Energy Levels of Light Nuclei
$A = 13$

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

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

Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), p. 1. This version of $A = 13$ 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 NNDC/TUNL format.

(References closed December 1, 1958)

The original work of Fay Ajzenberg-Selove was supported by the US Department of Energy [DE-AC02-76-ER02785]. 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 $A = 13$

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.

Table 13.1: Energy levels of ^{13}B

E_x (MeV)	$J^\pi; T$	$\tau_{1/2}$ (sec)	Decay	Reactions
0	$(\frac{3}{2}^-); \frac{3}{2}$	$(35 \pm 15) \times 10^{-3}$	β^-	1, 2

^{13}B
(Not illustrated)

GENERAL:

Mass of ^{13}B: The mass excess of ^{13}B is 20.40 ± 0.05 MeV from the Q of the reaction ^{7}Li(^{7}Li, p)^{13}B (1957NO14), and Wapstra's masses (1955WA1A) for ^{7}Li and ^{1}H. ^{13}B is then stable by 4.88 MeV to decay into $^{12}\text{B} + \text{n}$, by 11.00 MeV to decay into $^{10}\text{Be} + \text{t}$ and by 11.3 MeV to decay into $^9\text{Li} + \alpha$.

1. ^{13}B(β^-)^{13}C $\qquad Q_m = 13.44$

The half-life of ^{13}B is $(35\pm15)\times10^{-3}$ sec (1956NO1A). Attempts to observe delayed neutrons from the decay of neutron-unstable states of ^{13}C have been unsuccessful (1953HU1C, 1956NO1A). It is pointed out by (1957NO14) that transitions to such states are unlikely if ^{13}B has the expected $J = \frac{3}{2}^-$. See also (1948SN1A, 1952SH44).

2. ^{7}Li(^{7}Li, p)^{13}B $\qquad Q_m = 5.97$
$Q_0 = 5.97 \pm 0.05$ (1957NO14).

This reaction has been observed for $E(^7\text{Li}) = 1.4$ to 2.0 MeV (1956AL1F, 1957NO14, 1958LI42). At $E(^7\text{Li}) = 2$ MeV, no proton groups have been observed corresponding to excited states of ^{13}B below $E_x = 2.9$ MeV (1958LI42). See also ^{14}C.

3. ^{11}B(t, p)^{13}B $\qquad Q_m = 0.24$

Not reported.

^{13}C

(Fig. 22)

GENERAL:

Theory: See (1955AU1A, 1955LA1A, 1956DA1G, 1956DE1C, 1956KU1A, 1957BA1H, 1958FR1C, 1958SK1A).

1. (a) ^{6}Li(^{7}Li, p)^{12}B $\quad Q_{\rm m} = 8.338 \quad E_{\rm b} = 25.876$

   (b) ^{6}Li(^{7}Li, n)^{12}C $\quad Q_{\rm m} = 20.931$

   (c) ^{6}Li(^{7}Li, 2n)^{11}C $\quad Q_{\rm m} = 2.209$

See (1957NO17).

2. ^{7}Li(^{7}Li, n)^{13}C $\quad Q_{\rm m} = 18.624$

See (1957NO17).

3. ^{9}Be(α, γ)^{13}C $\quad Q_{\rm m} = 10.654$

At $E_{\alpha} = 1.60$ MeV, the capture cross section is less than 30 μb (1955AL16).

4. ^{9}Be(α, n)^{12}C $\quad Q_{\rm m} = 5.709 \quad E_{\rm b} = 10.654$

Resonances for neutrons and for γ-rays from ^{12}C*(4.4) are given in Table 13.3. Absolute cross sections for several resonances are reported by (1956BO61, 1959GI47). For the prominent 1.9 MeV resonance, dσ/dΩ (90°) for 4.4 MeV γ-rays is given as 12 mb/sr (lab) by (1956BO61) and as 26 mb/sr by (1955TA28). For $E_{\alpha} = 2.5$ to 8.2 MeV, absolute neutron yields have been measured by (1958MA1J, 1959GI47).

Separate excitation curves (at $0°$) for ground state neutrons (n$_0$) and for neutrons to the 4.4 MeV state (n$_1$) are reported by (1957RI38) in the range $E_{\alpha} = 1.7$ to 4.8 MeV (n$_0$) and 3.1 to 4.8 MeV (n$_1$). The n$_0$ yield curves show broad maxima at $E_{\alpha} = 1.9$, 2.0, 2.6, 4.2 and 4.5 MeV. The sharp 3.98 MeV resonance is strong for n$_1$, but quite weak for n$_0$. Angular distributions of ground-state neutrons suggest two broad resonances in the region $E_{\alpha} = 3.9$ to 4.6 MeV, probably $J = \frac{3}{2}^{+}$ and $\frac{5}{2}^{+}$ (1957RI38).

Table 13.2: Energy levels of ^{13}C

E_x (MeV ± keV)	J^π	τ_m or Γ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$	–	stable	2, 9, 15, 17, 23, 29, 30, 32, 34, 35, 37, 40, 41
3.085 ± 5	$\frac{1}{2}^+$	$\tau_m < 3 \times 10^{-13}$ sec	γ	9, 15, 18, 23, 29, 32, 40
3.680 ± 7	$\frac{3}{2}^-$	$\tau_m < 3 \times 10^{-13}$ sec	γ	9, 15, 17, 23, 29, 32, 34, 40
3.850 ± 10	$\frac{5}{2}^+$	$\tau_m > 3 \times 10^{-13}$ sec	γ	9, 15, 23, 32, 40
5.51 ± 50				15
6.10 ± 50				15
6.86 ± 10	$\frac{5}{2}^+$	$\Gamma = 6$	n	15, 18, 23, 40
7.470 ± 20				23, 40
7.533 ± 20				15, 23, 40
7.641 ± 20	$\frac{3}{2}^+$	55 ± 15	n	18, 23, 40
8.33 ± 100	$\frac{3}{2}^+$	1000 ± 250	n	18, 23, 35
8.82 ± 40			n	15, 18, 40
9.50 ± 20			n	15, 18, 23, 40
9.90 ± 20	> 0		n	15, 18, 23, 40
10.76 ± 20			n	18, 19, 23
10.94 ± 100			n	15, 18, 19
11.02 ± 30	$(\frac{1}{2}^+)$	50	α, n	4, 15
11.08 ± 30		sharp	α, n	4, 15
11.97 ± 15	$(\frac{7}{2}^-)$	70	α, n	4, 15, 18, 19
12.21 ± 30		≈ 140	α, n	4, 15, 18, 19
12.44 ± 30	$(\frac{1}{2}^-)$	≈ 140	α, n	4, 19
12.81 ± 100				15
13.41 ± 30		50	α, n	4
13.77 ± 30		≈ 280	α, n	4
14.1 ± 100		≈ 210	α, n	4
14.64 ± 30			α, n	4
16.1 ± 100			α, n	4
20.52 ± 20		115 ± 10	d, n	10
21.28 ± 20		160 ± 15	d, n	10

Table 13.3: Resonances in ^{9}Be(α, n)^{12}C

E_{α} [a] (MeV)	E_{α} [b] (MeV)	Γ (keV)	J^{π}	^{13}C* (MeV)	Refs.
0.53	0.53	70	$(\frac{1}{2}^{+})$ [j]	11.02	c
0.61	0.61	sharp		11.08	c
1.9	1.905	180	$(\frac{7}{2}^{-})$ [j]	11.97 [k]	d
2.24		≈ 200		12.21 [k]	e
2.58	2.6	≈ 200	$(\frac{1}{2}^{-})$ [j]	12.44 [k]	f
4.00	3.98	70		13.41	h,i
(4.2)		(≈ 300)		(13.6)	g
4.50	4.4	≈ 400		13.77 [k]	h,i
5.0	5.0	≈ 300		14.1 [k]	h
5.75				14.64	i
7.8				16.1	i

[a] Resonances in neutron yield.
[b] Resonances for 4.4 MeV γ-rays.
[c] (1954BE08).
[d] (1953TA06, 1954BE08, 1954TR09, 1955TA28, 1956BO61), $\Gamma_{n}/\Gamma_{\alpha} > 12$ (1955TA28).
[e] (1954TR09, 1956BO61).
[f] (1953TA06, 1954TR09, 1956BO61, 1958MA1J).
[g] (1957RI38).
[h] (1956BO61).
[i] (1958MA1J, 1959GI47).
[j] (1956JA28).
[k] Not corrected for effects of Coulomb barrier penetration.

Extensive angular distribution studies have been made for $E_{\alpha} < 2$ MeV by (1955TA28, 1956JA28). According to (1956JA28), the best fit to the distributions in the range $E_{\alpha} = 0.4$ to 1.3 MeV is obtained from the assignments $J = \frac{1}{2}^{+}, \frac{7}{2}^{-}, \frac{1}{2}^{-}$ for the 0.5, 1.9 and 2.6 (?) MeV resonances (see also (1955TA28)). The angular correlation of neutrons and 4.4 MeV gamma-rays is isotropic at $E_{\alpha} = 1.2$ and 2.8 MeV, indicating that stripping plays only a minor role at these energies (1958TA05). See also (1955MA1J; theor.) and (1956BE98).

5. ^{9}Be(α, p)^{12}B $\qquad Q_{m} = -6.884 \qquad E_{b} = 10.654$

See ^{12}B.

6. ^{9}Be(α, d)^{11}B $\qquad Q_{\rm m} = -8.022 \qquad E_{\rm b} = 10.654$

See ^{11}B.

7. (a) ^{9}Be(α, α')^{9}Be* $\qquad E_{\rm b} = 10.654$
(b) ^{9}Be(α, α'n)^{8}Be $\qquad Q_{\rm m} = -1.667$
(c) ^{9}Be(α, n)^{4}He^{4}He^{4}He $\qquad Q_{\rm m} = -1.572$

For reaction (a) see ^{9}Be and (1955TA28). For reactions (b) and (c), see (1952AJ38).

8. ^{10}B(t, α)^{9}Be $\qquad Q_{\rm m} = 13.210 \qquad E_{\rm b} = 23.882$

See ^{9}Be.

9. ^{10}B(α, p)^{13}C $\qquad Q_{\rm m} = 4.070$
$Q_0 = 4.064 \pm 0.012$ (W.J. Fader, quoted in (1957VA11)).
$Q_0 = 4.08 \pm 0.03$ (1956PI1A).
$Q_0 = 4.10 \pm 0.03$ (1956PA1B).

Four proton groups are observed, corresponding to the ^{13}C levels at 0, 3.09, 3.68 and 3.85 MeV (1953SH64, 1954FA1A, 1954FA1B, 1956PI1A). Additional groups are reported by (1957RO1F). The relative intensities depend strongly on bombarding energy (see ^{14}N, (1953SH64)). See also (1955AJ61).

A study of gamma rays from this reaction and from ^{12}C(d, p)^{13}C shows three lines with $E_\gamma = 0.1695 \pm 0.0004$, 3.844 ± 0.015 and 3.69 ± 0.02 MeV. The 3.85 MeV γ-ray exhibits no Doppler shift and therefore has a lifetime greater than 3×10^{-13} sec; the 3.69 MeV line shows approximately the maximum possible Doppler shift ($\tau < 3 \times 10^{-13}$ sec). The 170 keV line is due to the cascade transition between the 3.84 and 3.68 MeV states; the internal conversion coefficient is consistent with E1, although M1 cannot be excluded. The probability of this cascade decay of the 3.84 MeV state is 0.24 ± 0.05. Cascade transitions to the 3.1 MeV excited state have not been observed. Their intensities are less than 3% of the ground state transitions (1956MA1Q, 1956MA52): see Fig. 23. (For earlier work see (1953SH64) and (1954ST20)). The angular distributions and p-γ correlations for the 3.8 MeV radiation contain terms in ($\cos^4\theta$), indicating $J = \frac{5}{2}^+$ for the 3.84 MeV state (1954ST20: see ^{12}C(d, p)^{13}C). If the 170 keV line is due to an E1 transition, the J^π of the 3.68 MeV state is then $\frac{3}{2}^-$ ($J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$ follows from ^{12}C(d, p)^{13}C); the angular distribution of the 3.7 MeV radiation is consistent with M1 (1954ST20).

Angular distributions of the grounds state protons are reported at $E_\alpha = 4.9$, 6.0, 7.0 and 8.1 MeV (1957VO25) and at $E_\alpha = 30.5$ MeV (1957HU1E): in both cases direct interaction appears to be involved. See also (1957BA1K) and (1955BR1A).

10. ^{11}B(d, n)^{12}C $Q_m = 13.731$ $E_b = 18.677$

The yield of neutrons has been measured for $E_d = 0.2$ to 5.4 MeV. The total cross section for ground state neutrons in the 0.5 to 1.15 MeV range rises from 0.5 to 30 mb; both direct and exchange stripping processes seem to be involved (1956PA23, 1957AM48). The yield of the excited-state group, ^{12}C*(4.4) rises smoothly from $E_d = 0.5$ to 1.1 MeV and is essentially flat from $E_d = 1.1$ to 2.0 MeV (1959NE1A). At $E_d = 600$ keV, angular distributions indicate that stripping is important for the ground-state group. For the excited-state group (^{12}C*(4.4)), the interpretation is less clear; the observed distribution can be accounted for by p-wave formation of a $J = \frac{7}{2}^+$ level in ^{13}C (1955WA30). (1959NE1A) find evidence of strong "heavy-particle" stripping for this group in the range $E_d = 0.5$ to 2.0 MeV. The cross section for emission of neutrons in the forward direction is ≈ 270 mb/sr at $E_d = 5.4$ MeV (1955MA76). For $E_d = 1.6$ to 3.2 MeV, the yield of 15.1 MeV γ-rays shows resonances at $E_d = 2.180 \pm 0.010$ and 3.080 ± 0.015 MeV, corresponding to ^{13}C*(20.52, 21.28) with $\Gamma_{c.m.} = 115 \pm 10$ and 160 ± 15 keV, respectively; the cross section at $E_d = 2.2$ MeV is 29 ± 7 mb (1958KA31). See also (1954BU06, 1955RI1B) and ^{12}C.

11. ^{11}B(d, p)^{12}B $Q_m = 1.138$ $E_b = 18.677$

The thin-target yield rises smoothly from $E_d = 0.3$ to 3.1 MeV with no evidence of resonances (1949HU41, 1958KA31). At $E_d = 1.5$ MeV, $\sigma \approx 0.38$ b (1958KA31: see, however, (1949HU41)). See also ^{12}B and (1957JA37).

12. ^{11}B(d, d)^{11}B $E_b = 18.677$

See ^{11}B.

13. ^{11}B(d, α)^{9}Be $Q_m = 8.022$ $E_b = 18.677$

Some absolute cross sections are given by (1958KA31). See also ^{9}Be.

14. ^{11}B(t, n)^{13}C $Q_m = 12.419$

Table 13.4: Levels of ^{13}C from ^{11}B(^{3}He, p)^{13}C

E_x [a] (MeV $\pm$ keV)	E_x [b] (MeV)
0	0
3.09	3.08
3.68	3.77
3.86	
5.51 ± 50	
6.10 ± 50	
6.87	6.89
7.55 ± 40	7.63
8.87 ± 50	8.96
9.52 ± 60	
9.91 ± 50	10.00
10.9 ± 150 [c]	10.99
11.1 ± 150 [c]	
	11.67
12.08 ± 100 [c]	
12.81 ± 100 [c]	

[a] (1958MO99): $E(^3\text{He}) = 1.23$ MeV.
[b] (1955BI26): $E(^3\text{He}) = 0.9$ MeV; values are ± 100 keV.
[c] (1957GA01): $E(^3\text{He}) = 1.25$ MeV.

Not reported.

15. ^{11}B(^{3}He, p)^{13}C $\qquad Q_m = 13.184$

Levels derived from reported proton groups are listed in Table 13.4. The levels at 5.5 and 6.1 MeV have not been observed in any other reaction. From the fact that they do not appear in ^{12}C(n, n)^{12}C, an upper limit of $\Gamma = 10$ keV is estimated; the mirror levels in ^{13}N must be assumed to have $\theta_p^2 < 0.02$ (1958MO99).

Angular distributions have been measured for the p_0, p_1 and ($p_2 + p_3$) groups at $E(^3\text{He}) = 4.5$ MeV. The p_0 group appears to be peaked in both the forward and the backward direction. The other groups do not exhibit a strong angular variation (1957HO61). At $E(^3\text{He}) = 6.05$ MeV the p_0 group is strongly peaked forward ((1958SW63), and D.R. Sweetman, private communication).

16. ^{11}B(α, d)^{13}C $\quad Q_m = -5.167$

Not reported.

17. ^{12}C(n, γ)^{13}C $\quad Q_m = 4.946$

The thermal capture cross section is 3.3 ± 0.2 mb (1958HU18). In addition to the 4.95 MeV ground state transition ($E_\gamma = 4948 \pm 8$ keV), a γ-ray is reported with an energy of 3.68 ± 0.05 MeV and an intensity of 0.3 γ/capture. If 3.1 and 3.9 MeV γ-rays occur, their intensities are less than 0.10 and 0.06 γ/capture, respectively (1953BA18).

18. ^{12}C(n, n)^{12}C $\quad E_b = 4.946$

The cross section is approximately constant to 160 keV, then decreases monotonically to $E_n = 2$ MeV. There follows a region of resonances to 8.5 MeV, followed by a smooth variation of the cross section to $E_n = 100$ MeV (1958HU18). (1958CO07) finds a minimum of 1.3 b at $E_n = 14$ MeV, followed by a rise to 1.5 b at $E_n = 15.5$ MeV: see also ^{12}C(n, p)^{12}B. The average total cross section in the range $E_n = 14$ to 10000 eV is 4.69 ± 0.10 b (1956BR99).

The parameters of observed resonances are displayed in Table 13.5. A careful search for resonances in the region $E_n = 20$ to 1360 keV with 10 and 22 keV resolution revealed no deviation $> 5\%$ from a smooth monotonic decrease in σ_t (1950MI1A) (see, however, ^{11}B(^{3}He, p)^{13}C). The course of the cross section in this region can be accounted for by the broad $s_{1/2}$ state at ^{13}C*(3.09) (1952TH1D). A similar search, with 5 keV resolution, in the range $E_n = 2.73$ to 2.80 MeV revealed no deviations > 0.2 b from a smooth function (1958WI01: see ^{12}C(d, p)^{13}C).

Below $E_n = 4.0$ MeV, three d-wave resonances occur, at 2.08, 2.95, and 3.67 MeV. The total cross section and angular distributions establish the first as $D_{\frac{5}{2}}$ (1958WI36); phase shift analyses of angular distributions yield $D_{\frac{3}{2}}$ for the other two. The s-wave phase shift is everywhere negative and decreases slowly with energy: the behavior for $E_n = 0$ to 4 MeV can be accurately reproduced by a static potential well with a diffuse boundary (1958WI36). See also (1954HU1A). The $p_{1/2}$ and $p_{3/2}$ phase shifts are negative and small, not inconsistent with hard-sphere scattering (1954ME95, 1955BU56, 1958WI36). Polarization of scattered neutrons is discussed in these three papers and in (1956MC70, 1957MC1B). Other angular distribution studies in this range are reported by (1957LA14: $E_n = 0.06$ to 1.8 MeV), (1955WI25: $E_n = 0.55$ to 1.5 MeV), (1956MU96: $E_n = 1.66$ MeV), (1955LI50: $E_n = 2.7$ MeV), (1955WA27: $E_n = 4.1$ MeV).

Table 13.5: Resonances in ^{12}C(n, n)^{12}C

$E_{\rm res}$ (MeV)	$\Gamma_{\rm lab}$ (keV)	^{13}C* (MeV)	$l_{\rm n}$	J^{π}	θ^2
2.076 ± 0.008 [a]	7 [a]	6.862	2 [a]	$\frac{5}{2}^{+}$ [a]	0.006 [a]
2.95 [b]	90 [g]	7.67	2 [h]	$\frac{3}{2}^{+}$ [h]	0.038 [a]
3.67 [b]	1690 [g]	8.33	2 [h]	$\frac{3}{2}^{+}$ [h]	0.51 [a]
4.4 [c]		9.0			
4.95 [d]		9.51			
5.40 [d]		9.93	> 0 [d]	$> \frac{1}{2}$ [d]	
6.3 [e]		10.8			
7.5 [f]		11.9			
7.83 [f]		12.17			

[a] (1958WI36): see also (1951BO45).
[b] See (1950RI1B, 1951BO45, 1951RI1A, 1951RI1B, 1958WI36).
[c] (1950FR61).
[d] (1956BE98).
[e] See (1953NE01, 1957BO13, 1958HU18).
[f] (1956HA1E).
[g] (1958WI36): (1954ME95) report 60 and 1200 keV.
[h] See (1950RI1B, 1951BO45, 1951RI1A, 1951RI1B, 1954ME95, 1955BU56, 1958WI36).

For $E_{\rm n} = 4$ to 8 MeV, several additional resonances are reported by (1950FR61, 1956BE98, 1956HA1E, 1957BO13): see Table 13.5 and (1958HU18). The structure above $E_{\rm n} = 7$ MeV is undoubtedly quite complex: see ^{9}Be(α, n)^{12}C and ^{12}C(n, n$'$)^{12}C*. Further angular distribution measurements are reported by (1955JE27: 4.4 MeV), (1958HI68: 5 MeV), (1958BR1F: 5.6 MeV), (1956BE32: 7 MeV), (1956DO1D, 1958NA09: 14 MeV), (1958CO77: 14.5 MeV) and (1957KH1B: 14.8 MeV): see also (1956HU1A). Optical model effects become apparent at the higher energies; see (1956CU1A; theor.).

In the region beyond the resolved resonances, recent measurements of the total cross section have been made by (1958BR16: $E_{\rm n} = 7$ to 14 MeV), (1958CO07: $E_{\rm n} = 13.1$ to 15.6 MeV), (1958VE15, 1958VE21: $E_{\rm n} = 13.6$ to 14.75 MeV) and (1957KH1A: $E_{\rm n} = 14.8$ MeV). For a review of the earlier work, see (1955AJ61) and (1957HU1D). Non-elastic cross section measurements are reported by (1956BE32: $E_{\rm n} = 7$ MeV), (1958BA03: $E_{\rm n} = 7$ to 14 MeV), (1955TA29: $E_{\rm n} = 12.7$ and 14.1 MeV), (1955GR21, 1956FL1B, 1957ST1F: $E_{\rm n} = 14$ MeV) and (1958MA54: $E_{\rm n} = 21$, 26 and 29 MeV): see also (1947HU03, 1955MA1G, 1957ZA1A). See also (1956LA1C) and (1956KA1B; theor.).

19. (a) ^{12}C(n, n$'$)^{12}C* $E_b = 4.946$

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

In the range $E_n = 4.4$ to 8 MeV, four resonances are observed in the yield of 4.4 MeV γ-rays, at $E_n = 6.30$, 6.49, 7.6, 7.87 and 8.15 MeV, corresponding to ^{13}C*(10.76, 10.94, 12.0, 12.21, 12.47). The differential cross section at $90°$ reaches a maximum of 60 mb/sr at 7.87 MeV (1956HA1E, 1958HU18). At $E_n = 6.58$ MeV, the cross section for production of 4.4 MeV γ-rays is 353 ± 59 mb (1956DA23); at 14 MeV, it is 245 ± 35 mb (1955BA95). (1955GR21) estimate 160 mb for the inelastic cross section at $E_n = 14$ MeV to ^{12}C levels at 9.6 to ≈ 13 MeV and 100 to 300 mb as the cross section to the ^{12}C states at 4.4 and 7.6 MeV. See ^{12}C(n, n)^{12}C above, for further references on non-elastic cross sections.

Reaction (b) has been studied for $E_n = 12.3$ to 20.1 MeV. The cross section is 190 ± 50 mb at 12.9 MeV. It goes through a broad maximum of $\approx 300 \pm 60$ mb at ≈ 16.5 MeV and then decreases to 240 ± 50 mb at $E_n = 20.1$ MeV (1955FR35). See also (1955BE1D, 1955BF01, 1958VA1D), (1956SA1E; theor.) and (1955AJ61).

20. ^{12}C(n, 2n)^{11}C $Q_m = -18.722$ $E_b = 4.946$

See (1952BR61, 1958AS63).

21. ^{12}C(n, p)^{12}B $Q_m = -12.593$ $E_b = 4.946$

The cross section has been measured from threshold to $E_n = 17.5$ MeV. At $E_n = 17.5$ MeV, the cross section is 29.1 ± 4 mb (1958KR65, 1959KR1B). See also (1956KR1A, 1956KR1B).

22. ^{12}C(n, α)^{9}Be $Q_m = -5.709$ $E_b = 4.946$

See (1955GR21) and ^{9}Be.

23. ^{12}C(d, p)^{13}C $Q_m = 2.719$

$Q_0 = 2.721 \pm 0.002$ (1957VA11).

Measurements on the proton groups are summarized in Table 13.6. The level assignments were obtained by analysis of angular distributions (with deuterons of energies up to 24 MeV) in terms of direct interaction theories. A careful search with $E_d = 5$ to 8.5 MeV ($\theta = 90°$) reveals no further

Table 13.6: Levels of ^{13}C from ^{12}C(d, p)^{13}C

^{13}C* (MeV ± keV)					l_n	J^π	$\sigma(\theta)$ [e] (mb/sr)	θ_n^2 [h] (%)
(1951ST19, 1951VA1A)	(1954SP01)	(1956DO41)	(1953KH1A, 1955KH35) [a]	(1955MC75)				
0	0		0	0	1 [c]	$\frac{1}{2}^-, \frac{3}{2}^-$ [c]	26	7
3.086 ± 6	3.090 ± 10		3.107	3.09 [b]	0 [c]	$\frac{1}{2}^+$ [c]	103	25
3.686 ± 11	3.684 ± 10	$[3.681 \pm 3]$	3.699	3.68 [b]	1 [c]	$\frac{1}{2}^-, \frac{3}{2}^-$ [c]	16	2
	3.855 ± 7	$[3.851 \pm 3]$	3.869	3.84 [b]	2 [c]	$\frac{3}{2}^+, \frac{5}{2}^+$ [c]	152	10
				6.87 [b]	(0), (2) [d]	$(\leq \frac{5}{2}^+)$ [d]	36	
				7.470 ± 20			≈ 0.8	
				7.533 ± 20			9.6	
				7.641 ± 20 [f]			7.5	
				8.4 ± 300 [g]			100	
				9.500 ± 20			1.6	
				9.897 ± 20			2.2	
				10.759 ± 20			4.5	

[a] ±10 to 50 keV.
[b] Energies given for identification only.
[c] (1951RO1B, 1951RO1C, 1952BL1B, 1953CA1B, 1954FR24, 1955MC75, 1956CA1D, 1956GR37, 1957CO68).
[d] (1955MC75).
[e] (1955MC75); differential cross sections at the first maximum or in the forward direction; ±25%.
[f] $\Gamma = 70 \pm 15$ keV.
[g] $\Gamma = 1.1 \pm 0.3$ MeV.
[h] (1956EL1A, 1956GR37, 1958MC63).

proton proton groups corresponding to levels in the range 0 to 4.9 MeV with intensity greater than 0.5% of the ground state group (1954SP01). At $E_d = 14.8$ MeV, all groups show pronounced stripping distributions except that corresponding to ^{13}C*(9.50), for which the distribution is roughly isotropic. The proton spectrum exhibits a conspicuous broad structure attributed to a ^{13}C level at $E_x = 8.4$ MeV, $\Gamma = 1.1 \pm 0.3$ MeV. (It seems probable that this level is to be identified with the $D_{\frac{3}{2}}$ level of similar width observed in ^{12}C(n, n)^{12}C at $E_x = 8.33$ MeV: see Table 13.5.) Only one other level has a measurable width: $E_x = 7.64$ MeV, $\Gamma_{lab} = 70 \pm 15$ keV (compare Table 13.5) (1955MC75). It is of interest that the 7.47 and 7.53 MeV levels do not appear in ^{12}C(n, n)^{12}C (1958WI01).

Angular distributions at low energies have been studied by (1954TA1A: $E_d = 0.52$ to 0.84 MeV), by (1956JU1E, 1956JU1F, 1957JU1A: $E_d = 0.60$ to 1.45 MeV), by (1955AL1D, 1955AL1E: $E_d = 1.4$ to 2.0 MeV), by (1956BE1H, 1956MC88: $E_d = 1.86$ to 2.86 MeV for the p_0 group - on and off resonances - and $E_d = 2.74$ and 2.89 MeV for the p_1 group), by (1954HO48, 1956BO08: $E_d = 3.2$ to 4.4 MeV) and by (1956KO26, 1956VA17: $E_d = 0.26$ to 0.59 MeV). In the range $E_d = 1$ to 6 MeV, the (^{12}C + d) reactions are characterized by numerous strong, overlapping resonances (see ^{14}N); the angular distributions show evidence of both stripping and compound nucleus formation, even below 1 MeV (1956JU1E, 1956KO26, 1956VA17, 1957JU1A). From $E_d = 2$ to 6 MeV, angular distributions of the p_0 group (to $^{13}C_{g.s.}$) generally show a stripping maximum near $25°$, as expected for an $l = 1$ transfer; several of the "resonances" appear most conspicuously at the angle. The p_1-group, ^{13}C*(3.09), show even stronger stripping effects, with a pronounced forward maximum (1956BO08, 1956MC88, 1958MC63). A detailed comparison of distributions for ^{12}C(d, p)^{13}C and ^{12}C(d, n)^{13}N at $E_d = 2.68$ and 3.26 MeV indicates equality of the ground-state reduced widths (1956BE1H, 1958MC63). At $E_d = 9$ MeV, a similar comparison yields $\gamma^2(^{13}C)/\gamma^2(^{13}N) = 0.86$ (1956CA1D). See also (1955WI43).

Observed gamma rays are listed in Table 13.7. No γ-rays are observed with $E_\gamma = 3.9$ to 5.8 MeV with intensity $> 10\%$ of the 3.85 MeV γ-ray (1955BE62). An upper limit of 3% is placed on the fraction of cascade transitions from the 3.67 and 3.84 MeV levels via the 3.1 MeV level. The internal conversion coefficient of the 170 keV radiation indicates E1, though M1 is not excluded (1956MA1Q, 1956MA52). The internal pair formation coefficient for the 3.09 MeV level indicates an E1 transition (1952TH24); the angular correlation of internal pairs also indicates E1 (1954GO1E, 1956GO1K, 1958AR1B). Polarization of protons accompanying the formation of $^{13}C_{g.s.}$ and ^{13}C*(3.1) has been studied by (1956HI1B, 1958BO67, 1958HE47, 1958HI74, 1958JU39, 1958JU42). The sense of polarization is correlated with the coupling of l_n and s_n: $P = \pm$ when $j = l \mp \frac{1}{2}$ (1958HE47). See (1954CH1C, 1957SA1C; theor.). See also (1952CA1B, 1954CA1B, 1955KH31, 1956CA1H, 1957SE1C), (1957DA1C; theor.) and ^{14}N.

Table 13.7: Gamma radiation from ^{12}C(d, p)^{13}C

E_γ [a] (MeV ± keV)	E_γ [b] (MeV ± keV)	Reference
3.86 ± 20	(3.84 ± 30) [c]	(1955BE62)
3.844 ± 15		(1956MA1Q, 1956MA52)
0.1695 ± 0.4 [f]		(1956MA1Q, 1956MA52)
(3.76 ± 20) [c]	3.74 ± 30	(1955BE62)
(3.69 ± 20) [c]	3.675 ± 15 [d]	(1956MA1Q, 1956MA52)
(3.097 ± 5) [e]	3.082 ± 7	(1952TH24)

[a] Uncorrected for Doppler shift.

[b] Corrected for Doppler shift.

[c] Doppler shift correction is not required for the 3.86 MeV radiation, but is required for the 3.67 MeV radiation (1956MA1Q, 1956MA52): see ^{10}B(α, p)^{13}C.

[d] Value obtained by subtraction: $3.844 - 0.170$ (1956MA1Q, 1956MA52).

[e] Doppler shift required (1952TH24).

[f] From the proton groups $\Delta E = 170 \pm 3$ keV (1954SP01) and 170 ± 1.5 keV (1956DO41).

24. ^{12}C(t, d)^{13}C $\qquad Q_{\rm m} = -1.313$

Not reported.

25. ^{12}C(α, ^{3}He)^{13}C $\qquad Q_{\rm m} = -15.632$

Not reported.

26. ^{13}C(γ, n)^{12}C $\qquad Q_{\rm m} = -4.946$

The cross section for neutron production has been determined to 38 MeV. The (γ, n) cross section exhibits two peaks at 13.3 ± 1 MeV ($\Gamma = 5 \pm 1$ MeV, $\sigma = 3.3$ mb) and at ≈ 22 MeV ($\sigma \approx 6$ mb, $\Gamma \approx 7$ MeV). The total absorption cross section, $\sigma(\gamma,\ x{\rm n}) + \sigma(\gamma,\ {\rm p})$ shows maxima at $E_\gamma = 13.5$ and 25 MeV. The lower resonance is much too large to be explained on a single-particle model (1957CO57). Se also (1949SE1B, 1953GO13, 1956CO72).

27. ^{13}C(γ, p)^{12}B $\qquad Q_{\rm m} = -17.539$

The yield of β-particles from the ^{12}B decay has been determined to 45 MeV. The cross section shows a broad maximum of 8.8 mb near 25.5 MeV (1956CO72, 1957CO57).

28. ^{13}C(γ, α)^{9}Be $\qquad Q_{\rm m} = -10.654$

See (1953MI31).

29. ^{13}C(p, p$'$)^{13}C*

Angular distributions of the 3.09 MeV γ-rays are isotropic for $E_{\rm p} = 3.7$ to 4.2 MeV, consistent with the assignment $J = \frac{1}{2}$ to ^{13}C*(3.09). Angular distributions of the 3.68 MeV radiation have also been studied near the $E_{\rm p} = 4.5$ MeV resonance (1957BA29). See also (1952CO1C).

30. ^{13}N(β^+)^{13}C $\qquad Q_{\rm m} = 2.222$

See ^{13}N.

31. ^{14}C(p, d)^{13}C $\quad Q_{\mathrm{m}} = -5.947$

Not reported.

32. ^{14}C(d, t)^{13}C $\quad Q_{\mathrm{m}} = -1.915$

At $E_{\mathrm{d}} = 14.8$ MeV, triton groups have been observed leading to the ^{13}C states at 0, 3.09, 3.68 and 3.85 MeV (1958MO97). See ^{14}C.

33. ^{14}C(^{3}He, α)^{13}C $\quad Q_{\mathrm{m}} = 12.404$

Not reported.

34. ^{14}N(n, d)^{13}C $\quad Q_{\mathrm{m}} = -5.319$

At 14 MeV, deuteron groups to the 0 and 3.68 MeV (but not to the 3.09 and 3.84 MeV) states of ^{13}C have been observed (1957CA07). See also (1952LI24) and ^{14}N.

35. ^{14}N(p, 2p)^{13}C $\quad Q_{\mathrm{m}} = -7.546$

At $E_{\mathrm{p}} = 185$ MeV, the summed proton spectrum shows two peaks, corresponding to ejection of $\mathrm{p}_{1/2}$ and $\mathrm{p}_{3/2}$ protons, with binding energies of ≈ 7 and ≈ 15 MeV, ^{13}C* $= 0$ and ≈ 8 MeV (1958MA1B, 1958TY49).

36. ^{14}N(d, ^{3}He)^{13}C $\quad Q_{\mathrm{m}} = -2.052$

Not reported.

37. ^{14}N(t, α)^{13}C $\quad Q_{\mathrm{m}} = 12.267$

Table 13.8: ^{13}C states from ^{15}N(d, α)^{13}C

(1951MA08)	(1957WA01)	
^{13}C* (MeV $\pm$ keV)	^{13}C* (MeV $\pm$ keV) [a]	dσ/dΩ ($\theta_{\rm lab} = 12.6°$) (mb/sr)
0	0	0.85 ± 0.09
3.083 ± 5	3.09	0.18 ± 0.03
3.677 ± 5	3.68	2.4 ± 0.3
	3.85	< 0.3
	6.87	1.3 ± 0.2 [c]
	7.47, 7.53, 7.64 [b]	1.1 ± 0.2
	8.80 ± 40	0.56 ± 0.11
	9.5	0.15 ± 0.04
	9.9	0.26 ± 0.06

[a] Level energies for identification purposes only except for ^{13}C*(8.80).
[b] Not resolved.
[c] Measured at $\theta = 18°$.

This reaction has been observed at $E_{\rm t} = 1.9$ MeV (1958JA06).

38. ^{15}N(n, t)^{13}C $\qquad Q_{\rm m} = -9.903$

Not reported.

39. ^{15}N(p, ^{3}He)^{13}C $\qquad Q_{\rm m} = -10.668$

Not reported.

40. ^{15}N(d, α)^{13}C $\qquad Q_{\rm m} = 7.683$

Observed alpha particle groups are displayed in Table 13.8 (1951MA08, 1957WA01). The broad level at 8.4 MeV observed in ^{12}C(d, p)^{13}C does not appear in the present reaction; it is suggested that the direct (d, α) transition is forbidden by the nature of the configurations involved

(1957WA01). The angular distribution of the ground-state alpha particles at $E_d = 21$ MeV shows a maximum at $70°$ (c.m.) (1958FI27).

41. ^{16}O(n, α)^{13}C $\qquad Q_m = -2.203$

See (1951HU1A, 1952LI24) and ^{17}O.

^{13}N
(Fig. 24)

GENERAL:

Theory: See (1955LA1A, 1956DA1G, 1958FR1C, 1958HA1D, 1958SK1A).

1. ^{13}N(β^+)^{13}C $\qquad Q_m = 2.222$

Recent determinations of the half-life give 10.05 ± 0.03 min (1953CH34), 10.08 ± 0.04 min (1955WI43), 10.07 ± 0.06 min (1957NO17), 9.96 ± 0.03 min (1958AR15), 9.96 ± 0.03 min (1958DA09); see also (1957DE22). E_β(max) $= 1.202 \pm 0.005$ MeV (1950HO01), 1.185 ± 0.025 MeV (1954GR66), 1.190 ± 0.003 MeV (1958DA09). The positron spectrum shows no deviation from the allowed shape; it is concluded that the Fierz coefficient in the Fermi interaction is $< 11\%$. Log $ft = 3.66$ (1957DA08, 1958DA09). The positron polarization has been studied by (1957BO65, 1957HA27). The results indicate that the positrons are completely polarized and hence that Fermi transitions as well as G-T transitions exhibit the maximum effect of parity nonconservation.

2. ^{9}Be(^{6}Li, 2n)^{13}N $\qquad Q_m = 3.952$

See (1957NO17).

3. ^{10}B(^{3}He, n)^{12}N $\qquad Q_m = 1.46 \qquad E_b = 21.642$

At $E(^3\text{He}) = 2.54$ MeV, the cross section for formation of the ground state is $5.2^{+2.1}_{-1.6}$ mb. At $E(^3\text{He}) = 3.60$ MeV, the differential cross section for formation of the ground state at $\theta = 0°$ is 0.73 ± 0.30 mb/sr (1957AJ71).

Table 13.9: Energy levels of ^{13}N

E_x (MeV $\pm$ keV)	J^π	$\tau_{1/2}$ or Γ (keV)	Decay	Reactions
0	$(\frac{1}{2})^-$	$\tau_{1/2} = 10.02 \pm 0.02$ min	β^+	1, 2, 7, 9, 15, 16, 18, 19, 20, 21, 22
2.365 ± 3	$\frac{1}{2}^+$	$\Gamma = 32 \pm 2$	p, γ	7, 9, 12, 15, 22
3.507 ± 7	$\frac{3}{2}^-$	63 ± 6	p, γ	7, 9, 12, 15, 22
3.555 ± 10	$\frac{5}{2}^+$	61	p	12, 15, 22
6.379 ± 10	$\frac{5}{2}^+$	11	p	12
6.908 ± 10	$\frac{3}{2}^+$	115	p	12
7.415 ± 10	$(\frac{5}{2}^+)$	≈ 85	p	12
(8.08)	$(\frac{3}{2}^+)$	(350)	p	12
22.7 ± 300		≈ 1400	p	12
23.2		400	p, ^{3}He	4
24.5		550	p, ^{3}He	4
24.8		90	p, ^{3}He	4
25.2		120	p, ^{3}He	4

4. ^{10}B(^{3}He, p)^{12}C $\quad Q_m = 19.702 \quad E_b = 21.642$

The yields of the protons to the ground and 4.4 MeV excited states of ^{12}C have been measured for $E(^3\text{He}) = 1.3$ to 5 MeV. Resonances are observed at 2.0, 3.7, 4.1 and 4.6 MeV, with widths of 0.5, 0.7, 0.12 and 0.15 MeV, respectively, corresponding to ^{13}N*(23.2, 24.5, 24.8, 25.2). Angular distributions taken at six energies in the above range tend to be more asymmetric at the higher energies (1956SC01). See also (1956JO1B).

5. ^{10}B(^{3}He, d)^{11}C $\quad Q_m = 3.206 \quad E_b = 21.642$

See ^{11}C.

6. ^{10}B(^{3}He, α)^{9}B $\quad Q_m = 12.139 \quad E_b = 21.642$

See ^{9}B.

Table 13.10: Resonances in ^{12}C(p, γ)^{13}N

E_p (keV)	Γ_{lab} (keV)	σ_{res} (mb)	$\omega\Gamma_\gamma$ (eV)	^{13}N* (MeV)	References
456.8 ± 0.5	39.5 ± 1.0			2.363	(1953HU18)
456 ± 2	35				(1949FO18)
450	35	127	0.67		(1951SE1B, 1951SE67)
1697 ± 12	74 ± 9			3.507	(1949VA1A)
1698 ± 5	70 ± 10	35	1.39		(1951SE1B, 1951SE67)

7. ^{10}B(α, n)^{13}N $\qquad Q_m = 1.065$

Measurements at $E_\alpha = 8$ MeV with a proton recoil telescope and a neutron threshold detector are reported to indicate ^{13}N states at $2.4{\pm}0.3$, $3.6{\pm}0.3$, $(4.3{\pm}0.3)$ and $5.0{\pm}0.3$ MeV (1956QU1A). See also (1957BA1K) and ^{14}N.

8. ^{11}B(^{3}He, n)^{13}N $\qquad Q_m = 10.179$

Not reported.

9. (a) ^{12}C(p, γ)^{13}N $\qquad Q_m = 1.941$
(b) ^{12}C(p, γp$'$)^{12}C

Two resonances for capture radiation are reported, at $E_p = 0.46$ and 1.70 MeV (Table 13.10). The resonance at $E_p = 1.75$ MeV observed in ^{12}C(p, p)^{12}C does not appear in the γ-excitation curve (1951SE67). The displacement of the lower level (^{13}N*(2.37), $J = \frac{1}{2}^+$) from its mirror in ^{13}C*(3.09) is ascribed to the large reduced width (1951EH1A, 1952TH1D). The angular distribution of the ground-state radiation from the upper resonance (^{13}N*(3.51), $J = \frac{3}{2}^-$) has the form $W(\theta) = 1 - 0.52\cos^2\theta$ (1951DA1A, 1951DA1B).

The capture cross section at low energy is of interest in connection with stellar energy generation. Measurements have been reported in the range $E_p = 80$ to 360 keV by (1950BA89, 1950HA78, 1957DE22, 1957LA15). At 80 keV, $\sigma = (1.4 \pm 0.4) \times 10^{-5}$ μb; from 80 to 126 keV, the course of the cross section is reasonably well accounted for by extrapolation of the $E_p = 0.46$ MeV resonance (1957LA15: see also (1957DE22)).

From $E_p = 5$ to 11 MeV, the cross section for formation of ^{13}N changes only from 2.5 to 1.8 mb; this small change strongly indicates the predominance of direct capture in this region

(1955CO57). According to (1956RE39), however, the 90° differential cross section for formation of ^{13}N is < 1 μb/sr at $E_p = 4.8$ MeV. See also (1956CH1D).

In the range $E_p = 1.2$ to 2.5 MeV, reaction (b) is observed, involving a γ-transition to the 2.37 MeV state. Excitation functions at $\theta = 0^\circ$ and 90° indicate interference between p-wave resonant capture at $E_p = 1.70$ MeV, with $\Gamma_\gamma = 0.04$ eV, and direct p-wave capture (1954WO09). The angular distributions at $E_p = 1.37$ and 1.58 MeV have the form $W(\theta) = (0.02 \pm 0.02) + \sin^2\theta$ (1955HE1F).

10. ^{12}C(p, n)^{12}N $\quad Q_m = -18.24 \quad E_b = 1.941$

See (1957ST1D, 1958TA03) and ^{12}N.

11. ^{12}C(p, pn)^{11}C $\quad Q_m = -18.722 \quad E_b = 1.941$

See (1947CH1A, 1948MC1A, 1958WH34).

12. (a) ^{12}C(p, p)^{12}C $\quad E_b = 1.941$
(b) ^{12}C(p, p′)^{12}C*

Elastic scattering studies indicate a number of pronounced resonances in the range $E_p = 0$ to 6 MeV: see Table 13.11. The first five excited states correspond in character and approximately in reduced width to those of ^{13}C: see ^{12}C(d, p)^{13}C and ^{12}C(n, n)^{12}C. The relatively large reduced widths of the first and third ($s_{1/2}$ and $d_{5/2}$) excited states indicate a single-particle character (1953JA1B). The small and roughly equal widths of ^{13}N*(6.4, 6.9) suggest that they may comprise a doublet, built upon ^{12}C*(4.4) + p (1956RE39: see also (1953BL1A, 1953MA1D, 1956SC29)). Angular distribution measurements above $E_p = 10$ MeV generally show direct interaction effects: see ^{12}C. Some form of resonance structure may exist near 23 MeV (1955KI43). See also (1956KL55).

The yields of 4.4 MeV gamma rays and inelastic protons from ^{12}C*(4.4) show resonances at $E_p = 5.39$ and 5.93 MeV (1953MA1D, 1956BR27, 1957LI1B). Angular distributions of inelastic protons at $E_p = 6.1$ to 6.9 MeV do not fit direct interaction theory and suggest the effects of still higher compound nucleus levels (1956BR27).

Polarization studies for $E_p < 6$ MeV are reported by (1956GA66, 1956SO1C, 1958WA1D): see also ^{12}C. See also (1955DE50, 1956ER1A, 1956NI1B, 1957GL58; theor.) and (1957GO1D).

13. ^{12}C(p, d)^{11}C $\quad Q_m = -16.495 \quad E_b = 1.941$

Table 13.11: ^{13}N levels from ^{12}C(p, p)^{12}C and ^{12}C(p, p′)^{12}C*

$E_{\rm res}$ (MeV ± keV)	^{13}N* (MeV)	$\Gamma_{\rm c.m.}$ (keV)	$l_{\rm p}$	J^π	$\theta^2_{\rm p}$
0.461 ± 3 [a]	2.367	31	0	$\frac{1}{2}^+$	0.54
1.698 [b]	3.508	55	1	$\frac{3}{2}^-$	0.031
1.748 [b]	3.555	61	2	$\frac{5}{2}^+$	0.21
4.808 [c]	6.379	11	2	$\frac{5}{2}^+$	0.0031
(5.05) [e]		(75)	(0)	$(\frac{1}{2}^+)$	(0.014)
5.381 ± 7 [d]	6.908	115	2	$\frac{3}{2}^+$	0.012
5.930 ± 7 [f]	7.415	≈ 85	2	$\frac{5}{2}^+$	
6.65 [g]	(8.08)	(350)	(2)	$(\frac{3}{2}^+)$	(0.11)

[a] (1953JA1B). (1954MI05) finds $E_{\rm res} = 0.462$ MeV, $\Gamma = 32$ keV.
[b] (1953JA1B).
[c] (1956RE39).
[d] (1956RE39): parameters estimated from elastic scattering; $\theta^2_{\rm p'} = 0.2$. $E_{\rm res}$ from ^{12}C(p, p′)^{12}C* (1957LI1B). See also (1956SC29).
[e] (1956SC29): $E_{\rm p} = 4.8$ MeV, $J = \frac{5}{2}^+$ level not observed.
[f] ^{12}C(p, p′)^{12}C* (1957LI1B). (1956BR27) finds $E_{\rm res} = 5.891$ MeV, $\Gamma_{\rm lab} = 59$ keV. See also (1956SC29).
[g] (1956SC29). See, however, (1956BR27).

See ^{11}C.

14. ^{12}C(p, α)^{9}B $\qquad Q_{\rm m} = -7.563 \qquad E_{\rm b} = 1.941$

See ^{9}B.

15. ^{12}C(d, n)^{13}N $\qquad Q_{\rm m} = -0.286$

Neutron groups have been observed corresponding to excited states of ^{13}N at 2.29 ± 0.12 (1949GR1A), 2.38 ± 0.05 MeV (1953MI10) and 3.48 ± 0.12 (1949GR1A), 3.74 ± 0.05 (1957GR1A), 3.53 ± 0.05 MeV (1953MI10). The angular distributions of the ground state group and the groups corresponding to the 2.37 and (3.51 ± 3.56) MeV states at $E_{\rm d} = 9.0$ MeV are consistent with $l_{\rm p} = 1$, 0 and 2. The dimensionless reduced widths of the ground and (3.56) MeV states are respectively 0.056 and 0.19 (1957CA02: see also (1953MI10)). (1958MC63) finds that the reduced widths of the ground states of ^{13}C and ^{13}N are the same, 0.09 ± 0.035 (see also (1956BE1H, 1956CA1D, 1958KA16) and ^{12}C(d, p)^{13}C). In the range $E_d = 2.8$ to 3.7 MeV, a single neutron threshold is observed, at $E_d = 3.09 \pm 0.02$ MeV, corresponding to ^{13}N*(2.36 ± 0.02); the slow rise above threshold is attributed to p-wave neutron emission (1955MA76).

Polarization of neutrons has been studied for $E_d = 2.5$ to 3.6 MeV by (1957HA1J). See also (1956BO1F, 1956BO43, 1956DE1D).

16. ^{12}C(^{3}He, d)^{13}N $\quad Q_m = -3.553$

See (1952FR1A, 1958WE1E).

17. ^{12}C(α, t)^{13}N $\quad Q_m = -17.872$

Not reported.

18. ^{13}C(p, n)^{13}N $\quad Q_m = -3.005$

$E_{thresh.} = 3.2372 \pm 0.0016$ (1958BO76).

See also (1950RI59, 1955MA84, 1958BI1B) and ^{14}N.

19. ^{13}C(^{3}He, t)^{13}N $\quad Q_m = -2.240$

See (1952FR1A).

20. ^{14}N(γ, n)^{13}N $\quad Q_m = -10.551$

See ^{14}N.

21. ^{14}N(p, d)^{13}N $\quad Q_m = -8.324$

See ^{14}N.

22. ^{14}N(d, t)^{13}N $\qquad Q_{\rm m} = -4.292$

At $E_{\rm d} = 14.8$ MeV, triton groups are observed corresponding to the states at 0, 2.37 and (3.51 ± 3.56) MeV. The cross section for the transition to the 2.37 MeV state is two orders of magnitude smaller than that for the ground state transition. Transitions to ^{13}N*(2.37, 3.56) are shell-model forbidden (1957WA01).

23. ^{14}N(^{3}He, α)^{13}N $\qquad Q_{\rm m} = 10.027$

Not reported.

24. ^{15}N(p, t)^{13}N $\qquad Q_{\rm m} = -12.908$

Not reported.

25. ^{16}O(p, α)^{13}N $\qquad Q_{\rm m} = -5.208$

See (1958WH34).

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.

1947CH1A W.W. Chupp and E.M. McMillan, Phys. Rev. 72 (1947) 873

1947HU03 D.J. Hughes, C. Eggler and C.M. Huddleston, Phys. Rev. 71 (1947) 269

1948MC1A E.M. McMillan and R.D. Miller, Phys. Rev. 73 (1948) 80

1948SN1A Snell, Science 108 (1948) 167

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

1949GR1A J.C. Grosskreutz, Phys. Rev. 76 (1949) 482

1949HU41 E.L. Hudspeth and C.P. Swann, Phys. Rev. 76 (1949) 1150

1949SE1B Sexl, Acta Phys. Aust. 2 (1949) 377

1949VA1A Van Patter, Phys. Rev. 76 (1949) 1264

1950BA89 C.L. Bailey and W.R. Stratton, Phys. Rev. 77 (1950) 194

1950FR61 G. Freier, M. Fulk, E.E. Lampi and J.H. Williams, Phys. Rev. 78 (1950) 508

1950HA78 R.N. Hall and W.A. Fowler, Phys. Rev. 77 (1950) 197

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

1950MI1A D.W. Miller, Phys. Rev. 78 (1950) 806

1950RI1B Ricamo, Zunti, Baldinger and Huber, Helv. Phys. Acta 23 (1950) 508

1950RI59 H.T. Richards, R.V. Smith and C.P. Browne, Phys. Rev. 80 (1950) 524

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

1951DA1A R.B. Day and J.E. Perry Jr., Phys. Rev. 81 (1951) 662; J14

1951DA1B Day, Ph.D. Thesis, C.I.T. (1951)

1951EH1A J.B. Ehrman, Phys. Rev. 81 (1951) 412

1951HU1A Huber, Baldinger and Proctor, Helv. Phys. Acta 24 (1951) 302

1951MA08 R. Malm and W.W. Buechner, Phys. Rev. 81 (1951) 519

1951RI1A Ricamo and Zunti, Helv. Phys. Acta 24 (1951) 419

1951RI1B Ricamo, Nuovo Cim. 8 (1951) 893

1951RO1B Rotblat, Nature 167 (1951) 1027

1951RO1C J. Rotblat, Phys. Rev. 83 (1951) 1271

1951SE1B Seagrave, Ph.D. Thesis, C.I.T. (1951)

1951SE67 J.D. Seagrave, Phys. Rev. 84 (1951) 1219

1951ST19 E.N. Strait, D.M. Van Patter, W.W. Buechner and A. Sperduto, Phys. Rev. 81 (1951) 747

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

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

1952BL1B Black, Phys. Rev. 87 (1952) 205; L7

1952BR61 J.E. Brolley Jr., J.L. Fowler and L.K. Schlacks, Phys. Rev. 88 (1952) 618

1952CA1B Catala, Senent and Aguilar, An. Real. Soc. Espan. Fis. y Quim. A48 (1952) 73; Phys. Abs. 57 (1954) 1709

1952CO1C D.B. Cowie, N.P. Heydenburg and G.C. Phillips, Phys. Rev. 87 (1952) 304

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

1952LI24 A.B. Lillie, Phys. Rev. 87 (1952) 716

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

1952TH1D R.G. Thomas, Phys. Rev. 88 (1952) 1109

1952TH24 R.G. Thomas and T. Lauritsen, Phys. Rev. 88 (1952) 969

1953BA18 G.A. Bartholomew and B.B. Kinsey, Can. J. Phys. 31 (1953) 49

1953BL1A Bleuler, Helv. Phys. Acta 26 (1953) 597

1953CA1B Catala, Senent and Casanova, An. Real. Soc. Espan. Fis. y Quim. A49 (1953) 91; Nucl. Sci. Abs. (1953)

1953CH34 J.L.W. Churchill, W.M. Jones and S.E. Hunt, Nature 172 (1953) 460

1953GO13 F.K. Goward and J.J. Wilkins, Proc. Roy. Soc. A217 (1953) 357

1953HU18 S.E. Hunt and W.M. Jones, Phys. Rev. 89 (1953) 1283

1953HU1C E.L. Hubbard, L. Ruby and W.F. Stubbins, Phys. Rev. 92 (1953) 1494

1953JA1B Jackson and Galonsky, Phys. Rev. 89 (1953) 370

1953KH1A Khromchenko, Dokl. Akad. Nauk. SSSR 93 (1953) 451

1953MA1D Martin, Schneider and Sempert, Helv. Phys. Acta 26 (1953) 595

1953MI10 R. Middleton, F.A. El Bedewi and C.T. Tai, Proc. Phys. Soc. (London) A66 (1953) 95

1953MI31 C.H. Millar and A.G.W. Cameron, Can. J. Phys. 31 (1953) 723

1953NE01 N. Nereson and S. Darden, Phys. Rev. 89 (1953) 775

1953SH64 E.S. Shire, J.R. Wormald, G. Lindsay-Jones, A. Lundan and A.G. Stanley, Phil. Mag. 44 (1953) 1197

1953TA06 F.L. Talbott and N.P. Heydenburg, Phys. Rev. 90 (1953) 186

1954BE08 W.E. Bennett, P.A. Roys and B.J. Toppel, Phys. Rev. 93 (1954) 924, K4

1954BU06 W.H. Burke, J.R. Risser and G.C. Phillips, Phys. Rev. 93 (1954) 188

1954CA1B Catala and Senent, An. Real. Soc. Espan. Fis. y Quim. A50 (1954) 55

1954CH1C W.B. Cheston, Phys. Rev. 96 (1954) 1590

1954FA1A Fader and Sperduto, Phys. Rev. 94 (1954) 748; C8

1954FA1B Fader, M.I.T. Prog. Rept. (May, 1954)

1954FR24 R.G. Freemantle, W.M. Gibson and J. Rotblat, Phil. Mag. 45 (1954) 1200

1954GO1E Gorodetzky, Armbruster, Chevallier and Gallmann, Compt. Rend. 239 (1954) 1623

1954GR66 T. Grabowski and L. Natanson, Bull. Acad. Pol. Sci. 2 (1954) 379

1954HO48 H.D. Holmgren, J.M. Blair, B.E. Simmons, T.F. Stratton and R.V. Stuart, Phys. Rev. 95 (1954) 1544

1954HU1A Huber and Budde, Helv. Phys. Acta 27 (1954) 512

1954ME95 R.W. Meier, P. Scherrer and G. Trumpy, Helv. Phys. Acta 27 (1954) 577

1954MI05 E.A. Milne, Phys. Rev. 93 (1954) 762

1954SP01 A. Sperduto, W.W. Buechner, C.K. Bockelman and C.P. Browne, Phys. Rev. 96 (1954) 1316

1954ST20 A.G. Stanley, Phil. Mag. 45 (1954) 430

1954TA1A Takemoto, Dazai, Chiba, Ito, Suganomata and Watanabe, J. Phys. Soc. Jpn. 9 (1954) 447

1954TR09 R.E. Trumble Jr., Phys. Rev. 94 (1954) 748A

1954WO09 H.H. Woodbury, A.V. Tollestrup and R.B. Day, Phys. Rev. 93 (1954) 1311

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

1955AL1D Alba, Fernandez, Mazari, Serment and Vazquez, Rev. Mex. Fis. 4 (1955) 207

1955AL1E Alba, Brody, Fernandez, Mazari, Serment and Vazquez, An. del Inst. Fis., Univ. Nacional. Autonoma de Mexico 1 (1955) 1

1955AU1A T. Auerbach and J.B. French, Phys. Rev. 98 (1955) 1276

1955BA95 M.E. Battat and E.R. Graves, Phys. Rev. 97 (1955) 1266

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

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

1955BF01 J.R. Beyster, R.L. Henkel, R.A. Nobles and J.M. Kister, Phys. Rev. 98 (1955) 1216

1955BI26 C.B. Bigham, K.W. Allen and E. Almqvist, Phys. Rev. 99 (1955) 631A

1955BR1A R.J. Breen and M.R. Hertz, Phys. Rev. 98 (1955) 599

1955BU56 R. Budde and P. Huber, Helv. Phys. Acta 28 (1955) 49

1955CO57 B.L. Cohen, Phys. Rev. 100 (1955) 206

1955DE50 P.S. de Toledo and S. Watanabe, An. Acad. Brasil. Cienc. 27 (1955) 471; Phys. Abs. 644 (1959)

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

1955GR21 E.R. Graves and R.W. Davis, Phys. Rev. 97 (1955) 1205

1955HE1F Heiberg, James and Alexander, Can. J. Phys. 33 (1955) 34

1955JE27 B. Jennings, J. Weddell, I. Alexeff and R.L. Hellens, Phys. Rev. 98 (1955) 582

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

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

1955KI43 B.B. Kinsey, Phys. Rev. 99 (1955) 332

1955LA1A Lane, Proc. Phys. Soc. (London) A68 (1955) 197

1955LI50 R.N. Little, B.P. Leonard, J.T. Prud'homme and L. D. Vincent, Phys. Rev. 98 (1955) 634

1955MA1G MacGregor, Ball and Booth, Phys. Rev. 100 (1955) 1793A

1955MA1J L. Madansky and G.E. Owen, Phys. Rev. 99 (1955) 1608

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

1955MC75 J.N. McGruer, E.K. Warburton and R.S. Bender, Phys. Rev. 100 (1955) 235

1955RI1B Risser, Price and Class, Phys. Rev. 98 (1955) 1183, RA3

1955TA28 N.W. Tanner, Proc. Phys. Soc. (London) A68 (1955) 1195

1955TA29 H.L. Taylor, O. Lonsjo and T.W. Bonner, Phys. Rev. 100 (1955) 174

1955WA1A Wapstra, Physica 21 (1955) 367

1955WA27 M. Walt and J.R. Beyster, Phys. Rev. 98 (1955) 677

1955WA30 A. Ward and P.J. Grant, Proc. Phys. Soc. (London) A68 (1955) 637

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

1955WI43 D.H. Wilkinson, Phys. Rev. 100 (1955) 32

1956AL1F S.K. Allison, P.G. Murphy and E. Norbeck, Phys. Rev. 102 (1956) 1182

1956BE1H R.E. Benenson, K.W. Jones and M.T. McEllistrem, Phys. Rev. 101 (1956) 308

1956BE32 J.R. Beyster, M. Walt and E.W. Salmi, Phys. Rev. 104 (1956) 1319

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

1956BO08 T.W. Bonner, J.T. Eisinger, A.A. Kraus Jr. and J.B. Marion, Phys. Rev. 101 (1956) 209

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

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

1956BO61 T.W. Bonner, A.A. Kraus Jr., J.B. Marion and J.P. Schiffer, Phys. Rev. 102 (1956) 1348

1956BR27 C.P. Browne and J.R. Lamarsh, Phys. Rev. 104 (1956) 1099

1956BR99 R.M. Brugger, J.E. Evans, E.G. Joki and R.S. Shankland, Phys. Rev. 104 (1956) 1054

1956CA1D Calvert, Jaffe and Maslin, Phys. Rev. 101 (1956) 501

1956CA1H Catala, Villar, Bonett and Miralles, An. Real. Soc. Espan. Fis. y Quim. A52 (1956) 85

1956CH1D Chick, Evans, Hancock, Hunt and Pope, Proc. Phys. Soc. (London) A69 (1956) 624

1956CO72 B.C. Cook, A.S. Penfold and V.L. Telegdi, Phys. Rev. 104 (1956) 554

1956CU1A G. Culler, S. Fernbach and N. Sherman, Phys. Rev. 101 (1956) 1047

1956DA1G Davidson and Giambiagi, Centro Brasil. Pesquisas Fis., Notas Fis. Vol. II, No. 12 (1956)

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

1956DE1C De Saussure and Guth, Bull. Amer. Phys. Soc. 1 (1956) 21

1956DE1D De Pangher, HW-47284 (1956)

1956DO1D Dolan, Fincher, Kenny, Berko and Whitehead, Bull. Amer. Phys. Soc. 1 (1956) 339

1956DO41 R.A. Douglas, J.W. Broer, R. Chiba, D.F. Herring and E.A. Silverstein, Phys. Rev. 104 (1956) 1059

1956EL1A El-Bedewi, Proc. Phys. Soc. (London) A69 (1956) 221

1956ER1A T. Eriksson, Nucl. Phys. 2 (1956) 91

1956FL1B Flerov and Talyzin, Sov. J. Nucl. Energy 4 (1956) 617

1956GA66 B.V. Gavrilovskii, V.Y. Golovnya, K.V. Karadzhev, A.P. Kliucharev and V.I. Manko, Dokl. Akad. Nauk SSSR 111 (1956) 59; Sov. Phys. Dokl. 1 (1957) 611

1956GO1K Gorodetzky, Armbruster, Chevallier and Gallmann, J. Phys. Rad. 17 (1956) 548

1956GR37 T.S. Green and R. Middleton, Proc. Phys. Soc. (London) A69 (1956) 28

1956HA1E Hall and Bonner, Bull. Amer. Phys. Soc. 1 (1956) 96

1956HI1B P. Hillman, Phys. Rev. 104 (1956) 176

1956HU1A Hughes and Carter, BNL-400 (1956)

1956JA28 D.B. James, G.A. Jones and D.H. Wilkinson, Phil. Mag. 1 (1956) 949

1956JO1B Johnston and Holmgren, Bull. Amer. Phys. Soc. 1 (1956) 134

1956JU1E Juric, Physica 22 (1956) 1154A

1956JU1F Juric, Bull. Inst. Nucl. Sci. Boris Kidrich 6 (1956) 35

1956KA1B Kalos and Goldstein, NDA 12-16 (1956)

1956KL55 A.P. Kliucharev, L.I. Bolotin and V.A. Lutsik, Zh. Eksp. Teor. Fiz. 30 (1956) 573; JETP (Sov. Phys.) 3 (1956) 463

1956KO26 B. Koudijs, Ph.D. Thesis, Univ. of Utrecht (1956)

1956KR1A Kreger, Bolotin and Edelsack, USNRDL TR 81 (1956)

1956KR1B Kreger, Bolotin and Edelsack, Bull. Amer. Phys. Soc. 1 (1956) 325

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

1956LA1C Langsdorf, Lane and Monahan, ANL 5567 (1956)

1956MA1Q R.J. Mackin, Jr., W.R. Mills, Jr. and J. Thirion, J. Phys. Rad. 17 (1956) 551

1956MA52 R.J. Mackin, Jr., W.R. Mills, Jr. and J. Thirion, Phys. Rev. 102 (1956) 802

1956MC70 B.M. McCormac, M.F. Steuer, C.D. Bond and F.L. Hereford, Phys. Rev. 104 (1956) 718

1956MC88 M.T. McEllistrem, K.W. Jones, R. Chiba, R.A. Douglas, D.F. Herring and E.A. Silverstein, Phys. Rev. 104 (1956) 1008

1956MU96 C.O. Muehlhause, S.D. Bloom, H.E. Wegner and G.N. Glasoe, Phys. Rev. 103 (1956) 720

1956NI1B Nishimura and Ruderman, Bull. Amer. Phys. Soc. 1 (1956) 383

1956NO1A Norbeck, Bull. Amer. Phys. Soc. 1 (1956) 329

1956PA1B Papkow, Z. Naturforsch. A11 (1956) 776

1956PA23 E.B. Paul, Physica 22 (1956) 1140A

1956PI1A G.F. Pieper and G.S. Stanford, Phys. Rev. 101 (1956) 672

1956QU1A A.R. Quinton and W.T. Doyle, Phys. Rev. 101 (1956) 669

1956RE39 C.W. Reich, G.C. Phillips and J.L. Russell Jr., Phys. Rev. 104 (1956) 143

1956SA1E Sachs, Phys. Rev. 103 (1956) 671

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

1956SC29 H. Schneider, Helv. Phys. Acta 29 (1956) 55

1956SO1C Sorokin and Taranov, Dokl. Akad. Nauk SSSR 111 (1956) 82

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

1957AJ71 F. Ajzenberg-Selove, M.L. Bullock and E. Almqvist, Phys. Rev. 108 (1957) 1284

1957AM48 O. Ames, G.E. Owen and C.D. Swartz, Phys. Rev. 106 (1957) 775

1957BA1H Barker, Phil. Mag. 2 (1957) 780

1957BA1K Barker and Mann, Phil. Mag. 2 (1957) 5

1957BA29 J.K. Bair, H.O. Cohn and H.B. Willard, ORNL-2430 (1957) 26

1957BO13 R.O. Bondelid, K.L. Dunning and F.L. Talbott, Phys. Rev. 105 (1957) 193

1957BO65 F. Boehm, T.B. Novey, C.A. Barnes and B. Stech, Phys. Rev. 108 (1957) 1497

1957CA02 J.M. Calvert, A.A. Jaffe and E.E. Maslin, Proc. Phys. Soc. (London) A70 (1957) 78

1957CA07 R.R. Carlson, Phys. Rev. 107 (1957) 1094

1957CO57 B.C. Cook, Phys. Rev. 106 (1957) 300

1957CO68 H.E. Conzett and D.G. Hoffman, Bull. Amer. Phys. Soc. 2 (1957) 382, J10

1957DA08 H. Daniel and U. Schmidt-Rohr, Z. Naturforsch. A12 (1957) 750

1957DA1C Dabrowski and Tulczyjew, Acta Phys. Pol. 16 (1957) 231

1957DE22 A.S. Deineko, A.I. Taranov and A.K. Valter, Zh. Eksp. Teor. Fiz. 32 (1957) 251; JETP (Sov. Phys.) 5 (1957) 201

1957GA01 A. Galonsky, C.D. Moak, R.L. Traughber and C.M. Jones, Bull. Amer. Phys. Soc. 2 (1957) 51, RA1

1957GL58 A.E. Glassgold and P.J. Kellogg, Phys. Rev. 107 (1957) 1372

1957GO1D Gooding, Bull. Amer. Phys. Soc. 2 (1957) 350

1957GR1A Grismore and Parkinson, Rev. Sci. Instrum. 28 (1957) 245

1957HA1J Haeberli and Rolland, Bull. Amer. Phys. Soc. 2 (1957) 234

1957HA27 S.S. Hanna and R.S. Preston, Phys. Rev. 108 (1957) 160

1957HO61 H.D. Holmgren, E.A. Wolicki and R.L. Johnston, Bull. Amer. Phys. Soc. 2 (1957) 181, E7

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

1957HU1E Hunting and Wall, Bull. Amer. Phys. Soc. 2 (1957) 181

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

1957JU1A Juric, Bull. Inst. Nucl. Sci. Boris Kidrich 7 (1957) 1

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

1957KH1B Khaletskii, Dokl. Akad. Nauk SSSR 113 (1957) 553; Sov. Phys. Dokl. 2 (1958) 152

1957LA14 A. Langsdorf Jr., R.O. Lane and J.E. Monahan, Phys. Rev. 107 (1957) 1077

1957LA15 W.A.S. Lamb and R.E. Hester, Phys. Rev. 107 (1957) 550

1957LI1B Lidofsky, Weil, Bent and Jones, Bull. Amer. Phys. Soc. 2 (1957) 29

1957MC1B McCormac, Steuer, Bond and Hereford, Phys. Rev. 108 (1957) 116

1957NO14 E. Norbeck Jr., Phys. Rev. 105 (1957) 204

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

1957RI38 J.R. Risser, J.E. Price and C.M. Class, Phys. Rev. 105 (1957) 1288

1957RO1F Roy, Lagasse, Goes, Achari and de Henau, Compt. Rend. 244 (1957) 2907

1957SA1C J. Sawicki, Phys. Rev. 106 (1957) 172

1957SE1C Senent, Villar and Bonet, An. Real. Soc. Espan. Fis. y Quim. A53 (1957) 109; Phys. Abs. 8264 (1958)

1957ST1D Stafford, Tornabene and Whitehead, Phys. Rev. 106 (1957) 831

1957ST1F Strizhak, Sov. J. At. Energy 2 (1957) 72

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

1957VO25 P. von Hermann and G.F. Pieper, Phys. Rev. 105 (1957) 1556

1957WA01 E.K. Warburton and J.N. McGruer, Phys. Rev. 105 (1957) 639

1957ZA1A Zabel, WASH 192 (1957)

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

1958AR1B Armbuster, Ann. Phys. (France) 3 (1958) 88

1958AS63 V.J. Ashby, H.C. Catron, L.L. Newkirk and C.J. Taylor, Phys. Rev. 111 (1958) 616

1958BA03 W.P. Ball, M. MacGregor and R. Booth, Phys. Rev. 110 (1958) 1392

1958BI1B Bichsel, Phys. Rev. Lett. 1 (1958) 384

1958BO67 M.S. Bokhari, J.A. Cookson, B. Hird and B. Weesakul, Proc. Phys. Soc. (London) A72 (1958) 88

1958BO76 R.O. Bondelid and C.A. Kennedy, NRL Rept. 5083 (1958)

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

1958BR1F Braley and Cook, Bull. Amer. Phys. Soc. 3 (1958) 267

1958CO07 J.P. Conner, Phys. Rev. 109 (1958) 1268

1958CO77 J.H. Coon, R.W. Davis, H.E. Felthauser and D.B. Nicodemus, Phys. Rev. 111 (1958) 250

1958DA09 H. Daniel and U. Schmidt-Rohr, Nucl. Phys. 7 (1958) 516

1958FI27 V.K. Fischer and G.E. Fischer, Bull. Amer. Phys. Soc. 3 (1958) 199, P4

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

1958HA1D Haig, Nucl. Phys. 7 (1958) 429

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

1958HI68 R.W. Hill, Phys. Rev. 109 (1958) 2105

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

1958JU39 A.C. Juveland and W. Jentschke, Phys. Rev. 110 (1958) 456

1958JU42 M.K. Juric and S.D. Cirilov, Phys. Rev. 112 (1958) 1224

1958KA16 J. Kane, A.J. Elwyn, S. Ofer and D. Wilkinson, Bull. Amer. Phys. Soc. 3 (1958) 381, T6

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

1958KR65 W.E. Kreger and B.D. Kern, Bull. Amer. Phys. Soc. 3 (1958) 188, K13

1958LI42 C.S. Littlejohn and G.G. Morrison, Bull. Amer. Phys. Soc. 3 (1958) 227, XA3; Oral Report

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

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

1958MA54 M.H. MacGregor, W.P. Ball and R. Booth, Phys. Rev. 111 (1958) 1155

1958MC63 M.T. McEllistrem, Phys. Rev. 111 (1958) 596

1958MO97 W.E. Moore, J.N. McGruer and A.I. Hamburger, Phys. Rev. Lett. 1 (1958) 29

1958MO99 C.D. Moak, A. Galonsky, R.L. Traughber and C.M. Jones, Phys. Rev. 110 (1958) 1369

1958NA09 M.P. Nakada, J.D. Anderson, C.C. Gardner and C. Wong, Phys. Rev. 110 (1958) 1439

1958SK1A Skyrme, Proc. Rehovoth Conf. (North-Holland Publishing Co., Amsterdam, 1958)

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

1958TA05 N.W. Tanner, Proc. Phys. Soc. (London) A72 (1958) 457

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

1958VA1D Vasilev, Komarov and Popova, JETP (Sov. Phys.) 6 (1958) 1016

1958VE15 J.F. Vervier and A. Martegani, Nucl. Phys. 6 (1958) 260

1958VE21 J.F. Vervier and A. Martegani, Phys. Rev. 109 (1958) 947

1958WA1D Warner and Alford, Bull. Amer. Phys. Soc. 3 (1958) 204

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

1958WH34 A.B. Whitehead and J.S. Foster, Can. J. Phys. 36 (1958) 1276

1958WI01 H.B. Willard, J.K. Bair and H.O. Cohn, Bull. Amer. Phys. Soc. 3 (1958) 18, F2

1958WI36 J.E. Wills Jr., J.K. Bair, H.O. Cohn and H.B. Willard, Phys. Rev. 109 (1958) 891

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

1959KR1B W.E. Kreger and B.D. Kern, Phys. Rev. 113 (1959) 890

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