1954) 188
1954CO16 C.F. Cook and T.W. Bonner, Phys. Rev. 94 (1954) 651
1954DA20 R.B. Day and T. Huus, Phys. Rev. 95 (1954) 1003
1954DE38 J.A. De Juren and H. Rosenwasser, Phys. Rev. 93 (1954) 831
1954EV1A Evans and Parkinson, Proc. Phys. Soc. (London) A67 (1954) 684
1954HE22 N.P. Heydenberg and G.M. Temmer, Phys. Rev. 94 (1954) 1252
1954KH1A Khromchenko, Dokl. Akad. Nauk SSSR 94 (1954) 1037
1954LI48 C.W. Li and R. Sherr, Phys. Rev. 96 (1954) 389
1954MO1E Moak, Good and Kunz, Phys. Rev. 95 (1954) 641A
1954NE1A Nereson et al., LA 1655 (1954)
1954PA28 C.H. Paris, F.P.G. Valckx and P.M. Endt, Physica 20 (1954) 573
1954PA29 C.H. Paris and P.M. Endt, Physica 20 (1954) 585
1954RI15 F.L. Ribe and J.D. Seagrave, Phys. Rev. 94 (1954) 934
1954SC85 V.E. Scherrer, B.A. Allison and W.R. Faust, Phys. Rev. 96 (1954) 386
1954SC87 F. Scott, D. Thomson and W. Wright, Phys. Rev. 95 (1954) 582
1954VO1A von Dardel and Sjostrand, Phys. Rev. 96 (1954) 1566
1954WO23 C. Wong, Phys. Rev. 95 (1954) 761

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

1955AL16 H.R. Allan and N. Sarma, Proc. Phys. Soc. (London) A68 (1955) 535

1955BA1M Bach and Livesey, Phil. Mag. 46 (1955) 824

1955BA22 J.K. Bair, J.D. Kington and H.B. Willard, Phys. Rev. 100 (1955) 21.

1955BA63 W.C. Barber, W.D. George and D.D. Reagan, Phys. Rev. 98 (1955) 73

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

1955BE81 R.D. Bent, T.W. Bonner, J.H. McCrary, W.A. Ranken and R.F. Sippel, Phys. Rev. 99 (1955) 710

1955BO1A Borelli and Lalovic, Nature 176 (1955) 1021

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

1955GO1D Gorodetzky, Gallman, Croissiaux and Armbruster, Compt. Rend. 241 (1955) 1743

1955GR18 G.L. Griffith, Phys. Rev. 98 (1955) 579

1955HA01 T.M. Hahn Jr., B.D. Kern and G.K. Farney, Phys. Rev. 98 (1955) 1183A

1955HE83 R.E. Heft and W.F. Libby, Phys. Rev. 100 (1955) 799

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

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

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

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

1955MA76 J.B. Marion, T.W. Bonner and C.F. Cook, Phys. Rev. 100 (1955) 847.

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

1955RA14 D.C. Ralph and F.E. Dunnam, Phys. Rev. 98 (1955) 249A

1955RA41 V.K. Rasmussen, D.W. Miller, M.B. Sampson and U.C. Gupta, Phys. Rev. 100 (1955) 851

1955SA1B Sample, Neilson, Chadwick and Warren, Can. J. Phys. 33 (1955) 828

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

1955WA1A Wapstra, Physica 21 (1955) 367

1955WI1E Wignall, Aust. J. Phys. 8 (1955) 310

1955WI25 H.B. Willard, J.K. Bair and J.D. Kington, Phys. Rev. 98 (1955) 669

1956AJ22 F. Ajzenberg-Selove, G.D. Johnson, A. Rubin and M. Mazari, Phys. Rev. 103 (1956) 356

1956AL23 H.R. Allan, M. Govindjee and N. Sarma, Proc. Phys. Soc. (London) A69 (1956) 350

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

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

1956CE1B M. Cerineo, Physica 22 (1956) 1154A

1956CE73 M. Cerineo, Nucl. Phys. 2 (1956) 113

1956CH20 G.B. Chadwick, T.K. Alexander and J.B. Warren, Can. J. Phys. 34 (1956) 381

1956CO1E Collie, Meads and Lockett, Proc. Phys. Soc. (London) A69 (1956) 464

1956CR07 J.W. Cronin, Phys. Rev. 101 (1956) 298

1956DA01 R.B. Day, A.E. Johnsrud and D.A. Lind, Bull. Amer. Phys. Soc. 1 (1956) 56, R9

1956DA23 R.B. Day, Phys. Rev. 102 (1956) 767

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

1956GO1L S. Gorodetzky, A. Gallman and M. Croissiaux, Physica 22 (1956) 1160A

1956GO1M Gorodetzky, Gallman, Croissiaux and Armbruster, Compt. Rend. 242 (1956) 2545

1956GO39 S. Gorodetzky, A. Gallman and M. Croissiaux, J. Phys. Rad. 17 (1956) 550

1956GR1E Greider, Bull. Amer. Phys. Soc. 1 (1956) 376

1956GR54 A. Graue, Phil. Mag. 1 (1956) 1027

1956HL01 H.D. Holmgren, M.L. Bullock and W.E. Kunz, Phys. Rev. 104 (1956) 1446

1956JU17 M.J. Juric and S.D. Cirilov, Bull. Inst. Nucl. Sci. Boris Kidrich 6 (1956) 45

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

1956MA69 J.B. Marion and G. Weber, Phys. Rev. 103 (1956) 1408.

1956MA83 E.E. Maslin, J.M. Calvert and A.A. Jaffe, Proc. Phys. Soc. (London) A69 (1956) 754

1956ST1D K.G. Standing, Phys. Rev. 101 (1956) 152

1956VA17 F.P.G. Valckx, Ph.D. Thesis, Univ. of Utrecht (1956)

1956WE1B Werner, Nucl. Phys. 1 (1956) 9

1956WO1A Wolicki, Geer, Holmgren and Johnston, Bull. Amer. Phys. Soc. 1 (1956) 196

1956ZE1A Zeidman and Fowler, Bull. Amer. Phys. Soc. 1 (1956) 325

1957BA18 G.A. Bartholomew and P.J. Campion, Can. J. Phys. 35 (1957) 1347

1957BE71 A.A. Bergman, A.I. Isakov, I.P. Popov and F.L. Shapiro, Zh. Eksp. Teor. Fiz. 33 (1957) 9; JETP (Sov. Phys.) 6 (1958) 6

1957BI1F Bilpuch, Weston, Newson, Rohrer and Jones, Bull. Amer. Phys. Soc. 2 (1957) 218

1957BI78 J.R. Bird and R.H. Spear, Aust. J. Phys. 10 (1957) 268

1957BI84 H. Bichsel and T.W. Bonner, Phys. Rev. 108 (1957) 1025

1957BR18 D.A. Bromley, E. Almqvist, H.E. Gove, A.E. Litherland, E.B. Paul and A.J. Ferguson, Phys. Rev. 105 (1957) 957

1957CO54 S.A. Cox and R.M. Williamson, Phys. Rev. 105 (1957) 1799

1957FE1B Ferguson, Gove, Litherland, Almqvist and Bromley, Bull. Amer. Phys. Soc. 2 (1957) 51

1957GA1B Gallmann, Ph.D. Thesis, Univ. of Strasbourg (1957)

1957GO1B Gove, Litherland, Almqvist, Bromley and Ferguson, Bull. Amer. Phys. Soc. 2 (1957) 51

1957GR50 A. Graue and B. Trumpy, Phil. Mag. 2 (1957) 138

1957HA1H Harrison and Curtis, Bull. Amer. Phys. Soc. 2 (1957) 350

1957HU1D Hughes and Schwartz, BNL-325, Suppl. 1 (1957)

1957HU79 S.E. Hunt, R.A. Pope and W.W. Evans, Phys. Rev. 106 (1957) 1012

1957HY1A Hyder, Harmon and Curtis, Bull. Amer. Phys. Soc. 2 (1957) 267

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

1957JO1B Johnston, Holmgren and Wolicki, Bull. Amer. Phys. Soc. 2 (1957) 181

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

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

1957LE1F Lee and Wall, Bull. Amer. Phys. Soc. 2 (1957) 208

1957MC35 J.H. McCrary, T.W. Bonner and W.A. Ranken, Phys. Rev. 108 (1957) 392

1957ME1D Meyer-Schutzmeister and Hanna, Bull. Amer. Phys. Soc. 2 (1957) 28

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

1957PR53 Y.D. Prokoshkin and A.A. Tyapkin, Zh. Eksp. Teor. Fiz. 32 (1957) 177; JETP (Sov. Phys.) 5 (1957) 148

1957SC29 J. Scobie and G.M. Lewis, Phil. Mag. 2 (1957) 1089

1957SH65 A.I. Shpetni, Zh. Eksp. Teor. Fiz. 32 (1957) 423; JETP (Sov. Phys.) 5 (1957) 357

1957SJ1C Sjogren, Ark. Fys. 11 (1957) 383

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

1957WA07 H. Warhanek, Phil. Mag. 2 (1957) 1085

1957WI26 D.H. Wilkinson, Phys. Rev. 105 (1957) 666

1958AL96 D.E. Alburger and D.H. Wilkinson, Phil. Mag. 3 (1958) 1332

1958AR15 S.E. Arnell, J. Dubois and O. Almen, Nucl. Phys. 6 (1958) 196

1958BA52 G.A. Bartholomew and L.A. Higgs, AECL-669 (1958)

1958BI31 O.M. Bilaniuk and J.C. Hensel, Bull. Amer. Phys. Soc. 3 (1958) 188, K8; Univ. of Michigan, Cyclotron Rept. (July, 1958)

1958BO1C J. E. Bowcock, Phys. Rev. 112 (1958) 923

1958BR1D Bromley, Proc. Rehovoth Conf. (North-Holland Pub. Co., Amsterdam, 1958)

1958BU02 E. Bujdoso, Nucl. Phys. 6 (1958) 107

1958DO63 T. Doke, S. Suzuki and I. Ogawa, J. Phys. Soc. Jpn. 13 (1958) 656

1958EV01 N.T.S. Evans and A.P. French, Phys. Rev. 109 (1958) 1272

1958FE70 A.J. Ferguson, H.E. Gove, J.A. Kuehner, A.E. Litherland, E. Almqvist and D.A. Bromley, Phys. Rev. Lett. 1 (1958) 414

1958FR1C French, Univ. of Pittsburgh Tech. Rept. 9 (1958)

1958GO77 H.E. Gove, J.A. Kuehner, A.E. Litherland, E. Almqvist, D.A. Bromley, A.J. Ferguson, P.H. Rose, R.P. Bastide, N. Brooks and R.J. Connor, Phys. Rev. Lett. 1 (1958) 251

1958HE47 J.C. Hensel and W.C. Parkinson, Phys. Rev. 110 (1958) 128

1958HI74 B. Hird, J.A. Cookson and M.S. Bokhari, Proc. Phys. Soc. (London) A72 (1958) 489

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

1958JA06 N. Jarmie and R.C. Allen, Phys. Rev. 111 (1958) 1121

1958JU38 M.K. Juric and N.D. Zarubica, Bull. Inst. Nucl. Sci. Boris Kidrich 8 (1958) 17

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

1958MA1F Macklin and Gibbons, Bull. Amer. Phys. Soc. 3 (1958) 26

1958MA1J Macklin and Gibbons, Bull. Amer. Phys. Soc. 3 (1958) 187

1958MC1D McElhinney, Conf. on Photonucl. Reactions, National Bureau of Standards (1958)

1958MC1E McDonell and Sargood, Private Communication (1958)

1958ME77 L. Meyer-Schutzmeister and S.S. Hanna, Bull. Amer. Phys. Soc. 3 (1958) 188, K10

1958ME79 F.R. Metzger, C.P. Swann and V.K. Rasmussen, Phys. Rev. 110 (1958) 906

1958NE38 G.C. Neilson, W.K. Dawson and J.T. Sample, Bull. Amer. Phys. Soc. 3 (1958) 323, H11

1958NU40 M.J. Nurmia and R.W. Fink, Phys. Rev. Lett. 1 (1958) 23

1958RA13 W.A. Ranken, T.W. Bonner, J.M. McCrary and T.A. Rabson, Phys. Rev. 109 (1958) 917

1958RA14 V.K. Rasmussen, F.R. Metzger and C.P. Swann, Phys. Rev. 110 (1958) 154

1958SW63 D.R. Sweetman, Bull. Amer. Phys. Soc. 3 (1958) 186, K1

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

1958TY46 H. Tyren and T.A.J. Maris, Nucl. Phys. 6 (1958) 82

1958TY47 H. Tyren and T.A.J. Maris, Nucl. Phys. 6 (1958) 446

1958WE1E Wegner and Hall, Bull. Amer. Phys. Soc. 3 (1958) 338

1958WI41 D.H. Wilkinson, Phys. Rev. 109 (1958) 1610

1958WY66 W.E. Wyman, Bull. Amer. Phys. Soc. 3 (1958) 187, K7

1958WY67 M.E. Wyman, E.M. Fryer and M.M. Thorpe, Phys. Rev. 112 (1958) 1264

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

1959NE1A Neilson, Dawson and Johnson, Rev. Sci. Instrum. 30 (1959) 963

1959PO61 B. Povh, Phys. Rev. 114 (1959) 1114

1959WI49 D.H. Wilkinson and D.E. Alburger, Phys. Rev. 113 (1959) 563