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Energy Levels of Light Nuclei. IV*

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INTRODUCTION

THE art and practice of nuclear spectroscopy has engaged the attention of an increasingly large number of physicists in the past several years. Even in the somewhat restricted field covered by the present report, the literature now comprises several thousand papers—something over 500 of which have been published in the last two years. To assert that the material contained in these papers, many of which represent many months or years of intensive effort on the part of their authors, can be reduced two or more orders of magnitude in volume and adequately reported in summary form is a manifest absurdity. Clearly only those experimental results which are simply expressible in numerical form or which bear in an obvious way on current nuclear theory lend themselves well to such distillation. Nevertheless, we have found it useful for our own information to summarize from time to time what appear to be the salient facts and figures from the current literature and set them down in a systematic fashion, and we can only hope that the process does a minimum of violence to the opinions and intent of the originators of the work.

That the literature of a field is voluminous is not necessarily a reliable indication that the state of knowledge in the subject is advancing rapidly. On the other hand, in a field which has been characterized by an insufficiency of well-established numbers and undeniable facts, one may perhaps be pardoned for deriving comfort from the numerous accessions to what were a few years ago only skeleton outlines of the term-schemes of the light nuclei. It may be of interest, for example, to point out that the present compilation includes more than 400 energy levels of the 40-odd nuclides of charge number less than eleven. In about one-third of these nuclei, the first ten million electron volts of excitation—extending well above the binding energy—have been searched with sufficient thoroughness that one may say that most of the sharp stationary states in this interesting region are probably known. Thanks to the comparatively recent establishment of a precise nuclear energy scale and of a set of mutually consistent ground-state masses, the locations of many of these states can now be specified with three-figure accuracy or better.

Of perhaps even more significance is the fact that it has been possible to make reasonably unambiguous determinations of spin (total angular momentum) and parity in a good many cases. A part of this improvement in our situation can be ascribed to refinements in technique, perfection of high resolution instrumentation, and more reliable measurements of absolute cross sections. Another part has been due to an increased awareness among experimentalists of the power and practicability of studies of the angular correlations of radiations involved in nuclear reactions, while a third has resulted from a new and particularly simple interpretation of angular distributions observed at high bombarding energies in certain reactions.[1] As a consequence of the assiduous application of these and other techniques one can now catalog some tens of energy levels for which both spin and parity are known, and some scores in which one or the other quantity can be regarded as reasonably well established. Not the least interesting among these are the ground states of several nuclei of which the spins or parities have been determined for the first time by nuclear methods.

The implications of the vast store of numerical data here exhibited are not so easy to delineate, nor can the present authors claim competence to discuss their bearing on a theory of nuclear structure. One element of the picture which emerges rather clearly, however, is the evident similarity of isobaric sets. Among the odd-numbered isobars, one has the so-called mirror nuclei, such as He^5-Li^5 and Be^7-Li^7 which differ from one another only in the exchange of a single neutron for a proton, and hence, as regards the intra-nuclear forces, only in the replacement of some neutron-neutron bonds for proton-proton bonds: the number of neutron-proton bonds remains unchanged. The close agreement in mass of the ground states of such mirror pairs—after subtraction of electrostatic effects and of the intrinsic neutron-proton mass difference—has been recognized for many years as evidence for the symmetry of the purely nuclear parts of the neutron-neutron and proton-proton interactions. Considerable substantiating evidence for this hypothesis can now be derived from the one-to-one correspondence of the excited levels of these nuclei as revealed in the past few years. Except for small relative displacements—a few hundred kilovolts at most—one now finds complete agreement in the nuclides of mass 5, 7, 11, 13, and 17 in the locations and, where it has been possible to determine them, the spins and parities of the first few excited states. Even the displacements have found a satisfactory interpretation where they have been carefully investigated. It appears that the essential similarity of the structure of mirror

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[1] S. T. Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).

nuclei—and hence the charge-*symmetry* of nuclear forces—can be regarded as an established fact.

Still more interesting, and possibly even more fundamental, is the question of charge-*independence* of nuclear forces, e.g., of neutron-neutron and neutron-proton forces. Here a slight complication arises because of the operation of the exclusion principle in prohibiting certain interactions of like particles, and, hence, certain states in nuclei which have excess neutrons or protons. In a set of even isobars, such as Be^{10}, B^{10}, and C^{10}, the outer members differ only in the exchange of a neutron pair for a proton pair and they should correspond as mirror nuclei do, with each level of the one having a mate in the other. The center member, however, having equal numbers of neutrons and protons, differs in two important respects. As compared with its neighbors, it has more neutron-proton bonds and fewer neutron-neutron or proton-proton bonds; by the same token it may have many more states than its neighbors. On the charge-independence hypothesis, then, one expects that every state of the asymmetric members will have an analog in the symmetric one, but not vice versa. The states which are common should differ in energy only by the amounts of the Coulomb energy and neutron-proton mass difference. In three cases thus far it has been possible to establish such association between states. In Li^6, a level at 3.58 Mev has approximately the correct energy and the required properties (spin zero, even parity) to correspond to the ground state of He^6. In B^{10}, a level at 1.74 Mev almost certainly corresponds to the ground states of Be^{10} and C^{10}, and a level at 2.3 Mev in N^{14} appears to match very well the properties of C^{14} and O^{14}. Among the remaining even light isobars are several examples where a plausible association may be made, but no convincing evidence has yet appeared in these cases, nor has one yet been able to make a definite association for any excited states.

In a formal way, one may describe these corresponding states observed in both even and odd isobars as components of an "isobaric spin" multiplet,[2] characterized by the difference between the neutron and proton numbers. It follows from the assumption of charge-independence in the nuclear Hamiltonian that isobaric spin will be a conserved quantity, analogous to total angular momentum, in any nuclear reaction. Very recent experiments suggest strongly the operation of isobaric spin selection rules and furnish still more persuasive evidence for this far-reaching hypothesis.[3,4] It remains to be seen to what extent one can separate off the Coulomb and electromagnetic effects in weakening these selection rules and obtain a quantitative measure of their validity.

[2] E. P. Wigner, Phys. Rev. **51**, 106 (1937).
[3] R. K. Adair, Phys. Rev. **87**, 1041 (1952).
[4] R. F. Christy, University of Pittsburgh Conference (June, 1952).

GUIDE TO THE SUMMARY

Scope

The scope and organization of the present compilation closely follows that of three previous papers on the same subject.[5–7] We have attempted to include in the survey all the available (as of August, 1952) experimental material bearing on the energy levels of the nuclides from He^5 up to and including the neon isotopes. Generally speaking, very high energy reactions, leading to multiple-particle emission or spallation have not been included, nor have the very high energy scattering experiments. In view of the recent and impending appearance of a number of theoretical papers dealing with the problems of the light nuclei, we have contented ourselves with making occasional references to the theory, without attempting to present a detailed account of its application to specific nuclides.

In almost all cases, sufficient new material has appeared on the reactions included in the 1950 summary[7] to justify complete revision of the text. In the instances where no new work exists, we have repeated the earlier version in an abbreviated form or simply cited the previous summary. It is our hope that all the essential evidence for the energy levels claimed appears in the present article. For the earlier bibliography, the reader is referred to the 1950 summary, and, of course, to the 1937 work of Livingston and Bethe.[8]

Arrangement of the Material

The form and conventions of the diagrams and accompanying discussions have been treated in detail in "Energy Levels III."[7] Briefly, the energy level structure for each nucleus is presented in the form of a diagram, exhibiting the known levels, and indicating the nuclear reactions in which they are involved. Each diagram is accompanied by a discussion—largely in the form of an annotated bibliography—of the pertinent features of the various reactions. Each reaction will generally occur on two diagrams, and in two sections of the discussion: once under the compound nucleus (whether a compound nucleus is known to be formed or not) and once under the residual nucleus. In the former category will be found such information as is available on excitation functions and cross sections, and in the latter, information on Q-values and particle groups. Angular distributions are discussed under the one heading or the other, depending upon which seems more appropriate to the case in hand.

[5] W. F. Hornyak and T. Lauritsen, Revs. Modern Phys. **20**, 191 (1948).
[6] T. Lauritsen, N. R. C. Preliminary Report No. 5 (1949).
[7] Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 219 (1950).
[8] M. S. Livingston and H. A. Bethe, Revs. Modern Phys. **9**, 245 (1937).

Masses and Q-Values

The mass values used in the present compilation are listed at the end of the article. Almost all of these have been taken from the tables of Li *et al.*[9] and Li[10] which are based on recently measured precision Q-values. For such nuclides as were not included in these tables, we have estimated the masses from the available experimental data: the details of these estimates will be found in the text. For each reaction, the Q-value calculated from the masses, designated "Q_m", is listed with the reaction heading as is also the binding energy of the bombarding particle in the compound nucleus, "E_b". Both quantities are expressed in Mev. Although the mass values generally are assigned probable errors of fifteen to thirty kev, the Q-values are usually more accurate. Experimentally determined Q-values are cited in the text, whether they are among those used in fixing the masses or not.

Conventions

Within the limitations imposed by the requirement of brevity, we have endeavored to avoid the use of unfamiliar conventions and abbreviations. We set forth here some of the symbols which we have used, together with their definitions:

E	Energy in Mev, laboratory coordinates unless otherwise specified. Subscripts p, d, t, etc., refer to protons, deuterons, tritons, etc.
θ	Angle of observation, in laboratory coordinates unless otherwise specified.
$E_{\rm res}$	General: the bombarding energy at which resonance occurs; specific: the bombarding energy at which the resonant part of the phase shift of the partial wave in question reaches 90°.
Γ	Observed width of a resonance, in kev, laboratory coordinates unless otherwise specified.
E_λ	"Characteristic" energy of a level as determined by certain conditions on the logarithmic derivative of the wave function at the nuclear surface.[11]
$\omega\Gamma_a$	Statistical weight factor times partial width of particle a.
γ_λ^2	"Partial" width, after removal of barrier penetration factors, evaluated at E_λ.
Θ_λ^2	Dimensionless measure of γ_λ^2: $\Theta_\lambda^2 \equiv 2\gamma_\lambda^2 Ma/3\hbar^2$, a = channel radius, M = reduced mass.
J	Total angular momentum (sometimes referred to as "spin" in the case of ground states).
T, T_ζ	Isobaric (or "isotopic") spin quantum numbers: $T_\zeta \equiv \frac{1}{2}(N-Z)$.

[9] Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
[10] C. W. Li (to be published).
[11] E. P. Wigner and L. Eisenbud, Phys. Rev. **72**, 29 (1947); T. Teichmann and E. P. Wigner, Phys. Rev. **87**, 123 (1952).

ACKNOWLEDGMENT

It is again our pleasure to record our indebtedness to the many physicists who have aided us with suggestions and criticisms or who have supplied us with important information in advance of publication. We are grateful to Professors R. F. Christy, W. A. Fowler, and C. C. Lauritsen for their continued help and encouragement, without which this compilation would never have been initiated, much less completed.

He^5

Mass of He^5

The following observations bear on the mass of He^5:

1. $He^4(n\ n)He^4$: the cross section has a peak at $E_n = 1.15$ Mev (Ba 51a). A phase shift analysis of these data places $E_{\rm res}$ at 0.95 Mev ($E_{\rm res}$ = center-of-mass energy at which the resonant part of the $P_{\frac{3}{2}}$ phase shift reaches 90°) and E_λ at 2.4 Mev (E_λ = energy at which the logarithmic derivative of the wave function $= -l$ at the nuclear surface) (Ad 52). A value for $E_{\rm res}$ of $\sim$1.04 Mev is given by (Hu 52c). Since $E_{\rm res}$ usually differs from the energy for maximum cross section by only a small amount, we choose $E_{\rm res}$ as the "level energy," i.e., 1.00 Mev above He^4+n.

2. $He^4(d\ p)He^5$: the observed proton group indicates an instability for He^5 of 1.0 Mev and a width $\geq$0.32 Mev (Bu 51h).

3. $Li^7(d\ \alpha)He^5$: published values disagree by nearly 1 Mev, even as to whether the ground-state group has been resolved. The Q-value 14.2 Mev corresponds to a He^5 mass 1.0 Mev above He^4+n.

We adopt: $He^5 = 1.00 \pm 0.1$ Mev $+ He^4 + n$; mass defect $= 12.97 \pm 0.1$ Mev.

I. (a) $H^3(d\ n)He^4$ $Q_m = 17.577$ $E_b = 16.58$
(b) $H^2(t\ n)He^4$

A lower limit for Q of 17.548 Mev is reported (Wi 51d).

Absolute cross sections are tabulated for $E_d = 15$ to 105 kev by (St 52a), for $E_d = 10$ to 1700 kev by (Co 52f) and for $E_t = 80$ to 1200 kev by (Ar 52d). The yield is isotropic below $E_t = 600$ kev (Ar 52d, Al 51c, Br 49a) and exhibits a broad maximum at $E_d = 109$ kev (Co 52f), 107 kev (St 52a). The peak cross section is given as 5.14 ± 0.8 b by (Al 51c), 4.95 ± 0.3 b by (St 52a), 4.93 ± 0.5 b by (Ar 52d: limit of error), and 5.1 ± 0.1 b by (Co 52f). The magnitude of the cross section requires $J = \frac{3}{2}$ for the He^5 state, assumed to be formed by s-wave deuterons: conservation of spin and parity then require d-wave neutron emission (Co 52f, Ar 52d). A good fit to the data is obtained with the single level dispersion formula for a fairly broad range of parameters. The best values are given by (Co 52f) as

$$a = 5.0 \times 10^{-13} \text{ cm}$$
$$E_\lambda = -464 \text{ kev},$$
$$\gamma_d^2 = 10^{-9} \text{ kev-cm},$$
$$\gamma_n^2 = 2.8 \times 10^{-11} \text{ kev-cm},$$

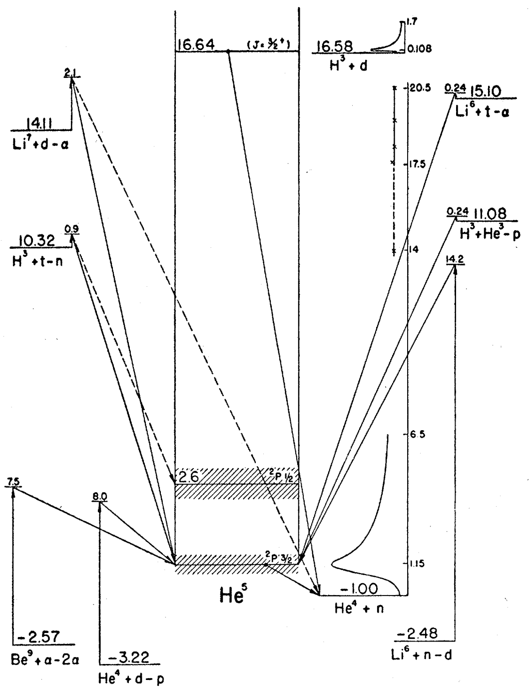

FIG. 1. Energy levels of He^5. In these diagrams, energy values are plotted vertically in Mev, based on the ground state as zero. Uncertain levels or transitions are indicated by dashed lines; levels which are known to be particularly broad are cross-hatched. For reactions in which He^5 is the compound nucleus, thin-target excitation functions are shown schematically (where known), with the yield plotted horizontally and the bombarding energy vertically. Bombarding energies are indicated in laboratory coordinates and plotted to scale in center-of-mass coordinates. Values of total angular momentum (J) and parity which appear to be reasonably well established are indicated on the levels: less certain assignments are enclosed in parentheses. Excited states of the residual nuclei involved in these reactions have generally not been shown: where transitions to such excited states are known to occur, a brace has been used to suggest reference to another diagram.

For reactions in which the present nucleus occurs as a residual product, excitation functions have not been shown; a vertical arrow with a number indicating some bombarding energy—usually the highest—at which the reaction has been studied, is used instead.

while (Ar 52d) use

$$a=7.0\times10^{-13}\text{ cm},$$
$$E_\lambda=-97\text{ kev},$$
$$\gamma_t^2=0.42\times10^{-9}\text{ kev-cm},$$
$$\gamma_n^2=1.2\times10^{-11}\text{ kev-cm}.$$

In either case, the reduced scattering width is close to the sum-rule limit. [The level indicated on the He^5 diagram is located at E_{res}, rather than at E_λ.]

Above the resonance the cross section drops smoothly. Near $E_t=1$ Mev the angular distribution deviates from isotropy, more neutrons coming off at the back angles (Ar 52d). At $E_d=2.21$ Mev, the center-of-mass differential cross section for α-particles is flat at 8 mb/sterad from θ (c.m.)$=40°$ to $90°$ and rises to about 13 mb/sterad at $\theta=140°$ (St 52c). At $E_d=10.5$ Mev, the α-particle distribution has minima at θ (c.m.)$=80°$ and $140°$ and rises sharply at greater angles (Br 51b). The angular distribution here can be accounted for on the assumption that a stripping process is taking place, with capture of an s-wave proton (Bu 51i; see also $He^3(d\ p)He^4$).

Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
St 52a Stovall, Arnold, Phillips, Sawyer, and Tuck, Phys. Rev. **88**, 159A (1952).
Co 52f Conner, Bonner, and Smith, Phys. Rev. (to be published).
Ar 52d Argo, Taschek, Agnew, Hemmendinger, and Leland, Phys. Rev. **87**, 612 (1952).
Al 51c Allen and Poole, Proc. Roy. Soc. (London) **204**, 488, 500 (1951).
Br 49a Bretscher and French, Phys. Rev. **75**, 1154 (1949).
St 52c Stratton and Freier, Phys. Rev. **88**, 261 (1952).
Br 51b Brolley, Fowler, and Stovall, Phys. Rev. **82**, 502 (1951).
Bu 51i Butler and Symonds, Phys. Rev. **83**, 858 (1951).
See also: Al 50i, Fl 51, Ar 52, Co 52c.

II. $H^3(d\ d)H^3$ $E_b=16.58$

The differential cross section for elastic scattering exhibits a minimum at $\theta=90°$ (center-of-mass) at $E_d=0.96$ Mev. The value at the minimum decreases steadily and the location of the minimum moves to higher angles as the deuteron energy is increased to $E_d=3.22$ Mev (St 52e). At $E_d=10$ Mev two minima appear for $\theta>50°$: curves for $He^3(d\ d)He^3$ are similar in this region. Below $\theta=50°$, the curves for H^3 and He^3 differ to an extent which can be attributed to the increased Coulomb scattering by He^3 (Ar 52a).

St 52e Stratton, Freier, Keepin, Rankin, and Stratton, Phys. Rev. **88**, 257 (1952).
Ar 52a Armstrong, Allred, Hudson, Potter, Robinson, Rosen, and Stovall, Phys. Rev. **87**, 238A (1952).
See also: St 52.

III. $H^3(d\ p)H^4$—Not observed: see (Mc 51a).

Mc 51a McNeill and Rall, Phys. Rev. **83**, 1244 (1951).

IV. $H^3(t\ n)He^5$ $Q_m=10.32$

At $E_t=400$ to 900 kev, the forward neutron spectrum exhibits two peaks, at 8.1 and 10.4 Mev, corresponding to formation of He^5 in the ground state and in a state at ~2.6 Mev (Le 51a). Observations at $E_t=220$ kev, $\theta=90°$, show the higher energy peak and do not exclude the lower (Al 51).

Le 51a Leland and Agnew, Phys. Rev. **82**, 559 (1951).
Al 51 Allen, Almqvist, Dewan, Pepper, and Sanders, Phys. Rev. **82**, 262 (1951).

V. $H^3(He^3\ p)He^5$ $Q_m=11.08$

The ground-state protons have been observed (Al 51a).

Al 51a Almqvist, Allen, Dewan, and Pepper, Phys. Rev. **83**, 202 (1951).

VI. $He^4(n\ n)He^4$ $E_b=-1.00$

The thermal cross section is 0.78 barn (Hi 51).

The total cross section rises from 0.8 barn at $E_n=40$ kev to a peak of 7.4 b at 1.15 Mev (Ba 51a) and there-after falls monotonically to a value of 1.7 b at 6.5 Mev (Coon and Henkel, private communication). At $E_n=14.1$, the cross section is 1.02 ± 0.02 b (Co 52i: see Co 52h). From $E_n=17.6$ to 20.6 Mev the cross section decreases smoothly from 0.90 to 0.78 b (Coon and Henkel).

The angular distributions have been studied for $E_n=0.4$ to 2.7 Mev by (Ad 52) and for E_n to 4.1 Mev by (Hu 52c). A phase-shift analysis of the lower energy data indicates the character $P_{\frac{3}{2}}$ for the ground state of He^5, at $E_{res}=0.95$ Mev (center-of-mass) above (He^4+n), with a width $\sim$1 Mev, in addition to a $P_{\frac{1}{2}}$ state about 3 Mev higher. The parameters used were: radius $a=2.9\times10^{-13}$ cm, reduced width $\gamma^2=17.6\times10^{-13}$ Mev-cm ($\sim$the sum-rule limit: Te 52), E_λ $(P_{\frac{3}{2}})=2.40$ Mev, E_λ $(P_{\frac{1}{2}})\sim7.4$ Mev. The same radius and width fit the proton scattering with E_λ $(P_{\frac{3}{2}})=3.65$ Mev (Ad 52: see Li^5). The analysis by (Hu 52c) yields E_{res} $(P_{\frac{3}{2}})=1.04$ Mev (center-of-mass) and E_{res} $(P_{\frac{1}{2}})=2.8$ Mev indicating a somewhat smaller doublet splitting than that found by (Ad 52) [E_{res} in the case of (Hu 52c) is the energy at which the total phase shift reaches 90°]. The s-wave phase shift obtained by (Hu 52c) decreases almost linearly, from $\sim-25°$ at $E_n=0.8$ Mev to $\sim-60°$ at 4 Mev while the d-wave shifts are of the order of 10° at $E_n=4$ Mev. (Do 52b) find that their parameters (see $He^4(p\ p)He^4$), indicating a larger level splitting and a greater width for the $P_{\frac{1}{2}}$ level than given by (Ad 52), give a satisfactory account of the total cross-section data.

Hi 51 Hibdon and Muehlhause, ANL 4680, September (1951).
Ba 51a Bashkin, Mooring, and Petree, Phys. Rev. **82**, 378 (1951).
Co 52i Coon, Bondelid, and Phillips (to be published).
Ad 52 Adair, Phys. Rev. **86**, 155 (1952).
Hu 52c Huber and Baldinger, Helv. Phys. Acta **25**, 435 (1952).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
Do 52b Dodder and Gammel (to be published).
See also: Ca 41, Ha 50f, Ad 51b, Ko 51a, Mc 51d, Co 52h, Hu 52e.

VII. (a) $He^4(d\ p)He^5$ $Q_m=-3.22$
(b) $He^4(d\ p)He^4+n$ $Q_m=-2.225$

An (approximately) homogeneous group of protons is observed at $E_d=6.5$ Mev: $Q=-2.9$ (Gu 47) and at $E_d=7.94$ Mev: $Q=-3.2$ (Bu 51h). The latter observation indicates an instability for He^5 of about 1 Mev, and a ground-state width of at least 0.32 Mev (Bu 51h).

Gu 47 Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. (London) **190**, 196 (1947).
Bu 51h Burge, Burrows, Gibson, and Rotblat, Proc. Roy. Soc. (London) **210**, 534 (1951).
See also: Al 51l.

VIII. $Li^6(n\ d)He^5$ $Q_m=-2.48$

See Li^7.

IX. $Li^6(t\ \alpha)He^5$ $Q_m=15.10$

The ground-state α-particles have been observed (Pepper *et al.*, Craig, private communication).

X. $Li^7(d\ \alpha)He^5$ $Q_m=14.11$

At low bombarding energies, $E_d=0.2$ to 0.9 Mev, a pronounced α-particle group is observed, with a width $\sim$0.2 Mev. Quoted Q-values are 14.3 (Wi 37c, Li 37), 13.43 (La 47b) and 14.2 ± 0.1 Mev (Fr 51b). The angular correlation of the two successive α-particles (the second resulting from the breakup of He^5) is not isotropic, a result which appears to exclude a dominant contribution from a $P_{\frac{1}{2}}$ state of He^5. The assumption of an almost pure $P_{\frac{3}{2}}$ ground state is not inconsistent with these measurements (Fr 51b). At $E_d=1.51$ Mev, $\theta=90°$, no well-defined α-group is observed (St 51).

The breakup of He^5 in this reaction results in a continuum of neutrons with energies up to $\sim$4 Mev, on which are superposed peaks from $Li^7(d\ n)Be^8$ (Wh 50c).

Wi 37c Williams, Shepherd, and Haxby, Phys. Rev. **52**, 390 (1937).
Li 37 Livingston and Bethe, Revs. Modern Phys. **9**, 245 (1937).
La 47b Lattes, Fowler, and Cüer, Proc. Phys. Soc. (London) **59A**, 883 (1947).
Fr 51b French and Treacy, Proc. Phys. Soc. (London) **64A**, 452 (1951).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Wh 50c Whitehead, Phys. Rev. **79**, 393 (1950).

XI. $Be^9(\alpha\ \alpha')He^5+He^4$ $Q_m=-2.57$

See C^{13}.

Li^5

Mass of Li^5

The following observations bear on the mass of Li^5:

1. $He^4(p\ p)He^4$: a phase-shift analysis of the elastic scattering data yields a resonance energy, $E_{res}=2.1$ Mev (center-of-mass) for the ground state (Ad 52. See discussion of He^5 mass).

2. $Li^6(\gamma\ n)Li^5$: from analysis of the reaction products observed in photographic emulsions, it is concluded that the ground state is 1.6 ± 0.2 Mev above He^4+H^1 (Ti 51). The photoneutron threshold also yields 1.6 ± 0.2 Mev (Sh 51d), but it is not entirely clear how the threshold is to be interpreted for such a broad state.

We adopt: $Li^5=1.8\pm0.3$ Mev above He^4+H^1; mass defect$=12.99\pm0.3$ Mev.

I. $He^3(d\ p)He^4$ $Q_m=18.341$ $E_b=16.54$

Cross sections for $E_d=35$ to 95 kev are tabulated by (Tu 52) and for $E_d=188$ to 1600 kev by (Bo 52a). The total cross section exhibits a broad maximum at $E_d=430\pm30$ kev, $\sigma=0.90\pm0.2$ b (Ya 52a), $E_d=400$ kev, $\sigma=0.69\pm0.03$ b (Bo 52a), and decreases slowly with energy to $E_d=3.56$ Mev. The protons are emitted isotropically at $E_d=260$, 400, and 460 kev and exhibit a forward preference at higher energies (Bo 52a, Ya 52a). At $E_d=0.98$ to 2.0 Mev, the differential cross section decreases with angle to the highest angle measured, $\theta=135°$ (Ya 52a). From $E_d=2.0$ to 3.5 Mev, the differ-

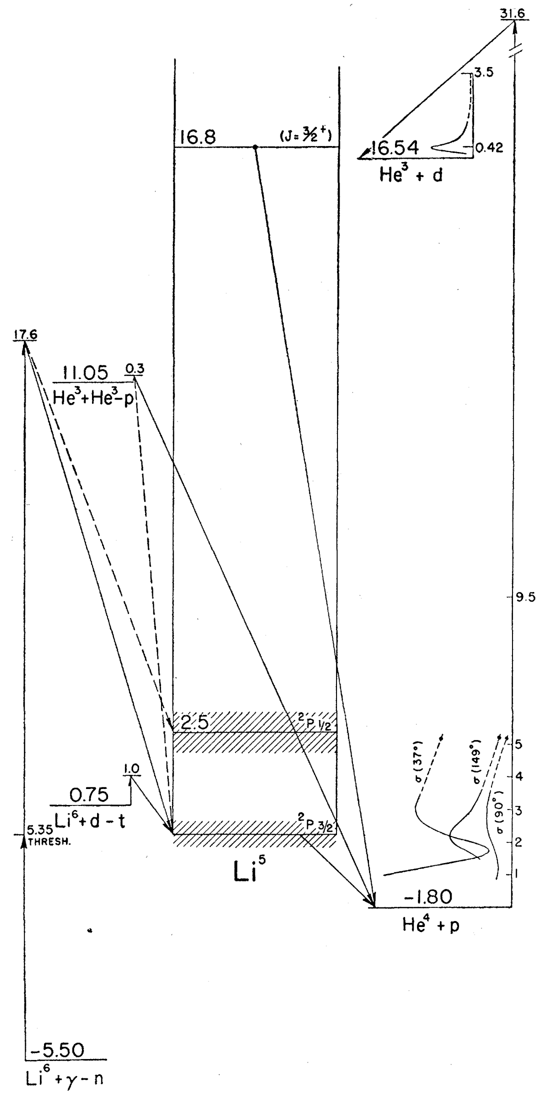

FIG. 2. Energy levels of Li^5: for notation, see Fig. 1.

ential cross section displays a minimum which moves to lower angles as the energy is increased, $\theta_{min}=100°$ at $E_d=3.56$ Mev (Ya 52a; see also Wy 49b). At $E_d=10.2$ Mev, two minima appear, at $\theta=50°$ and 100° (center-of-mass) (Al 51k). The angular distribution at $E_d=10.2$ Mev is quite similar to that of the mirror reaction, $H^3(d\ n)He^4$ and can be adequately accounted for by the stripping process, using an effective radius $a=4.3\times10^{-13}$ cm (Bu 51i). The cross section above $E_d=0.5$ Mev is also nearly the same as for the mirror reaction (Bo 52a).

The variation of the cross section near resonance is well fitted by a modified single-level dispersion formula with the following parameters

$$a=7.6\times10^{-13}\text{ cm},$$
$$E_\lambda=195\text{ kev},$$
$$\gamma_d^2=5.0\times10^{-10}\text{ kev cm},$$
$$\gamma_p^2=9.7\times10^{-12}\text{ kev cm}.$$

Formation of a state with $J=\frac{3}{2}$, even, by s-wave deuterons and emission of d-wave neutrons has been assumed. At higher energies, the observed cross section is higher than that given by the formula, possibly reflecting the contribution of other deuteron waves (Bo 52a).

Tu 52 Tuck, Arnold, Phillips, Sawyer, and Stovall, Phys. Rev. **88**, 159A (1952).
Bo 52a Bonner, Conner, and Lillie, Phys. Rev. (to be published).
Ya 52a Yarnell, Lovberg, Stratton, and Stratton (unpublished).
Wy 49b Wyly, Sailor, and Ott, Phys. Rev. **76**, 1532 (1949).
Al 51k Allred, Phys. Rev. **84**, 695 (1951).
Bu 51i Butler and Symonds, Phys. Rev. **83**, 858 (1951).
See also: Ya 52.

II. $He^3(d\ d)He^3$ $E_b=16.54$

The differential elastic scattering cross section at $E_b=10$ Mev exhibits two minima for $\theta>50°$ (Ar 52a: see $H^3(d\ d)H^3$).

Ar 52a Armstrong, Allred, Hudson, Potter, Robinson, Rosen, and Stovall, Phys. Rev. **87**, 238A (1952).

III. $He^3(He^3\ p)Li^5$ $Q_m=11.05$

See Be^6.

IV. $He^4(p\ p)He^4$ $E_b=-1.80$

1. $E_p<3.6$ Mev. Precision measurements of cross section for several energies, at angles from 10° to 170°, are reported by (Fr 49c): a broad maximum appears in the backward scattering at $E_p\sim2.2$ Mev. A phase-shift analysis of these data indicates p-wave resonance, either from a regular doublet with the ground state, $P_{\frac{1}{2}}$, at 1.8 Mev above He^4+H^1 and the $P_{\frac{3}{2}}$ state 0.9 Mev higher, or a $P_{\frac{3}{2}}$ ground state at 2.1 Mev above He^4+H^1 and the $P_{\frac{1}{2}}$ 3 or 4 Mev higher (Cr 49a). That the doublet is in fact inverted has been shown by measurement, at $E_p=3.25$ Mev, of the polarization of the scattered protons (He 52a). Further analysis of the scattering data, if one assumes an inverted doublet, yields $E_{res}(P_{\frac{3}{2}})\sim2.1$ Mev (center-of-mass), $E_\lambda(P_{\frac{3}{2}})=3.65$ Mev and $E_{res}(P_{\frac{1}{2}})\sim5.3$ Mev, $E_\lambda(P_{\frac{1}{2}})\sim9$ Mev. The parameters used are $a=2.9\times10^{-13}$ cm, $\gamma^2=17.6\times10^{-13}$ Mev-cm (Ad 52). The same parameters, with an energy displacement of 1.25 Mev attributable to Coulomb effect and $n-H^1$ mass difference, give a satisfactory account of the $n-He^4$ scattering (Ad 52).

2. $E_p=4.8$, 5.1 Mev: cross sections at five angles are reported by (Br 51h).

3. $E_p=5.82\pm0.06$ Mev: measurements at 28 angles, using photographic plates, yield phase shifts as follows: $S_{\frac{1}{2}}$: $-46°40'$, $P_{\frac{1}{2}}$: $34°22'$, $P_{\frac{3}{2}}$: $180°47'$, assuming an inverted doublet (Kr 52a).

4. $E_p=9.5$ Mev—see (Pu 52).

5. $E_p=31.6$ Mev: cross sections have been measured at six angles by (Co 52a).

6. Inelastic scattering at $E_p=31.6$ Mev: see (Be 52a).

A phase-shift analysis of the 5.8- and 9.5-Mev scattering data leads to a larger splitting of the $P_{\frac{3}{2}}$ and $P_{\frac{1}{2}}$ levels and a greater width for the latter than that found by (Ad 52). The parameters obtained are, for the $P_{\frac{3}{2}}$ level: $E_\lambda=-3.3$ Mev, $\gamma^2=20.0\times10^{-13}$ Mev-cm, for the $P_{\frac{1}{2}}$ level: $E_\lambda=2.7$ Mev, $\gamma^2=85\times10^{-13}$ Mev-cm (different boundary conditions to specify E_λ have been used). The reduced width of the $P_{\frac{3}{2}}$ level is of the order of the sum-rule limit, while the $P_{\frac{1}{2}}$ level is considerably broader. A small, negative D-wave phase shift appears also to be required (Do 52b).

Fr 49c Freier, Lampi, Sleator, and Williams, Phys. Rev. **75**, 1345 (1949).
Cr 49a Critchfield and Dodder, Phys. Rev. **76**, 602 (1949).
He 52a Heusinkveld and Freier, Phys. Rev. **85**, 80 (1952).
Ad 52 Adair, Phys. Rev. **86**, 155 (1952).
Br 51h Braden, Phys. Rev. **84**, 762 (1951).
Kr 52a Kreger, Kerman, and Jentschke, Phys. Rev. **86**, 593A (1952).
Pu 52 Putnam, Phys. Rev. **85**, 774A (1952), Ph.D. thesis, University of California Rad. Lab. No. 1447, August (1951), and Phys. Rev. **87**, 932 (1952).
Co 52a Cork, Phys. Rev. **83**, 893A (1951), and University of California Rad. Lab. No. 1673, February (1952).
Do 52b Dodder and Gammel (to be published).
See also: Ad 51b, Be 52a.

V. $He^4(p\ d)He^3$ $Q_m=-18.341$ $E_b=-1.80$

The angular distribution of deuterons, observed at $E_p=31.6$ Mev, is in good agreement with the stripping theory of (Bu 51b). An effective radius 4.2×10^{-13} cm is used (Be 52a). See also $He^3(d\ p)He^4$.

Bu 51b Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).
Be 52a Benveniste, Ph.D. thesis, UCRL 1689 (1952).
See also: Be 51a.

VI. $Li^6(\gamma\ n)Li^5$ $Q_m=-5.50$

A threshold of 5.35 ± 0.20 Mev is reported (Sh 51d). Analysis of 70 events in photographic emulsions, indicates two broad groups of $(\alpha+p)$ tracks (from the disintegration of Li^5), corresponding to a ground state at 1.6 ± 0.2 Mev above (He^4+p) and an excited state 2.5 ± 0.5 Mev higher. The cross section at $E_\gamma=17.6$ Mev is 0.5 ± 0.2 mb (Ti 51).

Sh 51d Sher, Halpern, and Mann, Phys. Rev. **84**, 387 (1951).
Ti 51 Titterton and Brinkley, Proc. Phys. Soc. (London) **64A**, 212 (1951).

VII. $Li^6(d\ t)Li^5$ $Q_m=0.75$

A continuous distribution of protons attributed to the disintegration of Li^5 formed in this reaction and consistent with a Q of 0.8 Mev is observed at $E_d=1$ Mev (Ge 52).

Ge 52 Gelinas and Hanna, Phys. Rev. **86**, 253 (1952).

He^6

Mass of He^6

The mass-difference He^6-Li^6 is given as 3.55 ± 0.03 Mev from combination of the Q of the reaction $Li^7(t\ \alpha)He^6$ (9.79 Mev) with other accurately known Q-values (De 52). This value is in serious disagreement with the beta end point of 3.215 ± 0.015 reported by (Pe 50) but agrees with earlier determinations (Ho 50b). The observed threshold for $Be^9(n\ \alpha)He^6$, $E_n\geq0.6$ Mev (Al 47b), indicates a lower limit of 3.45 Mev for the mass-difference. Since the reaction Q-value determination appears to us to contain fewer pitfalls than does the beta-measurement, *we adopt* $He^6-Li^6=3.55\pm0.03$ Mev; He^6 mass defect$=19.40\pm0.036$ Mev.

I. $He^6(\beta^-)Li^6$ $Q_m=3.55$

Reported β-spectrum end points vary between 3.215 and 3.7 Mev (see Ho 50b). The spectrum is of the simple allowed shape for $E_\beta>200$ kev (Pe 50), and no γ-radiation is observed (Kn 48a). The weighted mean of reported half-lives is 0.828 ± 0.01 sec (Ho 50b). Using $E_\beta(\max)=3.55$ Mev, log ft$=2.95$.

A recent report by (Wu 52) gives an end point of 3.50 ± 0.05 Mev; ft$=815\pm70$ sec. The Fermi plot is straight down to about 0.6 Mev.

Pe 50 Perez-Mendez and Brown, Phys. Rev. **77**, 404 (1950).
Kn 48a Knox, Phys. Rev. **74**, 1192 (1948).
Wu 52 Wu, Rustad, Perez-Mendez and Lidofsky, Phys. Rev. **87**, 1140 (1952).
See also: Al 47b, Ho 50b, Ba 52e.

II. (a) $H^3(t\ \alpha)2n$ $Q_m=11.320$ $E_b=12.25$
(b) $H^3(t\ \alpha)n^2$
(c) $H^3(t\ n)He^5$ $Q_m=10.32$

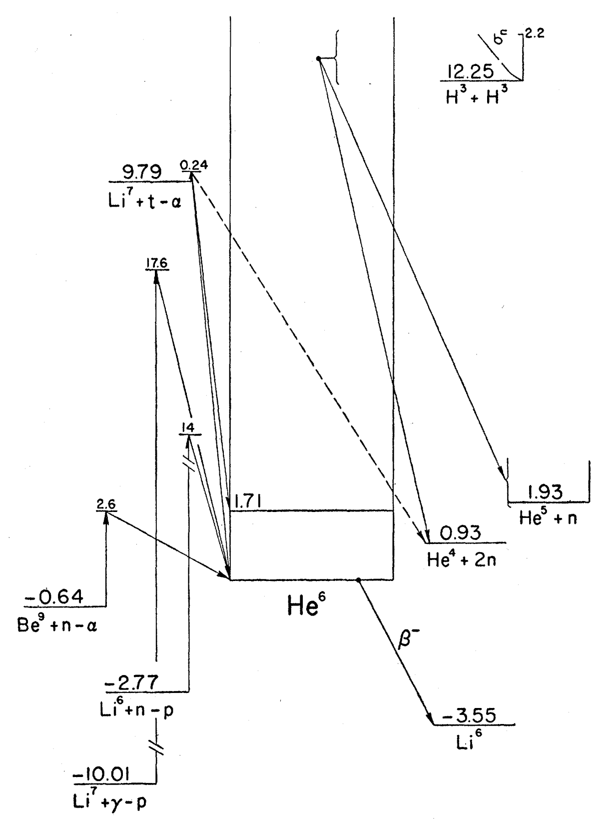

FIG. 3. Energy levels of He^6: for notation, see Fig. 1.

Reaction (a) leads to a continuum of α-particles and neutrons; (b), if it occurs, to a monochromatic α-group of width depending on the lifetime of the dineutron. Reaction (c) yields approximately monochromatic groups of neutrons, corresponding to the ground and excited states of He^5, plus a continuum of neutrons and α-particles from the subsequent breakup.

The α-spectrum observed at $E_t=220$ kev, $\theta=90°$, indicates only the continuum, extending to 3.8 Mev. No group from reaction (b) is observed, unless its energy coincides with a peak at 3.5 Mev due to contaminating $H^2(t\ \alpha)n$. If the dineutron is bound, it is formed in fewer than 1 percent of the disintegrations; if it is unbound by ≤ 0.6 Mev, an upper limit of 1 percent may be placed on the existence of an α-group of width ~ 0.2 Mev, corresponding to a lifetime $\sim 3\times 10^{-21}$ sec. (Al 51: see, however, Lo 50).

The forward neutron spectrum at $E_t=400$ to 900 kev exhibits two peaks, at 8.1 and 10.4 Mev (see He^5), superposed on the continuum extending to $E_n\sim 11.5$ Mev (Le 51a). The $\theta=90°$ spectrum at $E_t=200$ kev shows the higher peak and is not inconsistent with the existence of the lower (Al 51).

The cross section for neutron production rises monotonically from 0.1 to 2.2 Mev, reaching a value of about 0.18 b at 2.2 Mev. The angular distribution of neutrons has a minimum, 0.6 of the forward yield, at $\theta\sim 90°$ (Ag 51).

Al 51 Allen, Almqvist, Dewan, Pepper, and Sanders, Phys. Rev. **82**, 262 (1951).
Lo 50 Los Alamos Scientific Laboratory, Phys. Rev. **79**, 238A (1950).
Le 51a Leland and Agnew, Phy, Rev. **82**, 559 (1951).
Ag 51 Agnew, Leland, Argo, Crews, Hemmendinger, Scott, and Taschek, Phys. Rev. **84**, 862 (1951).

III. $He^4(n^2\ \gamma)He^6$

Not observed: see (Fe 52).

IV. $Li^6(n\ p)He^6$ $Q_m=-2.77$

See Li^7.

V. $Li^7(n\ d)He^6$ $Q_m=-7.79$ (not illustrated)

See Li^8.

VI. (a) $Li^7(t\ \alpha)He^6$ $Q_m=9.79$
(b) $Li^7(t\ \alpha)He^4+2n$ $Q_m=8.855$

At $E_t=240$ kev, $\theta=90°$, two α-particle groups are observed in reaction (a), corresponding to the ground state of He^6, $Q=9.79\pm 0.03$, and to an excited state at 1.71 ± 0.01 Mev. The width of the excited state is probably less than 50 kev: the intensity is about five times that of the ground-state group. Under the same conditions of observation, reaction (b) accounts for 80 percent of the $(t\ \alpha)$ disintegrations (De 52). Reaction (b) may proceed through intermediate steps: see Be^{10}. One case, observed in a Li-loaded photographic emulsion appears to involve a state of He^6 at 6 ± 1 Mev (Cu 52a).

R. W. Crews (private communication) finds a Q-value for the ground state of 9.75 ± 0.07 Mev and locates the excited state at 1.94 ± 0.08 Mev.

De 52 Dewan, Pepper, Allen, and Almqvist, Phys. Rev. **86**, 416 (1952).
Cu 52a Cüer and Magnac-Valette, Compt. rend. **234**, 1049 (1952).

VII. $Li^7(\gamma\ p)He^6$ $Q_m=-10.01$

At $E_\gamma=17.6$ Mev, nine events have been observed in lithium-loaded emulsions in which the ground state of He^6 is formed and one which may be attributed to an excited state.

Ti 50b Titterton, Proc. Phys. Soc. (London) **63A**, 1297 (1950).

VIII. $Be^9(n\ \alpha)He^6$ $Q_m=-0.64$

The threshold is $E_n\geq 0.6$ Mev (Al 47b).

Al 47b Allen, Burcham, and Wilkinson, Proc. Roy. Soc. (London) **192**, 114 (1947).
See also: Ba 52e.

Li^6

I. (a) $H^3(He^3\ d)He^4$ $Q_m=14.308$ $E_b=15.786$
(b) $H^3(He^3\ p)He^5$ $Q_m=11.08$
(c) $H^3(He^3\ p)He^4+n$ $Q_m=12.083$

With 200-kev He^3 particles, $\theta=50°$, reactions (a) and (c) are about equal in intensity, while reaction (b) is observed to occur in fewer than 10 percent of the disintegrations (Al 51a).

Al 51a Almqvist, Allen, Dewan, and Pepper, Phys. Rev. **83**, 202 (1951).

II. $He^4(d\ d)He^4$ $E_b=1.477$
$H^2(\alpha\ \alpha)H^2$

Absolute values for the differential elastic scattering cross section have been reported for $E_d=0.88$ to 3.51 Mev (Bl 49), 6.5 (Gu 47: not absolute), 7.94 (Bu 51h) and 10.3 Mev (Al 51l). At the higher energies, the angular distribution exhibits pronounced minima at $\theta\sim 60°$ and 130° (center-of-mass system) with a maximum at $\sim 100°$ and a sharp rise for both forward and backward angles. The total cross section ($\theta=18°$ to 159°) is 1.01 ± 0.06 b at 10.3 Mev.

At low energies and large scattering angles, pronounced deviations from Coulomb scattering occur—particularly as observed in the forward deuteron recoils in α-particle scattering in deuterium (Mo 37, Po 35b). A resonance is reported at $E_\alpha=2.6$ Mev which may correspond to the narrow 2.187-Mev level of Li^6 (Po 35b). This level would presumably influence the deuteron scattering by He^4 at $E_d=1.06$ Mev. The 3.58-Mev level would not be expected to affect the $\alpha-d$ scattering if it is a spin zero, even state, or if it has isobaric spin $T=1$.

Bl 49 Blair, Freier, Lampi, and Sleator, Phys. Rev. **75**, 1678 (1949).
Gu 47 Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. (London) **190**, 196 (1947).
Bu 51h Burge, Burrows, Gibson, and Rotblat, Proc. Roy. Soc. (London) **210**, 534 (1951).
Al 51l Allred, Froman, Hudson, and Rosen, Phys. Rev. **82**, 786 (1951).
Mo 37 Mohr and Pringle, Proc. Roy. Soc. (London) **160**, 190 (1937).
Po 35b Pollard and Margenau, Phys. Rev. **47**, 833 (1935).

III. (a) $He^4(d\ p)He^5$ $Q_m=-3.22$ $E_b=1.477$
(b) $He^4(d\ p)He^4+n$ $Q_m=-2.225$

Both the (approximately) homogeneous group of protons from reaction (a) and the continuum from reaction (b) are observed at $E_d=6.5$ Mev, 7.94 Mev (Bu 51h) and, possibly, at 10.3 Mev (Al 51l). At the intermediate energy, the probabilities for (a) and (b) are roughly equal: at 6.5 and 10.3 Mev the angular distribution of protons is strongly forward (Al 51l, Bu 51h). The total cross section ($\theta=18°$ to 159°) is 0.3 ± 0.1 b at 10.3 Mev (Al 51l).

Bu 51h Burge, Burrows, Gibson, and Rotblat, Proc. Roy. Soc. (London) **210**, 534 (1951).
Al 51l Allred, Froman, Hudson, and Rosen, Phys. Rev. **82**, 786 (1951).

IV. $He^6(\beta^-)Li^6$ $Q_m=3.55$

See He^6.

V. $Li^6(\gamma\ n)Li^5$ $Q_m=-5.50$ (not illustrated)

The cross section is 0.5 ± 0.2 mb for $E_\gamma=14.8$ to 17.6 Mev (Ti 51).

Ti 51 Titterton and Brinkley, Proc. Phys. Soc. (London) **64A**, 212 (1951).
See also: Ch 52a.

VI. $Li^6(\gamma\ d)He^4$ $Q_m=-1.477$

The cross section is $\leq 8\pm2\times10^{-3}$ mb for $E_\gamma=2.76$ Mev, $\leq 6\pm3\times10^{-3}$ mb for $E_\gamma=6.3$ Mev and $\leq 5\pm3\times10^{-3}$ mb for $E_\gamma=(17.6+14.8)$ Mev (Titterton, private communication). (An electric dipole transition is presumably forbidden by isobaric spin selection rules: see, e.g. Ra 52.)

See also: Ti 50a, Ra 52.

VII. $Li^6(p\ p')Li^6$

Observed proton groups indicate a level in Li^6 at 2.12 Mev. The Q-values quoted are -2.12 ± 0.05 Mev (Ha 51c: $E_p=7$ Mev, magnetic spectrometer), -2.2 Mev (Go 51a, $E_p=7.9$ Mev, range), -2.18 ± 0.12 Mev (Fr 52; $E_p=18.3$ Mev, pulse height).

Ha 51c Harris, Phys. Rev. **84**, 1249 (1951).
Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).
Fr 52 Franzen and Likely, Phys. Rev. **87**, 667 (1952).

VIII. $Li^7(p\ d)Li^6$ $Q_m=-5.020$

At $E_p=18.3$ Mev, deuteron groups corresponding to states of Li^6 at 0, 2.2 ± 0.2, and 3.7 ± 0.2 Mev are observed (Fr 52).

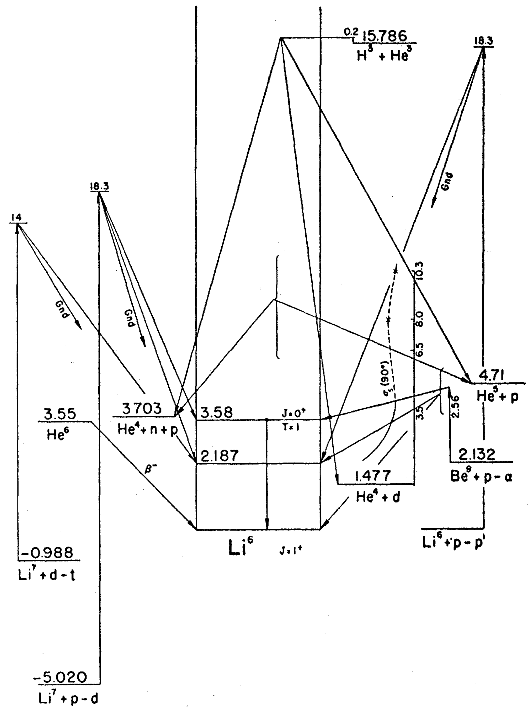

FIG. 4. Energy levels of Li^6: for notation, see Fig. 1.

Fr 52 Franzen and Likely, Phys. Rev. **87**, 667 (1952).

IX. $Li^7(d\ t)Li^6$ $Q_m=-0.988$

At $E_d=14$ Mev, two triton groups are observed, corresponding to the ground state and to an excited state at 2.15 ± 0.2 Mev (Go 51a).

Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).

X. $Be^9(p\ \alpha)Li^6$ $Q_m=2.132$

Recent Q-values for the ground state are:

$Q_0=2.121\pm0.007$ (To 49b: mag. spectrometer).
$Q_0=2.142\pm0.006$ (St 51: mag. spectrometer).
$Q_0=2.130\pm0.010$ (Ca 51: electrostatic analyzer).
$Q_0=2.123\pm0.004$ (Wi 51d: electrostatic analyzer)

A second group is observed at $E_p=2.3$ to 3.3 Mev, with $Q=-0.064\pm0.005$, locating the level at 2.187 ±0.009 Mev: the width is less than 8 kev. At $E_p=2.34$ Mev, $\theta=135°$, the differential cross section is 2.2 ± 1 mb/sterad (Br 51f).

A gamma-ray of 3.58 ± 0.04 Mev is observed in coincidence with α-particles at $E_p=2.56$ Mev. The fact that gamma-radiation can compete successfully with disintegration into (He^4+H^2) suggests that this is the expected $J=0$, even level analogous to the ground state of He^6 (Da 52). If it is indeed the analog level, it has isobaric spin $T=1$, and thus disintegration into (He^4+H^2) is prohibited independently of ordinary spin and parity selection rules (Ad 52a). The internal pair conversion coefficient of the γ-transition is consistent with magnetic dipole radiation (R. J. Mackin, private communication).

To 49b Tollestrup, Fowler, and Lauritsen, Phys. Rev. **76**, 428 (1949).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Ca 51 Carlson, Phys. Rev. **84**, 749 (1951).
Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Br 51f Browne, Williamson, Craig, and Donahue, Phys. Rev. **83**, 179 (1951).
Da 52 Day and Walker, Phys. Rev. **85**, 582 (1952).
Ad 52a Adair, Phys. Rev. **87**, 1041 (1952).

Be^6

(not illustrated)

Mass of Be^6

Be^6 is almost certainly unstable (by about 2 Mev) to disintegration into He^4+2H^1. See (Be 38a).

I. (a) $He^3(He^3\ 2p)He^4$ $Q_m=12.884$
(b) $He^3(He^3\ p)Li^5$ $Q_m=11.08$

A continuous distribution of protons extending to $E_p\sim 11$ Mev is observed at $E(He^3)=300$ kev. A departure in shape from that expected for a classical three-body distribution suggests that reaction (b) also occurs (Go 51g).

Go 51g Good, Kunz, and Moak, Phys. Rev. **83**, 845 (1951).
See also: Fo 51, Bo 52.

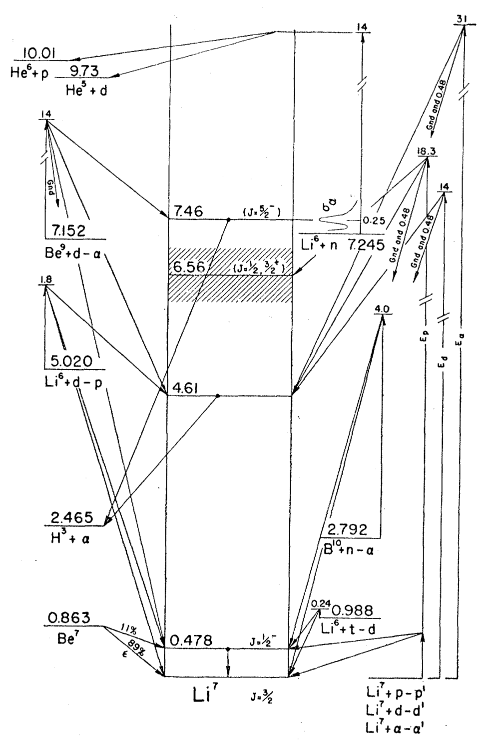

FIG. 5. Energy levels of Li^7: for notation, see Fig. 1.

Li^7

I. $Li^6(n\ n)Li^6$ $E_b=7.245$

The coherent scattering cross section is ~ 6 b (Sh 51b: bound atoms, epithermal neutrons, total σ_s not reported). The total cross section at $E_n=14$ Mev is 1.39 ± 0.05 b (Co 52h).

Sh 51b Shull and Wollan, Phys. Rev. **81**, 527 (1951).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
See also: Hu 52e.

II. $Li^6(n\ p)He^6$ $Q_m=-2.77$ $E_b=7.245$

The cross section for formation of He^6 is 6.7 ± 0.8 mb at $E_n=14$ Mev (Ba 52e).

Ba 52e Battat and Ribe, Phys. Rev. **88**, 159A (1952).

III. $Li^6(n\ d)He^5$ $Q_m=-2.48$ $E_b=7.245$

The cross section at $E_n=14.2$ Mev is ~ 140 mb (Ri 52a).

Ri 52a Ribe, Phys. Rev. **87**, 205A (1952).

IV. $Li^6(n\ \alpha)H^3$ $Q_m=4.780$ $E_b=7.245$

The ranges of the α-particle (1.04 ± 0.02 cm) and triton (6.00 ± 0.06 cm) observed in this reaction with thermal neutrons are used in conjunction with the Q-value 4.788 ± 0.023 Mev, obtained from $Q(Li^6(p\ \alpha)He^3)+Q(He^3(n\ p)H^3)$, to fix points on the range-energy curve (Be 50d, Je 50g, see also Fr 51). The weighted mean of $Q(Li^6(p\ \alpha)He^3)+Q(He^3(n\ p)H^3)$ is 4.783 ± 0.006 Mev, while the "adjusted" value is 4.780 ± 0.006 Mev (Li 51a). A direct determination, from an ionization chamber measurement, is 4.804 ± 0.022 (Fa 51, Fa 51a: not corrected for possible variation of energy per ion pair, see, e.g., Ha 50e).

The isotopic thermal capture cross section is 910 b; up to $E_n\sim 50$ ev the cross section varies as $1/v$ (Hu 52e). In the region $E_n=0$ to 0.8 Mev, one resonance, at 0.25 Mev, with a peak cross section of 3.5 b and a width of ~ 150 kev is reported (Hu 52e, Ad 50). There is some evidence for a broad resonance at $E_n\sim 2.0$ Mev (Ke 50a). The cross sections at $E_n=2.49$ and 14.2 Mev are 188 and 26 mb, ± 14 percent, respectively (Ri 52a).

The angular distribution of the tritons at the $E_n=0.25$-Mev resonance has a maximum in the forward direction and a minimum at $\theta=90°$ (Ro 51). At $E_n=0.6$ Mev the minimum occurs at $\theta=110°$ (Ro 51f). These observations are consistent with the assumption of resonant p-wave capture, with interference from non-resonant s-waves (Pe 51a).

The cross section of 3.5 b at the 0.25-Mev resonance points to $J=5/2$: larger values of J are excluded by the Wigner sum rule (if $\Gamma_n>\Gamma_\alpha$). If the state is assumed to be formed by p-wave neutrons, the reduced width and the energy agree well with the mirror state in Be^7. The $1/v$ cross section at low energy is attributed to a broad state at ~6.4 Mev formed by *s*-wave neutrons (see $Li^6(p\,p')Li^6$) (Ba 51e).

Be 50d Bethe, Revs. Modern Phys. **22**, 213 (1950).
Je 50g Jesse and Sadauskis, Phys. Rev. **78**, 1 (1950).
Li 51a Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
Fa 51 Facchini, Gatti, and Germagnoli, Phys. Rev. **81**, 475; **82**, 555 (1951).
Fa 51a Facchini, Gatti, and Germagnoli, Nuovo cimento **8**, 145 (1951).
Ha 50e Hanna, Phys. Rev. **80**, 530 (1950).
Hu 52e Hughes, *et al.*, AECU 2040 (1952).
Ke 50a Keepin, Phys. Rev. **80**, 768 (1950).
Ri 52a Ribe, Phys. Rev. **87**, 205A (1952).
Ro 51 Roberts, Darlington, and Haugsnes, Phys. Rev. **82**, 299 (1951).
Ro 51f Roberts and Mann, Phys. Rev. **83**, 202 (1951).
Pe 51a Peshkin and Siegert, Phys. Rev. **83**, 202 (1951).
Ba 51e Bashkin and Richards, Phys. Rev. **84**, 1124 (1951).
See also: Ro 49d, Ti 49, Ad 50, Co 50d, Ke 50, Ke 50b, Wa 50e, Fr 51, Pe 52c.

V. $Li^6(d\,p)Li^7$ $Q_m = 5.020$

$Q = 5.019 \pm 0.007$ (St 51: mag. spectrometer)

The excitation energy of the first excited state is given as 483 ± 6 kev from measurement of the proton groups (Bu 48c) and 477.4 ± 2 kev from the γ-ray energy (Th 52, corrected for Doppler shift and broadening). A third proton group, corresponding to a level at 4.61 ± 0.02 Mev, is observed at $E_d \sim 1.0$ Mev (Ge 52).

The angular distributions of both long- and short-range protons (ground and 478 kev state) have been measured from $E_d = 0.3$ to 1.4 Mev. In the range $E_d = 0.3$ to 1.0 Mev, the long-range protons appear to require terms as high as $\cos^4\theta$ and are at least as complex as the distributions for short-range protons, which may only involve $\cos^2\theta$ and lower terms (Du 51a, Du 51b). The present results agree with those of (Wh 50d), but not those of (Kr 50), and are consistent with a spin of $\frac{1}{2}$ for the excited state. At higher energies, both groups become increasingly complex, involving terms as high as $P_6(\cos\theta)$ (Wh 50d). The strong fore-and-aft symmetry indicates mixing of entering deuteron waves of opposite parity: it is not unlikely that the stripping process provides a more realistic description of the behavior of this reaction at $E_d > 1$ Mev.

The angular distribution of γ-rays (with respect to the deuteron beam) is isotropic at $E_d = 0.7$ Mev (Cl 52: ± 2 percent). The correlation of short-range protons and γ-rays is isotropic to within ~2 percent at $E_d = 0.5$ to 1.0 Mev (Ne 51a, Th 51d, Bu 52e, Cl 52, Ph 52). Since the protons are themselves anisotropically distributed at these energies, a spin of $\frac{1}{2}$ for the Li^{7*} state at 478 kev is strongly indicated.

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Bu 48c Buechner, Strait, Stergiopoulos, and Sperduto, Phys. Rev. **74**, 1569 (1948).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Ge 52 Gelinas and Hanna, Phys. Rev. **86**, 253 (1952).
Du 51a Dunbar and Hirst, Phys. Rev. **83**, 164 (1951).
Du 51b Dunbar and Hirst, Australian J. Sci. Res. **4**, 268 (1951).
Wh 50d Whaling and Bonner, Phys. Rev. **79**, 258 (1950).
Kr 50 Krone, Hanna, and Inglis, Phys. Rev. **80**, 603 (1950).
Cl 52 Class and Hanna, Phys. Rev. **87**, 247 (1952).
Ne 51a Newton, Proc. Phys. Soc. (London) **64A**, 938 (1951).
Th 51d Thirion, Compt. rend. **232**, 2418 (1951).
Bu 52e Burke and Risser, Phys. Rev. **87**, 294 (1952).
Ph 52 Phillips, Heydenburg, and Cowie, Phys. Rev. **85**, 742 (1952).
See also: Cu 50a, Cl 51, Ta 51d, In 52a.

VI. $Li^6(t\,d)Li^7$ $Q_m = 0.988$

$Q = 0.982 \pm 0.007$ (Pe 52: mag. analysis)

At $E_t = 240$ kev, $\theta = 90°$, the 478-kev excited state is produced in ~20 percent of the disintegrations. If *p*-wave deuterons are assumed, the barrier factors are in the ratio 4:1, indicating that the ground state and the 478-kev state would be formed with equal probability in the absence of the barrier (Pe 52).

Pe 52 Pepper, Allen, Almqvist, and Dewan, Phys. Rev. **85**, 155 (1952).

VII. $Li^7(p\,p')Li^{7*}$

At low bombarding energies, ~1 Mev, two proton groups appear, corresponding to the ground state and the first excited state at 479.0 ± 1 kev (Br 51a), 478.2 ± 1.2 kev (Wi 51d; limit of error quoted). The γ-ray transition energy is reported as 476.7 ± 1 kev (Ho 49a; includes a 1.6-kev Doppler correction, see, however, Th 52). The angular distribution of γ-radiation is isotropic from $E_p = 0.8$ to 1.08 Mev, suggesting $J = \frac{1}{2}$ for the 0.48-Mev state (Li 50b; see, however, Ar 51c). The inelastically scattered protons are not isotropic (Br 51a, Cl 52).

At $E_p = 7.9$ Mev, groups corresponding to the 0.48-Mev level and to one at 4.67 ± 0.08 Mev are observed; no other levels appear between these with intensity > 5 percent (Go 51a). The angular distribution of the $Q = -4.67$ Mev group is isotropic from $\theta = 32°$ to $84°$ (center-of-mass) (Go 51d). The 4.67-Mev level does not decay by γ-radiation, suggesting disintegration into $He^4 + H^3$ (Go 51h).

At $E_p = 18.3$ Mev, inelastically scattered protons corresponding to levels at 4.56 ± 0.10 and 6.56 ± 0.12 Mev are observed. The latter group has a considerable breadth. No group corresponding to the 7.46-Mev level was observed above a high background presumably due to protons from the $Li^7(p\,pn)Li^6$ reaction (see Li^6) (Fr 52).

Br 51a Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951).
Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Ho 49a Hornyak, Lauritsen, and Rasmussen, Phys. Rev. **76**, 731 (1949).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Li 50b Littauer, Proc. Phys. Soc. (London) **63A**, 294 (1950).
Ar 51c Arfken, Biedenharn, and Rose, Phys. Rev. **84**, 89 (1951).
Cl 52 Class and Hanna, Phys. Rev. **87**, 247 (1952).
Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).
Go 51d Gove and Harvey, MIT Prog. Rept. (LNSE) January (1951).

Go 51h Gove, Phys. Rev. **84**, 1059 (1951).
Fr 52 Franzen and Likely, Phys. Rev. **87**, 667 (1952).

VIII. $Li^7(d\ d')Li^{7*}$

The Q-value for the first excited state is -477 ± 1.5 kev: an average of this value and that from $Li^7(p\ p')Li^{7*}$, measured in the same experiment, is $Q=-478.0\pm1.2$ (Wi 51d: limit of error quoted). At $E_d=14$ Mev, a deuteron group corresponding to a level at 4.86 ± 0.15 Mev is observed: no group corresponding to the 7.5-Mev level appears (Go 51a).

Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).
See also: Sh 51a.

IX. $Li^7(\alpha\ \alpha')Li^{7*}$

At $E_\alpha=31$ Mev a group with $Q=-4.8\pm0.2$ Mev is observed. No group corresponding to the 7.5-Mev level appears. A continuum, corresponding to $Li^7(\alpha\ 2\alpha)H^3$, is also observed (Go 51a).

Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).

X. $Li^7(\gamma\ p)He^6$ $Q_m=-9.678$ (not illustrated)

The threshold is 9.8 ± 0.5 Mev (Mc 49). Ten events have been observed in Li-loaded emulsions at $E_\gamma=14$ 8 to 17.6 Mev: $\sigma=0.2\pm0.09$ mb (Ti 50b).

Mc 49 McElhinney, Hanson, Becker, Duffield, and Diven, Phys. Rev. **75**, 542 (1949).
Ti 50b Titterton, Proc. Phys. Soc. (London) **63A**, 1297 (1950).

XI. $Li^7(\gamma\ t)He^4$ $Q_m=-2.465$ (not illustrated)

Six hundred events have been observed in lithium-loaded emulsions bombarded with 6.1-Mev γ-rays. The cross section is 0.0265 ± 0.01 mb; the angular distribution of tritons with respect to the incident γ-rays is $1-(0.1\pm0.09)\cos\theta$. It is suggested that the transition goes mainly by EQ and MD radiation, leading to a $^2P_{\frac{1}{2}}$, odd state, with some admixture of ED transition (Na 52a). At $E_\gamma=14$ to 17 Mev, $\sigma=0.12\pm0.06$ mb (Ti 50a).

Na 52a Nabholz, Stoll, and Wäffler, Phys. Rev. **86**, 1043 (1952).
Ti 50a Titterton, Proc. Phys. Soc. (London) **63A**, 915 (1950).

XII. $Be^7(\epsilon)Li^7$‡ $Q_m=0.863$

The spectrum of recoils exhibits a peak at the high energy end, indicating that only a single neutrino is emitted (Da 52b): the maximum recoil energy is 55.9 ±1.0 ev (Da 52b), 56.6 ± 1.0 ev (Sm 51).

About 11 percent of the transitions lead to the first excited state. The weighted mean of reported values for the γ-ray energy is 478.0 ± 0.8 kev (Ho 50b).

The half-life is 52.93 ± 0.22 days (Se 49). Log $ft=3.36$ (ground state), 3.56 (excited state) (Fe 51b).

‡ The symbol (ϵ) indicates orbital electron capture.

Da 52b Davis, Phys. Rev. **86**, 976 (1952).
Sm 51 Smith and Allen, Phys. Rev. **81**, 381 (1951).
Se 49 Segrè and Wiegand, Phys. Rev. **75**, 39 (1949).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
See also: Ho 50b, Se 51a, Le 51.

XIII. (a) $Be^9(d\ \alpha)Li^7$ $Q_m=7.152$
(b) $Be^9(d\ 2\alpha)H^3$ $Q_m=4.687$

Recently reported ground-state Q-values are:

$Q=7.150\pm0.008$ (St 51: mag. spectrometer),
$Q=7.151\pm0.010$ (Wh 51: mag. spectrometer),
$Q=7.159\pm0.009$ (Wi 51d: electrostatic analyzer).

The energy of the first excited state is given as 482 ± 3 kev from the α-particle groups (Bu 48c): the γ-ray line is asymmetrically broadened by Doppler effect (Ra 49a, Ra 50a).

At $E_d=0.6$ to 1 Mev, three α-particle groups are observed, corresponding to the ground state, the 0.48-Mev state, and one at 4.62 ± 0.02 Mev (Ge 51b, Ha 52c). There are, in addition, continuous distributions of α-particles and tritons which correspond to the breakup of Li^{7*} in the 4.6-Mev state into He^4+H^3 and to the reaction $Be^9(d\ t)Be^{8*}$ (Ha 52c, Cu 52). At $E_d=1.0$ Mev, about one-third of the $(d\ \alpha)$ processes lead to the 4.6-Mev state: the direct three-body reaction (b) apparently does not occur (Cu 52: see, however, In 50b). At $E_d=0.3$ to 0.7 Mev, the combined α_0 and α_1 groups, corresponding to the ground- and 0.48-Mev states, are approximately isotropic (Re 51a).

At $E_d=5.3$ Mev the second level is reported as 4.59 ±0.1 Mev (As 52). At $E_d=14$ Mev, three groups of α-particles are observed, corresponding to the ground state of Li^7 (not resolved from the 478-kev level) and to levels at 4.76 ± 0.15 and 7.5 ± 0.17 (?) Mev (Go 51a).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Wh 51 Whaling and Li, Phys. Rev. **81**, 150 (1951).
Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Bu 48c Buechner, Strait, Stergiopoulos, and Sperduto, Phys. Rev. **74**, 1569 (1948).
Ra 49a Rasmussen, Lauritsen, and Lauritsen, Phys. Rev. **75**, 199 (1949).
Ra 50a Rasmussen, Ph.D. thesis, California Institute of Technology (1950).
Ge 51b Gelinas, Class, and Hanna, Phys. Rev. **83**, 1260 (1951).
Ha 52c Hanna and Gelinas, NYO 3290, The Johns Hopkins University (1952).
Cu 52 Cüer and Yung, Compt. rend. **234**, 204 (1952).
In 50b Inglis, Phys. Rev. **78**, 104 (1950).
Re 51a Resnick and Hanna, Phys. Rev. **82**, 463 (1951).
As 52 Ashmore and Raffle, Proc. Phys. Soc. (London) **65A**, 296 (1952).
Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).
See also: In 50, Ho 50b, Ge 51a.

XIV. $B^{10}(n\ \alpha)Li^7$ $Q_m=2.792$

Recently reported Q-values are:

$Q=2.80\pm0.05$ (Bu 50g: magnetic analysis),

$\begin{cases} 2.695\pm0.02 \\ 2.775\pm0.02^* \end{cases}$ (Bi 52: ion chamber),

$\begin{cases} 2.693\pm0.023 \\ 2.793\pm0.027^* \end{cases}$ (Ha 50e: ion chamber).

The 0.720-cm range of the α-particle group leading to the excited state ($Q=2.316$) is used to fix a point on the range-energy relation (Be 50d, Je 50g). An ionization measurement gives Q for this group as 2.310 ± 0.010 (Je 50).

The relative yield of short-range α-particles depends on neutron energy: see B^{11}.

The angular distribution of γ-rays with respect to the direction of alpha-particles is spherically symmetrical, suggesting that the excited state has $J=\frac{1}{2}$ (Ro 50).

Bu 50g Burcham and Freeman, Phil. Mag. **41**, 337 (1950).
Bi 52 Bichsel, Halg, Huber, and Stebler, Helv. Phys. Acta **25**, 119 (1952).
Ha 50e Hanna, Phys. Rev. **80**, 530 (1950).
Rh 52 Rhodes, Franzen, and Stephens, Phys. Rev. **87**, 141 (1952).
Be 50d Bethe, Revs. Modern Phys. **22**, 213 (1950).
Je 50g Jesse and Sadauskis, Phys. Rev. **78**, 1 (1950).
Je 50 Jesse, Forstat, and Sadauskis, Phys. Rev. **77**, 782 (1950).
Ro 50 Rose and Wilson, Phys. Rev. **78**, 68 (1950).
See also: Av 50, Fr 50f, Cu 51, In 51, Hu 51a, In 51a, In 52, Rh 52.

XV. $B^{11}(\gamma\ \alpha)Li^7$ $Q_m=-8.667$ (not illustrated)

See B^{11}.

Be^7

I. $Be^7(\epsilon)Li^7$‡ $Q_m=0.863$

The decay is complex: see Li^7.

II. $Li^6(p\ \gamma)Be^7$ $Q_m=5.600$

The thick-target yield of capture radiation at $E_p=0.95$ Mev is $<2.5\times10^{-10}\ \gamma/p$ (Cu 39).

Cu 39 Curran and Strothers, Proc. Roy. Soc. (London) **172**, 72 (1939).

III. (a) $Li^6(p\ \alpha)He^3$ $Q_m=4.017$ $E_b=5.600$
(b) $Li^6(p\ p')Li^{6*}$

Recently reported Q-values for reaction (a) are:

$Q=4.017\pm0.022$ (To 49b: mag. spectrometer),
$Q=4.021\pm0.006$ (St 51: mag. spectrometer),
$Q=4.015\pm0.006$ (Co 51d: mag. spectrometer),
$Q=4.024\pm0.005$ (Wi 51d: elect. analyzer).

The excitation function for He^3 particles observed at $\theta=164°$ exhibits a broad, low maximum at $E_p=0.6$ to 0.9 Mev and a pronounced peak at $E_p=1.82\pm0.08$ Mev, where the differential cross section is $\sim$8 mb/sterad. In the range $E_p=1.3$ to 3.1 Mev, the elastically scattered protons have a single maximum, $\sigma=120$ mb/sterad, at $E_p=1.75\pm0.1$ Mev with a width $\Gamma=0.5$ Mev (Ba 51e).

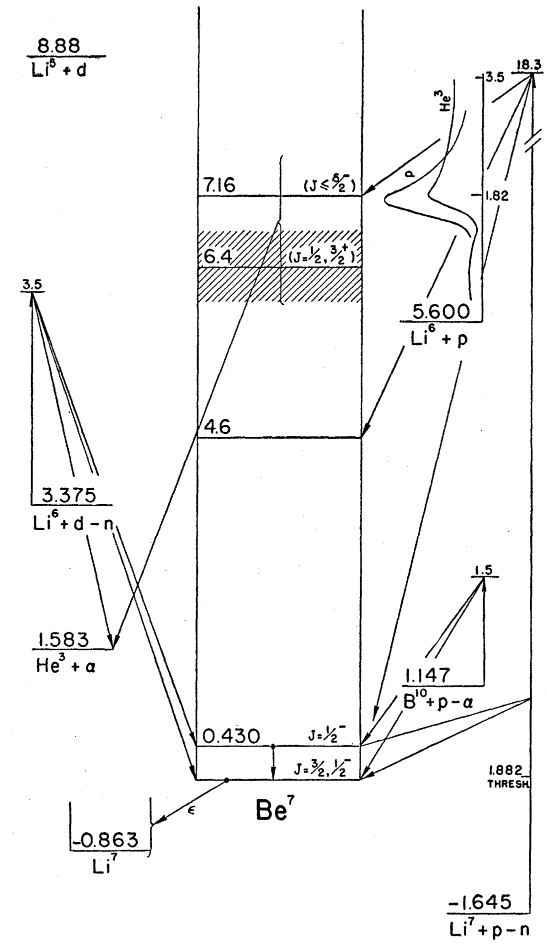

FIG. 6. Energy levels of Be^7: for notation, see Fig. 1.

The low energy resonance is attributed to s-wave protons, forming a state in Be^7 with $J=\frac{3}{2}$ or $\frac{1}{2}$, even. A rough fit to the total cross-section data is given by the parameters, $(2J+1)\Gamma_\alpha=0.24$ Mev, $E_\lambda=6.4$ Mev (above the ground state) and a reduced width, $\gamma^2\sim0.9\times10^{-12}$ Mev-cm, of the order of the sum-rule limit. This state corresponds both in location and in character to the level required to account for the strong 1/v s-wave neutron absorption of Li^6, subsequently identified in $Li^6(p\ p')Li^{6*}$ (see Li^7). The 1.8-Mev resonance is formed either by s-waves or p-waves: higher angular momenta lead to reduced widths exceeding the sum-rule limit. The parameters γ^2 and E_λ agree with those for the corresponding level of Li^7 (0.25-Mev resonance in $Li^6(n\ \alpha)H^3$) only if $l=1$ is assumed, for which $\gamma_p{}^2=0.26\times10^{-12}$ Mev cm, $E_\lambda=7.31$ Mev ($\Gamma_p=0.4$ Mev, $\Gamma_\alpha=0.03$ Mev, center-of-mass system), $J\leq5/2$, odd (Ba 51e).

From the relative yield of He^4 and He^3 particles at $\theta=164°$, it appears that the He^3 are strongly bunched forward. For $E_p<0.9$ Mev the asymmetry increases with bombarding voltage. This observation is consistent

* (The values indicated by asterisks have been corrected for an assumed variation of energy loss per ion pair: see Ha 50e, Rh 52.)
‡ The symbol (ϵ) indicates orbital electron capture.

with the interference expected from the two states of opposite parity (Ba 51e). The angular distribution of α-particles is isotropic at $E_p=0.2$ Mev (Ne 37a).

To 49b Tollestrup, Fowler, and Lauritsen, Phys. Rev. **76**, 428 (1949).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Co 51d Collins, McKenzie, and Ramm, Nature **167**, 682 (1951).
Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Ba 51e Bashkin and Richards, Phys. Rev. **84**, 1124 (1951).
Ne 37a Neuert, Physik. Z. **38**, 618 (1937).

IV. (a) $Li^6(d\,n)Be^7$ $Q_m=3.375$
(b) $Li^6(d\,n)He^3+He^4$ $Q_m=1.792$

At low bombarding energies, $E_d\sim 1$ Mev (far below the threshold for the 4.6-Mev level), reactions (a) and (b) are roughly equally probable (see Ho 50b). Reaction (a) results in two well-defined neutron groups, corresponding to the ground- and 0.43-Mev states of Be^7, in ratio about 2:1. At $E_d=3.5$ Mev, the angular distributions of the neutron groups indicate odd parity and $J=\frac{1}{2}$ or $\frac{3}{2}$ for both states. No convincing observation of an expected level near 4.6 Mev was possible because the continuum due to reaction (b) and neutrons from oxygen contamination combined to obscure the region in which such a level might have been observed (Aj 52, Aj 52a).

The γ-ray energy is 430.0±1.5 kev: correction for Doppler shift and broadening effects gives 428.9±2 kev. The difference between the Li^7 and Be^7 energies is 48.5±1.0 kev (Th 52). The γ-rays are emitted isotropically, $I(90°)/I(180°)=1.06\pm0.08$, with respect to the neutrons at $E_d=0.550$ Mev. Since the neutrons are not isotropic with respect to the deuteron beam, it is concluded that the 430-kev state of Be^7 has $J=\frac{1}{2}$ (Th 51f). The γ-rays are isotropic with respect to the deuteron beam within ~2 percent at $E_d=0.7$ Mev (Cl 52).

Aj 52 F. Ajzenberg, Phys. Rev. **87**, 205A (1952).
Aj 52a F. Ajzenberg, Ph.D. thesis, University of Wisconsin (1952).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Th 51f Thirion, Comptes rend. **233**, 37 (1951).
Cl 52 Class and Hanna, Phys. Rev. **87**, 247 (1952).
See also: Ho 50b, Hu 51g, Fe 51, Mo 51, In 51.

V. $Li^7(p\,n)Be^7$ $Q_m=-1.645$

The threshold of this reaction is used as a reference energy for many voltage measurements: recent determinations are listed in Table I(7).

TABLE I(7). $Li^7(p\,n)Be^7$ threshold determinations.

Thresh., Mev (abs)	Reference	Method
1.8822±0.0019	He 49	Absolute electrostatic analyzer
1.8812±0.0019	Sh 49d	Radiofrequency velocity measurement
1.8813±0.0007	St 51g	Electrostatic analyzer:[a] relative to RaC′
(1.8816±0.0009)		Unweighted mean: see St 51g

[a] RaC′ =7.6802 Mev ±0.007 percent: relative to this, the Po α-energy is, according to (St 51g), 5.296±0.002 Mev.

TABLE II(7). $Li^7(p\,n)Be^7$ neutron groups.

ΔQ	E_p (Mev)	θ	I_1/I_0(%)[a]	Reference
431±5	2.75	30°	9±1.5	Jo 50b
	2.89	30°	10.5±1	
	3.66	30°	12±1	
470±70	5.0	20°–90°	52.5	[b]Gr 50
435±15	3.31	0°	17±10	Jo 50
	3.91	0°	9±4	
	3.91	60°	16±6	
428±20	3.12	0°	8±2	Ha 50b
	2.70	0°	8±2	
428±15	3.49	0°	10±3	Fr 50a
433±26	3.00	0°, 30°, 90°		Ke 50a
	3.60			
	4.35			

[a] Relative intensity of first excited state and ground-state groups.
[b] Two other levels at 0.2 and 0.7 Mev reported by (Gr 50) have not been confirmed.

TABLE III(7). $B^{10}(p\,\alpha)Be^7$ Energy of first excited state.

ΔQ (kev)	Reference	Method
434 ±4	Br 51a	α's, magnetic spectrometer
431 ±5	Va 50	α's, magnetic spectrometer
430 ±3	Cr 52c	α's, electrostatic spectrometer
428.5±1.8	Th 52	γ's, corr. for Doppler effect[a]
432 ±2	Da 52a	γ's, scintillation spectrometer

[a] 429.8±1.5 uncorrected.

At $E_p>2.4$ Mev, two neutron groups are observed, corresponding to the formation of Be^7 in the ground and in the 430 kev excited state. Table II(7) exhibits the reported data. A threshold for production of slow neutrons at $E_p=2.378$ Mev yields a value 434 kev for Be^{7*} (Wi 51a).

Work at $E_p=18.2$ Mev, $\theta=16°$ and 60°, photoplate, indicates levels in Be^7 at 4.6±0.2 and 7.1±0.2 Mev (D. M. Thomson, private communication).

He 49 Herb, Snowden, and Sala, Phys. Rev. **75**, 246 (1949).
Sh 49d Shoupp, Jennings, and Jones, Phys. Rev. **76**, 502 (1949).
St 51g Sturm and Johnson, Phys. Rev. **83**, 542 (1951).
Wi 51a Willard and Preston, Phys. Rev. **81**, 480 (1951).
See also: Gr 50, Jo 50, Jo 50b, Ha 50b, Fr 50a, Ke 50a.

VI. $B^{10}(p\,\alpha)Be^7$ $Q_m=1.147$ Mev

Reported values of the ground-state Q are:

$Q=1.148\pm0.006$ (Br 51a: mag. spectrometer),
$Q=1.152\pm0.004$ (Va 50: mag. spectrometer),
$Q=1.147\pm0.010$ (Bu 50g: mag. spectrometer),
$Q=1.147\pm0.0025$ (Cr 52b, Cr 52c: electr. analyzer).

Measurements of the energy of the first excited state of Be^7 are reported in Table III(7). A search at $E_p=7$ Mev for a group corresponding to a possible level at ~4.7 Mev has thus far been unsuccessful (Bu 52a).

Br 51a Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951).
Va 50 Van Patter, Sperduto, Strait, and Buechner, Phys. Rev. **79**, 900 (1950).
Bu 50g Burcham and Freeman, Phil. Mag. **41**, 337 (1950).
Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).

Cr 52c Craig, Donahue, and Jones, Phys. Rev. (to be published).
Bu 52a Buechner *et al.*, M. I. T. Progress Report (LNSE), February (1952).
See also: Li 51a, Cr 52, Da 52a, Th 52, Cr 52c.

Li^8

I. $Li^8(\beta^-)Be^8$ $Q_m=15.987$

The half-life is 0.825 ± 0.02 sec (Ra 51). The decay is complex: see Be^8. Li^8 frequently appears as a fragment in violent nuclear disintegrations: see, e.g., Wr 50, Mi 50d, Ti 51a, Ho 51c.

Ra 51 Rall and McNeill, Phys. Rev. **83**, 1244 (1951).
See also: Wr 50, Mi 50d, Ti 51a, Ho 51c.

II. $Li^6(t\,p)Li^8$ $Q_m=0.800$

$Q=0.784\pm0.015$ Mev (Pe 52: mag. analysis).

At $E_t=240$ kev, $\theta=90°$, the $(t\,p)$ reaction is about 4 percent as intense as the $Li^6(t\,d)Li^7$ ground-state reaction (Pe 52). Production of Li^8 has been confirmed (Mo 52).

Pe 52 Pepper, Allen, Almqvist, and Dewan, Phys. Rev. **85**, 155 (1952).
Mo 52 Moak, Good, and Kunz, Phys. Rev. **85**, 928 (1952).

III. $Li^7(n\,\gamma)Li^8$ $Q_m=2.037$

The thermal capture cross section is 33 ± 5 mb (Hu 47a). This anomalously high value can be understood as the result of a large extra-nuclear contribution to the matrix element of the dipole moment. The required magnitude is consistent with the known features of the thermal neutron scattering (Th 51g).

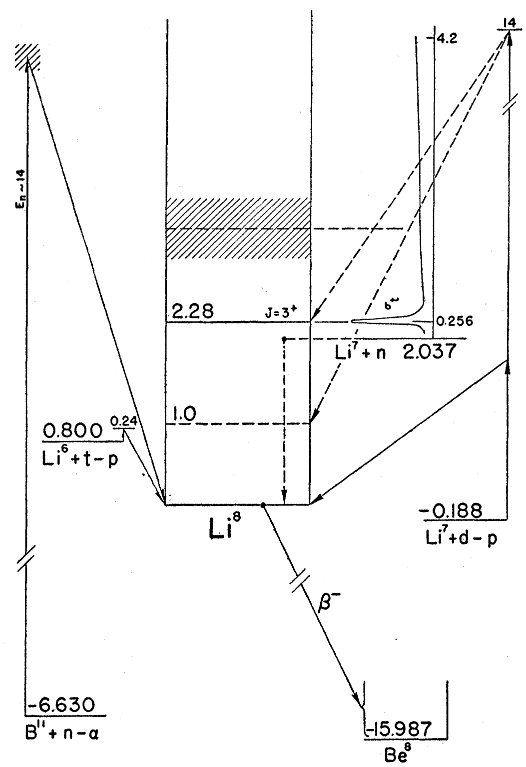

FIG. 7. Energy levels of Li^8: for notation, see Fig. 1.

Hu 47a Hughes, Hall, Eggler, and Goldfarb, Phys. Rev. **72**, 646 (1947).
Th 51g Thomas, Phys. Rev. **84**, 1061 (1951).

IV. $Li^7(n\,n)Li^7$ $E_b=2.037$

The coherent scattering amplitude is negative: $\sigma_{coh}=0.80\pm0.05$ b, $\sigma_{total}=1.5\pm0.4$ b (bound atoms, epithermal neutrons) (Sh 51b, Hu 52e).

The cross section has a sharp peak at $E_n=256$ kev. It rises monotonically from 1.2 b at $E_n=0.6$ Mev to 2.25 b at $E_n=4.2$ Mev (Bo 51c, C. H. Johnson, private communication).

Parameters for the resonance are:

$$E_{res}=260,\quad \sigma_{max}-\sigma_{pot}=7\text{ b},\quad \Gamma=45\text{ kev (Ad 50a)},$$
$$E_{res}=256,\quad \sigma_{max}-\sigma_{pot}=10\text{ b},\quad \Gamma=40\text{ kev (St 51f)}.$$

The resonance is attributed to a state with $J=3$, formed by p-wave neutrons (St 51f: see, however, Bo 51c). The reduced width γ_λ^2 is 11 percent of the sum-rule limit. The rise in cross section at higher energies is attributed to a superposition of several broad levels (Bo 51c). It can be shown that scattering lengths of Li^7 are negative for both channel spins, indicating that two levels with $J=1$ and 2 are to be expected at $E_n\sim1.5$ Mev (Ad 50a, Sh 51b, and R. K. Adair, private communication).

The total cross section at $E_n=14.1$ Mev is 1.45 ± 0.03 b (Co 52h).

Sh 51b Shull and Wollan, Phys. Rev. **81**, 527 (1951).
Hu 52e Hughes *et al.*, AECU 2040 (1952).
Bo 51c Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).
Ad 50a Adair, Phys. Rev. **79**, 1018 (1950).
St 51f Stelson and Preston, Phys. Rev. **84**, 162 (1951).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
See also: Wa 51e, Te 52.

V. $Li^7(n\,d)He^6$ $Q_m=-7.79$ $E_b=2.037$

(not illustrated)

The cross section for formation of He^6 is 9.8 ± 1.1 mb at $E_n=14$ Mev (Ba 52e).

Ba 52e Battat and Ribe, Phys. Rev. **88**, 159A (1952).

VI. $Li^7(d\,p)Li^8$ $Q_m=-0.188$

Recently reported Q-values are:

$Q=-187\pm10$ kev (Pa 50a, angular threshold),
$Q=-188\pm7$ (St 51, mag. spectrometer),
$Q=-192\pm1$ (Wi 51d, elect. analyzer).

At $E_d\sim14$ Mev, proton groups are observed which may correspond to levels at 1.0 ± 0.2 and 2.3 ± 0.2 Mev (Go 51a).

Pa 50a Paul, Phil. Mag. **41**, 942 (1950).

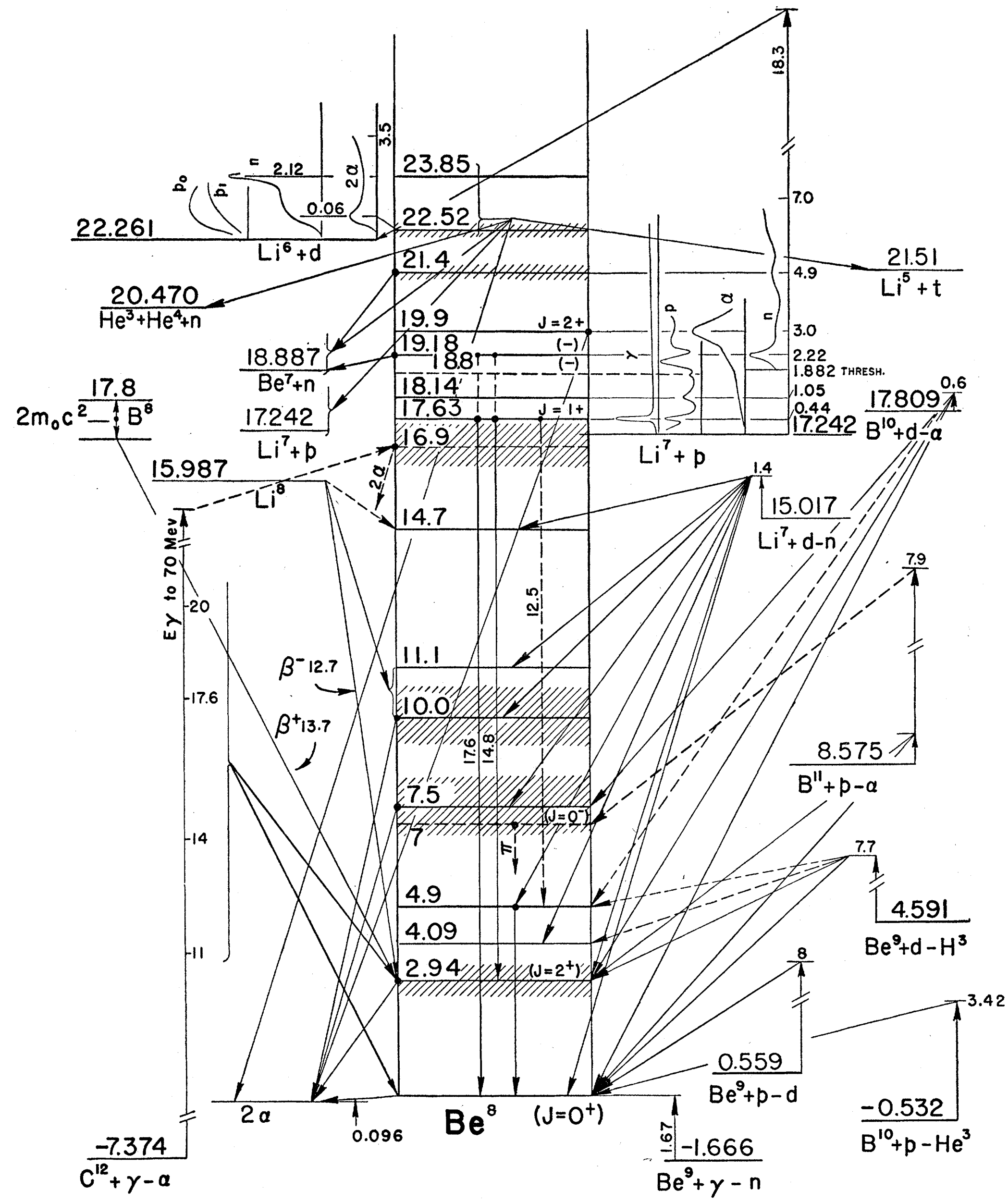

FIG. 8. Energy levels of Be^8: for notation, see Fig. 1.

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).

VII. $Be^9(\gamma\ p)Li^8$ $Q_m = -16.871$ (not illustrated)

$Q = 16.93 \pm 0.15$ Mev (Tu 52a).

See also (Ho 50b).

Tu 52a Tucker and Gregg, Phys. Rev. **87**, 907 (1952).

VIII. $B^{11}(n\ \alpha)Li^8$ $Q_m = -6.630$

See (Ho 50b).

Be^8

I. $Be^8 \rightarrow 2He^4$ $Q_m = 0.096$

Direct determinations of the disintegration energy are: Q (kev) $= 103 \pm 10$ (He 49b), 89 ± 5 (To 49b), 85 ± 9 (Cr 50, Cr 50a), 96 ± 3 (Do 52a). According to the Chicago group (private communication), preliminary attempts to confirm the Q of 77.5 ± 5 kev reported by (Ca 51) have not succeeded. It is suspected that interference from scattered proton groups arising from an unfocused portion of the beam may have led to the spurious result. A half-life of $< 5 \times 10^{-14}$ sec is reported from a study of $O^{16}(\gamma\ 4\alpha)$ tracks (Mi 51, Wi 51g, and A. G. W. Cameron, private communication). An upper limit of 2×10^{-14} sec is given by (Ho 52d).

He 49b Hemmendinger, Phys. Rev. **75**, 1267 (1949).
To 49b Tollestrup, Fowler, and Lauritsen, Phys. Rev. **76**, 428 (1949).
Cr 50 Crussard, Compt. rend. **231**, 141 (1950).
Cr 50a Crussard, Nature **166**, 825 (1950).
Do 52a Donahue, Ph.D. thesis, University of Wisconsin (1952).
Ca 51 Carlson, Phys. Rev. **84**, 749 (1951).
Mi 51 Millar and Cameron, Phys. Rev. **81**, 316 (1951).
Wi 51g Wilkins and Goward, Proc. Phys. Soc. (London) **64A**, 849 (1951).
Ho 52d Hodgson, Phil. Mag. **43**, 190 (1952).

II. $He^4(\alpha\ \alpha)He^4$ $E_b=-0.096$

A phase shift analysis of early scattering data indicates a state of Be^8 at 3 Mev, 0.8 Mev wide, with spin zero and even parity (Wh 41a). It is suggested, however, that a reasonable fit to the observations can also be obtained by assuming a ${}^1D_2$ character for the state as is expected on a simple α-particle model. This assignment is also more consistent with observations in $Li^8(\beta^-)Be^8$ and $B^{11}(p\ \alpha)Be^8$ (Ha 51e).

The scattering of 30-Mev α-particles in He exhibits strong angular dependence: analysis indicates $-85.5°$, $+45.5°$, $+35.5°$ for the nuclear component of the s-, d-, and g-wave phase shifts, respectively (Gr 51). At $E_\alpha=20$ Mev, the differential cross section decreases monotonically with increasing angle (Ma 51a) although there is indication in later data of a rise at $\theta_{cm}=90°$ (Br 51i).

Scattering at $E_\alpha=0.4$ to 1.0 Mev is under investigation (Co 52b).

Wh 41a Wheeler, Phys. Rev. **59**, 16 (1941).
Ha 51e Haefner, Revs. Modern Phys. **23**, 228 (1951).
Gr 51 Graves, Phys. Rev. **84**, 1250 (1951).
Ma 51a Mather, Phys. Rev. **82**, 126 (1951).
Br 51i Braden, Carter, and Ford, Phys. Rev. **84**, 837 (1951).
Co 52b Cowie, Heydenburg, Temmer, and Little, Phys. Rev. **86**, 593A (1952).

III. (a) $Li^6(d\ n)Be^7$ $Q_m=3.374$ $E_b=22.261$
(b) $Li^6(d\ n)He^4+He^3$ $Q_m=1.791$

A broad resonance for neutron production at 90° is observed at 0.41 Mev (after correction for barrier factor); a further, sharp resonance appears at 2.12 Mev. The differential cross sections at 868 kev are 15 mb/sterad at 90° and 33.6 mb/sterad at 0° (Ba 52).

The thick $Li^6{}_2SO_4$-target yield of 430-kev radiation (from Be^{7*}) at $E_d=1.49$ Mev is 1×10^{-6} γ/d (Th 52).

Ba 52 Baggett and Bame, Phys. Rev. **85**, 434 (1952).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).

IV. (a) $Li^6(d\ p)Li^7$ $Q_m=5.020$ $E_b=22.261$
(b) $Li^6(d\ p)He^4+H^3$ $Q_m=2.555$

The excitation function for the ground-state proton group rises to a maximum at $E_d\sim0.8$ Mev, $\sigma(0°)=7$ mb/sterad, and falls slowly to $E_d=1.8$ Mev. The short-range protons (0.48-Mev state of Li^7) exhibit a similar behavior, although their yield continues to rise slowly above $E_d=0.8$ Mev. For the former, the evidence is consistent with a broad resonance at $E_d=347$ kev (see $Li^6(d\ \alpha)He^4$) (Wh 50d). The angular distribution of long-range protons involves all powers of $(\cos\theta)$ up to and including $\cos^4\theta$, requiring d-wave deuterons. The existence of odd powers of $\cos\theta$ indicates mixing of entering deuteron waves of opposite parity (Du 51a, Du 51b: see Li^7).

It is to be expected in analogy with the $Li^6(d\ n)$ reactions, that the three-body reaction (b) will also occur. A continuum of protons is in fact observed but is attributed to $Li^6(d\ t)Li^5(p)He^4$ (Ge 52).

Wh 50d Whaling and Bonner, Phys. Rev. **79**, 258 (1950).
Du 51a Dunbar and Hirst, Phys. Rev. **83**, 164 (1951).
Du 51b Dunbar and Hirst, Australian J. Sci. Res. **4**, 3, 268 (1951).
Ge 52 Gelinas and Hanna, Phys. Rev. **86**, 253 (1952).
See also: Kr 50.

V. $Li^6(d\ \alpha)He^4$ $Q_m=22.357$ $E_b=22.261$

The yield curve exhibits a broad maximum, $\sigma(90)°$ ~5 mb/sterad, at $E_d=0.6$ Mev, falling off to ~2 mb/sterad at $E_d=1.6$ Mev. After correction for the variation with energy of the barrier penetration, the resonance energy is found to be $E_d=347$ kev and the width ~520 kev (Wh 50d). The yield appears to rise again at higher energies, possibly approaching a second peak at $E_d>3.5$ Mev (He 48e).

The angular distribution is of the form $1+A(E)\cos^2\theta+B(E)\cos^4\theta$: the behavior of $A(E)$ and $B(E)$ reflects the increasing contribution of d-wave deuterons at the higher energies. A reasonable fit to the data is obtained if a "sharp" state at $E_d\sim0.75$ Mev with $J=2^+$ and a broad state with $J=0^+$ are assumed (Re 49b). The assumption of an additional state near $E_d=4$ Mev leads to some improvement, but this improvement is not considered to be very significant because of the large number of parameters involved (Re 51).

Wh 50d Whaling and Bonner, Phys. Rev. **79**, 258 (1950).
He 48e Heydenburg, Hudson, Inglis, and Whitehead, Phys. Rev. **74**, 405 (1948).
Re 49b Resnick and Inglis, Phys. Rev. **76**, 1318 (1949).
Re 51 Resnick, Phys. Rev. **82**, 447 (1951).
See also: Du 51b.

VI. $Li^6(d\ t)Li^5$ $Q_m=0.75$ $E_b=22.261$

See Li^5.

VII. $Li^6(d\ He^3)He^5$ $Q_m=0.77$ $E_b=22.261$
(not illustrated)

This reaction has not been reported.

VIII. $Li^6(t\ n)He^4+He^4$ $Q_m=16.100$ (not illustrated)

This reaction has been observed in Li-loaded emulsions at $E_t=3.8$ Mev. The disintegration is believed to proceed through the 7.5-Mev level of Be^8 (Cu 52a).

Cu 52a Cüer and Magnac-Valette, Compt. rend. **234**, 1049 (1952).

IX. $Li^7(p\ \gamma)Be^8$ $Q_m = 17.242$

A strong resonance exists at $E_p = 441.1 \pm 0.5$ kev with a width of 12 kev and a resonance cross section of 6.6 mb (Fo 49b, Bo 48c). The reduced width γ_λ^2 is 0.063 of the sum-rule limit (Te 52); the radiation width $\omega\Gamma\gamma$ is 9.4 ev (Fo 49b). A recent report by (Hu 52f) gives $E_p = 441.5 \pm 0.5$ kev, $\Gamma = 12.2 \pm 0.5$ kev for the resonance (absolute elect. analyzer).

There is an appreciable background above resonance which rises slowly to $E_p = 5.2$ Mev; no further resonances greater than 3 percent of the 440-kev resonance are observed (Ba 52a).

The γ-radiation comprises two components: $Q = 17.2 \pm 0.2$ Mev (sharp) and $Q = 14.4 \pm 0.3$ Mev (broad) with relative intensities which vary with bombarding energy: both components exhibit resonance (Wa 48). There is some indication of a third line at $E_\gamma = 12.5$ Mev (Na 52, Go 52a). At resonance, the 14.8- and 17.6-Mev γ-rays are individually isotropic, within ~ 6 percent (De 50a, St 51c, Na 52). This observation is automatically consistent with s-wave formation ($Be^{8*} = 1^-$) and is consistent with p-wave formation only if the mixing ratio t of channel spin 1 to channel spin 2 is $\frac{1}{5}$ (De 50a). The ratio $t = \frac{1}{5}$ is not inconsistent with the $Li^7(p\ p)Li^7$ analysis and is exactly the ratio obtained with either pure $L-S$ coupling, $^3S_1$ state, or pure $j-j$ coupling, $j = \frac{1}{2}$ for the incoming proton (Ch 52b).

The angular distribution off resonance is anisotropic, different for the two γ-rays, and contains a strong ($\cos\theta$) term, indicating interference in the neighborhood of the resonances between the resonant (p) waves and other, nonresonant, waves of opposite parity (De 49d, St 51c, Na 52). At higher energies, $E_p \sim 1$ Mev, it would seem that components of opposite parity in the nonresonant entering waves may account for the interference effects. The fact that the angular distributions are different for the two γ-ray lines suggests that the ground- and 2.9-Mev states of Be^8 have different angular momenta (St 51c, Na 52).

Observation of the α-particles associated with the 14.8-Mev γ-ray yields an energy 3.03 ± 0.1 Mev and a width ~ 2 Mev for the lower Be^8 level (Bu 50h).

Fo 49b Fowler and Lauritsen, Phys. Rev. **76**, 314 (1949).
Bo 48c Bonner and Evans, Phys. Rev. **73**, 666 (1948).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
Hu 52f S. E. Hunt (to be published).
Ba 52a Bair, Willard, Snyder, Hahn, Kington, and Green, Phys. Rev. **85**, 946 (1952).
Wa 48 Walker and McDaniel, Phys. Rev. **74**, 315 (1948).
Na 52 Nabholz, Stoll, and Wäffler, Helv. Phys. Acta **25**, 153 (1952).
Go 52a Goward and Wilkins, A.E.R.E. Memo G/M 127, March (1952).
De 50a Devons and Lindsey, Proc. Phys. Soc. (London) **63A**, 1202 (1950).
St 51c Stearns and McDaniel, Phys. Rev. **82**, 450 (1951).
Ch 52b Christy (to be published).
De 49d Devons and Hine, Proc. Roy. Soc. (London) **199**, 56, 73 (1949).
Bu 50h Burcham and Freeman, Phil. Mag. **41**, 921 (1950).
See also: Na 50, Ho 50b, Na 51, Ca 51a.

X. $Li^7(p\ p)Li^7$ $E_b = 17.242$

The elastic scattering yield exhibits maxima at $E_p \simeq 0.44$, 1.05, 2.1, and 2.6 Mev (Br 51a, Ba 51e). The first is clearly associated with the 440-kev resonance in $Li^7(p\ \gamma)Be^8$. The peak cross section varies from 1.4 times Rutherford scattering at $\theta = 50°$ to 2.2 times at $\theta = 160°$ (center-of-mass system) (Wa 52a, Br 51a). The variation of the cross section and the shift of the peak location with energy require interpretation in terms of p-wave resonance scattering with, possibly, a small amount of s-wave potential scattering. The "mixing ratio," t, of channel spin 1 to 2 is not critically determined and the ratio $t = \frac{1}{5}$ required to account for the isotropy of the γ-rays (see $Li^7(p\ \gamma)Be^8$) is not unreasonable (Christy and Lieberman, private communication).

The second maximum is associated with the $E_p = 1.03$-Mev resonance observed in $Li^7(p\ p')Li^{7*}$. The peak cross section is 0.112 barn/sterad at $\theta = 90°$, 0.097 b/sterad at $\theta = 145°$ (Br 51a) and ~ 0.08 barn/sterad at $\theta = 166°$ (Ba 51e) (center-of-mass system).

A small cusp occurs at the neutron threshold ($E_p = 1.88$ Mev). It is not clear whether this cusp is to be associated with the neutron threshold (Te 52) or with a possible resonance just below (Ba 51e) (see $Li^7(p\ n)Be^7$).

The structure near $E_p = 2.2$ Mev may be associated with the pronounced resonance observed in $Li^7(p\ n)Be^7$ (Ba 52e).

Br 51a Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
Ba 51e Bashkin and Richards, Phys. Rev. **84**, 1124 (1951).
Wa 52a Warters and Milne, Phys. Rev. **85**, 761 (1952).
Ba 52e Battat and Ribe, Phys. Rev. **88**, 159A (1952).

XI. $Li^7(p\ p')Li^{7*}$ $E_b = 17.242$

A pronounced resonance appears at $E_p = 1.030 \pm 0.005$ Mev with a width of 168 kev (corrected for variation of penetration factors). The protons are anisotropically distributed: $\sigma(90°) \sim 2.9$ mb/sterad, $\sigma(145°) \sim 5$ mb/sterad (Br 51a). From $E_p = 1.5$ to 3.5 Mev, the yield rises smoothly except for a change in slope between 2.2 and 2.3 Mev (Ba 51e). (There appears to be some discrepancy between the two experiments as regards absolute values.)

Br 51a Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951).
Ba 51e Bashkin and Richards, Phys. Rev. **84**, 1124 (1951).
See also: Cl 52.

XII. $Li^7(p\ n)Be^7$ $Q_m = -1.645$ $E_b = 17.242$
Threshold: $E_p = 1.882$ Mev (see Be^7).

Resonances occur in neutron yield at $E_p = 2.22$ Mev ($\Gamma \sim 0.2$ Mev), $\sigma_{res} = 0.50$ b (Ta 48) and 4.89 Mev, $\Gamma \sim 0.4$ Mev (Ba 52a, Bl 51a). The reduced width γ_λ^2 of the 2.2-Mev resonance is 2.0 percent of the sum-rule limit (Te 52).

The angular distribution in the range $E_p = 2.0$ to 2.5 Mev exhibits a strong ($\cos\theta$) dependence, with a coefficient which changes rapidly in the neighborhood of the resonance (Ta 48). The course of the angular distribution and the cross section suggests that the reaction takes place mainly through the entry of s-wave protons, forming a state at $E_p=2.2$ Mev ($J=1$ or 2, odd) and possibly another similar state somewhat below threshold, with strong interference from a general p-wave background (Br 48a).

The cross section for formation of the compound nucleus appears to be a decreasing function of energy just above threshold, lending support to the hypothesis of a level just below (Bo 51b) (see also $Li^7(p\ p)Li^7$).

Ta 48 Taschek and Hemmendinger, Phys. Rev. **74**, 373 (1948).
Ba 52a Bair, Willard, Snyder, Hahn, Kington, and Green, Phys. Rev. **85**, 946 (1952).
Bl 51a Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
Br 48a Breit and Bloch, Phys. Rev. **74**, 397 (1948).
Bo 51b Bonner and Butler, Phys. Rev. **83**, 1091 (1951).

XIII. $Li^7(p\ \alpha)He^4$ $Q_m=17.337$ $E_b=17.242$

Recently reported Q-values are:

$Q=17.340\pm0.014$ (St 51: mag. spectrometer),
$Q=17.338\pm0.011$ (Wh 51: mag. spectrometer),
$Q=17.325\pm0.013$ (Co 51d: mag. spectrometer).

The yield exhibits a broad maximum at $E_p=3$ Mev. The angular distribution is of the form $Y(\theta)=1+A(E)\cos^2\theta+B(E)\cos^4\theta$: the coefficient $A(E)$ has a maximum value of ~2.2 at $E_p\sim1$ Mev, while $B(E)$ varies slowly from about -0.5 at $E_p=1$ to 2 Mev to 0 at $E_p=3.5$ Mev. Analysis indicates a level ~1 Mev broad, possibly at $E_p=3$ Mev, with $J=2$, even, and a several Mev broad level of $J=0$, even, underlying the whole region (see Ho 50b).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Wh 51 Whaling and Li, Phys. Rev. **81**, 150 (1951).
Co 51d Collins, McKenzie, and Ramm, Nature **167**, 682 (1951).
See also: Ho 50b, Ta 51a, Hi 51a.

XIV. $Li^7(p\ d)Li^6$ $Q_m=-5.020$ $E_b=17.242$

See Li^6.

XV. $Li^7(d\ n)Be^8$ $Q_m=15.017$

Neutron groups indicate levels in Be^8 at: $E_d=2.8$ ($\Gamma=0.8$), 4.05, 4.9, 7.5 ($\Gamma=1.7$), 10 ($\Gamma\sim1.5$), 11.1, and 14.7 Mev. A 4.9 ± 0.3 Mev γ-ray is observed (see Ho 50b).

The $n-\gamma$ angular correlation at $E_d=0.55$ Mev has the form $1-A\cos^2\theta$, with $A=0.41\pm0.03$. Analysis suggests $J=\frac{1}{2}$ for the Be^9 state at 17.21 Mev and $J=1$ for the 4.9-Mev state of Be^8 (Th 51f: see, however, Ch 52b).

Th 51f Thirion, Compt. rend. **233**, 37 (1951).
Ch 52b Christy (to be published).
See also: Ho 50b, Th 51e, Tu 51, Hu 51g.

XVI. $Li^7(t\ 2n)He^4+He^4$ $Q_m=8.55$ (not illustrated)

See (Cu 52a).

XVII. $Li^8(\beta^-)Be^8$ $Q_m=15.987$

The β-spectrum indicates about 90 percent of the transitions going to the 3-Mev state, 10 percent to states at ~10 and ~13 Mev, less than 2 percent to the ground state, and less than 5 percent to the 4.9-Mev state (Ho 50). The α-spectrum exhibits a peak corresponding to a level at 2.98 ± 0.06 Mev, of width 1.26 Mev (corrected for E^5 dependence of electron distribution but not for barrier penetration). The high energy α-particles observed seem insufficient to fit the β-decay data, suggesting that some γ-emitting states may be involved (Li 51 and private communication). A weak $\beta-\gamma$ coincidence effect is observed, attributed tentatively to a 2 ± 1 percent branch leading to the 4.9-Mev level of Be^8 (Ve 51b). Log ft for the transition to the 2.9-Mev state is 5.60 (Fe 51b).

The $\beta-\alpha$ angular correlations have been calculated for two suggested schemes: $0^+\rightarrow2^+$ and $3^-\rightarrow2^+$ (Ga 51a).

Ho 50 Hornyak and Lauritsen, Phys. Rev. **77**, 160 (1950).
Li 51 Li and Whaling, Phys. Rev. **81**, 661 (1951).
Ve 51b Vendryes, Compt. rend. **233**, 391 (1951).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
Ga 51a Gardner, Phys. Rev. **82**, 283 (1951).
See also: Ba 50e, Ch 52.

XVIII. $Be^9(\gamma\ n)Be^8$ $Q_m=-1.666$

Recently reported Q-values are:

$Q=-1.666\pm0.002$ (Mo 50),
$Q=-1.664\pm0.002$ (No 52).

Mo 50 Mobley and Laubenstein, Phys. Rev. **80**, 309 (1950).
No 52 Noyes, Van Hoomissen, Miller, and Waldman, Phys. Rev. **85**, 727 (1952).

XIX. $Be^9(p\ d)Be^8$ $Q_m=0.559$

Recently reported Q-values are:

$Q=0.558\pm0.003$ (To 49b: mag. spectrometer),
$Q=0.562\pm0.004$ (St 51: mag. spectrometer),
$Q=0.558\pm0.005$ (Ca 51: elect. analyzer),
$Q=0.558\pm0.002$ (Wi 51d: elect. analyzer).

At $E_d=5$ to 8 Mev, the deuterons are strongly bunched forward (Ha 51a); see also B^{10}.

To 49b Tollestrup, Fowler, and Lauritsen, Phys. Rev. **76**, 428 (1949).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Ca 51 Carlson, Phys. Rev. **84**, 749 (1951).
Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Ha 51a Harvey, Phys. Rev. **82**, 298 (1951).

XX. (a) $Be^9(d\ t)Be^8$ $Q_m=4.591$
(b) $Be^9(d\ t)He^4+He^4$

Recently reported Q-values for reaction (a) are:

$Q=4.597\pm0.013$ (St 51: mag. spectrometer),
$Q=4.61\ \pm0.04$ (Re 51a: range),
$Q=4.67\ \pm0.03$ (El 51: range).

At $E_d\sim1$ Mev a broad group of tritons and a continuum of α-particles are observed, corresponding to formation of the 2.94-Mev state of Be^8 and its subsequent breakup (Ha 52c, Cu 52). The excited state is formed about twice as frequently as the ground state: the three-body reaction (b) appears not to occur (Cu 52: see Li^7).

There is some evidence for a triton group with $Q=-0.025$, corresponding to a state at 4.62 Mev (W. W. Buechner, private communication, Bo 50d). (Sa 52a) reports a triton group corresponding to a level energy of 4.090 ± 0.018 Mev ($E_d=0.5$ Mev, $\theta=90°$).

The angular distribution of ground-state tritons is reported by (Re 51a, $E_d=0.6$ to 0.7 Mev), by (Fu 52, $E_d=3.6$ Mev), and by (El 51, $E_d=7.70$ Mev). The distributions exhibit a pronounced forward bunching, suggesting that a pick-up process occurs, without the intervention of a compound nucleus (El 51).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Re 51a Resnick and Hanna, Phys. Rev. **82**, 463 (1951).
Fu 52 Fulbright, Bruner, Bromley, and Goldman, Phys. Rev. (to be published).
El 51 El-Bedewi, Proc. Phys. Soc. (London) **64A**, 947 (1951).
Ha 52c Hanna and Gelinas, NYO 3290, The Johns Hopkins University (1952).
Cu 52 Cüer and Yung, Compt. rend. **234**, 204 (1952).
Bo 50d Boyer, MIT Prog. Rept. (LNSE), July (1950).
Sa 52a Salmon, (to be published).

XXI. $B^8(\beta^+)Be^8$ $Q_m=17.8$

The maximum positron energy, obtained by the Feather comparison method, is 13.7 ± 0.3 Mev. The absorption curve of α-particles is in agreement with that calculated from the Li^8 spectrum: it appears that B^8 decays mainly to the 2.9-Mev level of Be^8 as does Li^8 (Al 50g).

Al 50g Alvarez, Phys. Rev. **80**, 519 (1950).

XXII. $B^{10}(d\ \alpha)Be^8$ $Q_m=17.809$

Alpha-particle groups corresponding to levels at 0, 3.0, 4.8, and 7.0 Mev are reported: the 4.8-Mev group may be due to contamination (Sm 39). Recently reported Q-values for the first two groups are $Q=17.92\pm0.15$ and $Q=15.19\pm0.15$, giving a level energy of 2.73 ± 0.20 Mev. The level width is 0.95 ± 0.20 Mev (Wh 51b).

Sm 39 Smith and Murrell, Proc. Cambridge Phil. Soc. **35**, 298 (1939).
Wh 51b Whitehead, Phys. Rev. **82**, 553 (1951).

XXIII. $B^{10}(n\ t)Be^8$ $Q_m=0.232$ (not illustrated)

One-hundred stars resulting from this reaction, observed in boron-loaded photographic emulsions bombarded by neutrons with energies up to 24 Mev, have been analyzed. The relative probability of formation of various states of Be^8 is a function of neutron energy and appears to be determined largely by the penetrability of the triton. The transition to the ground state is not observed (Pe 51b).

Pe 51b Perkin, Phys. Rev. **81**, 892 (1951).

XXIV (a) $B^{10}(\gamma\ d)He^4+He^4$ $Q_m=-\ 5.930$
(b) $B^{11}(\gamma\ t)Be^8$ $Q_m=-11.227$

(not illustrated)

These reactions have been observed in boron-loaded photographic emulsions. Reaction (b) appears to involve both the ground- and 2.9-Mev states of Be^8. There is no conclusive evidence that Be^8 occurs in reaction (a) (Goward and Wilkins, private communication).

See: Go 50e, Wi 50d, Ca 51d, Br 51g, Br 51j, Ch 52a, Ro 52c.

XXV. $B^{10}(p\ He^3)Be^8$ $Q_m=-0.532$

$Q=-0.536\pm0.003$ (Cr 52b: elect. analyzer).

Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).

XXVI. $B^{11}(p\ \alpha)Be^8$ $Q_m=8.575$

$Q_0=8.567\pm0.011$ (St 51: mag. spectrometer)
$Q_0=8.574\pm0.014$ (Li 51a: mag. spectrometer)

At $E_p=1.00$ Mev, $\theta=90°$, the α-spectrum consists of a sharp peak, corresponding to the ground-state transition, a broad but well-resolved group, 35 times as intense, corresponding to a level at 2.94 ± 0.06 Mev of width 1.1 Mev (uncorrected for barrier penetration), and a continuum extending to lower energies, attributed to the breakup of the recoiling Be^{8*} (Li 51 and private communication).

The reaction exhibits a sharp resonance at $E_p=163$ kev, where the ground-state group comprises only a few percent of the total yield. Since it appears probable that the compound state of C^{12} has $J=2$ and even parity, this observation is consistent with $J=2^+$ and $J=0^+$ for the 2.9-Mev and ground state of Be^8, respectively (Ha 51e).

A strongly anisotropic correlation is observed, both at $E_p=163$ and 340 kev between the α-particle leading to the 2.9-Mev state of Be^8 and one of the two α-particles from the subsequent disintegration of Be^8. This result rules out the possibility of zero spin for the 2.9-Mev state of Be^8 (Nelson and Wolicki, private communication).

At $E_p=7.9$ Mev, a soft radiation consisting of coincident components is observed: it is suggested that the radiation may be due to nuclear pairs from an odd parity level at about 7 Mev in Be^8 (Ph 51b).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).

Li 51a Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
Li 51 Li and Whaling, Phys. Rev. **81**, 661 (1951).
Ha 51e Haefner, Revs. Modern Phys. **23**, 228 (1951).
Ph 51b Phillips, Cowie, and Heydenburg, Phys. Rev. **83**, 1049 (1951).
See also: Ch 52, Th 52c.

XXVII. $C^{12}(\gamma\ \alpha)Be^8$ $Q_m = -7.374$

The yield exhibits pronounced peaks at $E_\gamma \sim 18$ and ~ 28 Mev, which have been resolved into several resonances (see C^{12}). At $E_\gamma \sim 11$ Mev, about 20 percent of the transitions lead to the ground state: near $E_\gamma = 18$ Mev, only ~ 2 percent lead to the ground state, the remainder presumably going to the 2.9-Mev state (or possibly via a 3-body reaction: Ch 51b). The fraction to the ground state again rises for $E_\gamma \sim 20$ to 25 Mev.

At $E_\gamma = 17.6$ Mev, where the reaction goes mainly to the 2.9-Mev state, the α-particle distribution has a pronounced peak at $E_\alpha = 4.88$ Mev, a minimum at ~ 2.5 Mev and a second, smaller maximum at ~ 1.2 Mev. The main peak yields a level energy of 2.9 Mev and a width 1.1 ± 0.1 Mev (Te 50c). The shape is well accounted for by the assumptions that the γ-interaction is about equally due to electric quadrupole and magnetic dipole and that the 2.9-Mev state of Be^8 has $J = 2^+$, respectively: the minimum results from the angular correlation in the magnetic dipole case. A small amount of electric dipole radiation, increasing at higher energies, may also be involved (Te 51b, Ed 52).

Two-hundred stars have been observed for $E_\gamma \geq 26$ Mev nearly all of which involve a state of Be^8 at 16.8 ± 0.2 Mev; the observed width of <0.7 Mev can be accounted for entirely by experimental resolution, and the real width is therefore unknown. Strong angular correlations indicate $J = 2$ or higher (Wi 51f and private communication). [It is not impossible that this is the isobaric spin $T = 1$ state analogous to the ground states of Li^8 and B^8. If this is the case, it might be expected that the actual width is considerably less than 0.7 Mev, since the isobaric spin selection rule would discourage disintegration into two alpha-particles.]

Ch 51b Chastel, Compt. rend. **233**, 1440 (1951).
Go 52a Goward and Wilkins, AERE Memo G/M 127, March (1952).
Te 50c Telegdi and Züntі, Helv. Phys. Acta **23**, 745 (1950).
Te 51b Telegdi, Phys. Rev. **84**, 600 (1951).
Ed 52 Eder and Telegdi, Helv. Phys. Acta **25**, 55 (1952).
Wi 51f Wilkins and Goward, Proc. Phys. Soc. (London) **64A**, 1056 (1951).
See also: Go 50h, Wi 50d, Wi 51c, Go 51c, Te 52a.

XXVIII. (a) $O^{16}(\gamma\ \alpha)C^{12*} \rightarrow Be^8 + He^4$ $Q_m = -14.522$

(not illustrated)

The reaction appears to proceed mainly through states of C^{12}. At $E_\gamma = 18$ Mev, the ground state of Be^8 is produced in almost 100 percent of the cases; the proportion drops approximately linearly to ~ 10 percent at $E_\gamma = 30$ Mev (Go 52a).

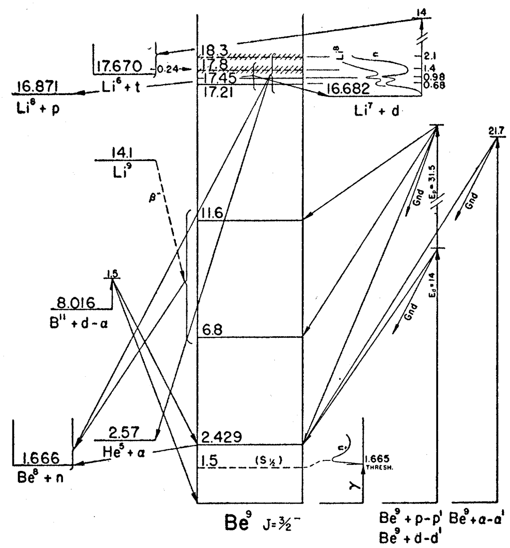

FIG. 9. Energy levels of Be^9: for notation, see Fig. 1.

Go 52a Goward, and Wilkins, AERE Memo G/M 127, (March, 1952).
See also: Go 50h, Wi 50d, Go 51c, Mi 51, Wi 51g, Ed 52.

B^8

(not illustrated)

Mass of B^8

From the $B^{10}(p\ t)B^8$ threshold, one obtains a mass defect of 26.0 Mev for B^8: it is stated, however, that the true threshold may be somewhat lower. Stability against proton emission requires a mass defect <25.4 Mev. The mass quoted by (Al 50g) is 8.027 M.u., corresponding to a mass defect of 25.1 Mev for which we adopt a probable error of 0.3 Mev.

I. $B^8(\beta^+)Be^8$ $Q_m = 17.8$

The half-life is 0.46 ± 0.03 sec (A. C. Birge, private communication); the decay is complex (see Be^8). A half-life of 0.61 ± 0.11 sec is reported by (Sh 52).

Sh 52 Sheline, Phys. Rev. **87**, 557 (1952).

II. $B^{10}(p\ t)B^8$ $Q_m = -18.3$

The threshold is $E_p \leq 21.2$ Mev $(Q \geq -19.3)$. B^8 is also produced in the reactions $Be^9(p\ 2n)B^8$ and $C^{12}(p\ n\alpha)B^8$ (Al 50g).

Al 50g Alvarez, Phys. Rev. **80**, 519 (1950).

Li^9

(not illustrated)

Mass of Li^9

The threshold for the reaction $Be^9(d\ 2p)Li^9$ is 19 ± 1 Mev (Ga 51c), implying a mass-difference $Li^9 - Be^9$ of 14.1 Mev; mass defect $= 28.1 \pm 1$ Mev.

I. $Li^9(\beta^-)Be^{9*}\to Be^8+n$ $Q_m=12.4$

Li^9 decays to excited states of Be^9 (half-life$=0.168\pm0.004$ sec, Ga 51c; 0.170 ± 0.005 sec, Ho 52b) which decay by neutron emission. Li^9 has been observed as a 0.19 ± 0.05 sec β^- emitter in the γ-bombardment of B^{11} (Sh 52).

Ga 51c Gardner, Knable, and Moyer, Phys. Rev. **83**, 1054 (1951).
Ho 52b Holt, Thorn, and Waniek, Phys. Rev. **87**, 378 (1952).
Sh 52 Sheline, Phys. Rev. **87**, 557 (1952).

II. $Be^9(d\ 2p)Li^9$ $Q_m=-15.5$

The threshold is $E_d=19\pm1$ Mev (Ga 51c).

Ga 51c Gardner, Knable, and Moyer, Phys. Rev. **83**, 1054 (1951).

Be^9

The ground state J of Be^9 is $\frac{3}{2}$ (Sc 51a, Gu 51b, Ha 51i).

I. (a) $Li^6(t\ d)Li^7$ $Q_m=0.988$ $E_b=17.670$
(b) $Li^6(t\ p)Li^8$ $Q_m=0.799$
(c) $Li^6(t\ n)Be^8$ $Q_m=16.004$
(d) $Li^6(t\ \alpha)He^5$ $Q_m=15.10$
(e) $Li^6(t\ n)He^4+He^4$ $Q_m=16.100$

At $E_t=240$ kev, $\theta=90°$, reaction (a) results in two deuteron groups, corresponding to the ground- and 0.48-Mev states of Li^7, in the ratio 54:14. Protons corresponding to the ground state of Li^8, produced in reaction (b) have intensity 2 on the same scale (Pe 52). A strong continuum of α-particles (from reactions (b), (c), (d), or (e)) is also observed (Pe 51).

Pe 52 Pepper, Allen, Almqvist, and Dewan, Phys. Rev. **85**, 155 (1952).
Pe 51 Pepper, Allen, Almqvist, and Dewan, Phys. Rev. **81**, 315A (1951).
See also: Mo 52, Cu 52a.

II. $Li^6(\alpha\ p)Be^9$ $Q_m=-2.132$ (not illustrated)

This reaction has not been observed: see (Ho 50b).

III. $Li^7(d\ p)Li^8$ $Q_m=-0.189$ $E_b=16.682$

Resonances for production of Li^8 occur at $E_d=0.75$, 1.00, and 1.4 Mev with cross sections 0.230, 0.235, and 0.255 b, and widths 0.25, 0.060, and 0.5 Mev, respectively (Ba 52).

Ba 52 Baggett and Bame, Phys. Rev. **85**, 434 (1952).

IV. (a) $Li^7(d\ n)Be^8$ $Q_m=15.016$ $E_b=16.682$
(b) $Li^7(d\ \alpha)He^5$ $Q_m=14.11$
(c) $Li^7(d\ n)He^4+He^4$ $Q_m=15.112$

Resonances for neutrons ($\theta=90°$) occur at $E_d=0.68$, 0.98, and 2.1 Mev; the cross sections are 39, 43, and 58 mb/sterad, and the widths are 0.25, 0.060, and 0.4 Mev, respectively (Ba 52). For further discussion of these reactions, see Be^8, He^5, and (Ho 50b).

The $n-\gamma$ angular correlation in reaction (a) has been studied: see Be^8.

Ba 52 Baggett and Bame, Phys. Rev. **85**, 434 (1952).
See also: Ho 50b.

V. $Li^7(d\ t)Li^6$ $Q_m=-0.988$ $E_b=16.682$

See Li^6.

VI. $Li^9(\beta^-)Be^{9*}\to Be^8+n$ $Q_m=12.4$

See Li^9.

VII. (a) $Be^9(\gamma\ n)Be^8$ $Q_m=-1.666$
(b) $Be^9(e\ e'n)Be^8$

(a) The cross section at $E_\gamma=2.76$ Mev is 0.674 mb ±8 percent (Sn 50: an average cross section for Ga^{72} γ-radiation is also cited). The course of the cross-section curve and of the angular distribution suggest that the transitions involved are $P_{\frac{3}{2}}\to S_{\frac{1}{2}}$ and $P_{\frac{3}{2}}\to D_{\frac{5}{2}}$, with the S-state at $\sim$1.5 Mev and the D-state somewhat higher (Mu 49); see (Ho 50b). (These levels have not appeared in any other experiment.)

(b) See (Ho 50b).

Sn 50 Snell, Barker, and Sternberg, Phys. Rev. **80**, 637 (1950).
Mu 49 Mullin and Guth, Phys. Rev. **76**, 682 (1949).
See also: Pr 50a, Hi 50, Ho 50b, Ar 51b, Sh 51d, Be 51c.

VIII. $Be^9(\gamma\ n)He^4+He^4$ $Q_m=-1.570$

The cross section for this reaction is $<10^{-3}$ mb at $E_\gamma=1.63$ Mev (Al 52a).

Al 52a Alburger, Phys. Rev. (to be published).

IX. $Be^9(\gamma\ p)Li^8$ $Q_m=-16.871$

The cross section for γ-rays of 18 to 24 Mev is 0.25 ± 0.1 mb (Ti 50). The yield has a broad maximum at $E_\gamma\sim32$ Mev (Ba 49b).

Ti 50 Titterton, Nature **165**, 721 (1950).
Ba 49b Baldwin, Phys. Rev. **76**, 182 (1949).

X. $Be^9(n\ n')Be^{9*}$

The cross section for this reaction is <14 mb at $E_n=2.5$ Mev (Gr 51a).

Gr 51a Grace, Beghian, Preston, and Halban, Phys. Rev. **82**, 969 (1951).

XI. $Be^9(p\ p')Be^{9*}$

Recent values for the energy of the first excited state are:

$2.39\ \pm0.05$	Mev	(Rh 50),
$2.5\ \ \pm0.2$	Mev	(Br 51e),
2.42	Mev	(Ar 52b),
2.57	Mev	(Co 52g),
2.433 ± 0.005	Mev	(Br 51f).

This state has approximately the energy expected from the α-particle model, which predicts $J=5/2^-$.

With this spin and parity, the level would not appear in the $Be^9(\gamma\ n)Be^8$ cross section (Ha 51e).

With 3.46-Mev protons the differential cross section at 135° is 1.4±0.4 mb/sterad. The level width is <3 kev (Br 51f).

Levels in Be^9 at 6.8±0.2 and 11.6±0.2 Mev have also been observed in the bombardment of Be^9 by 32-Mev protons (Br 51e, see Table I(9)).

Rh 50 Rhoderick, Proc. Roy. Soc. (London) **201**, 348 (1950).
Br 51e Britten, Princeton Univ. Rept. NYO **971**, June (1951).
Ar 52b Arthur, Allen, Bender, Hausman, McDole, Diana, Rhodes, and Barjon, Phys. Rev. **87**, 237A (1952).
Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).
Br 51f Browne, Williamson, Craig, and Donahue, Phys. Rev. **83**, 179 (1951).
Ha 51e Haefner, Revs. Modern Phys. **23**, 228 (1951).
See also: Br 51, Da 51a.

XII. $Be^9(\alpha\ \alpha')Be^{9*}$

A group of α-particles observed at 21.7-Mev bombarding energy corresponds to a level energy of 2.63 ±0.15 Mev (Mc 51b: range in Al). The slow neutrons observed at $E_\alpha>4.9$ Mev may be from this reaction: see C^{13}.

Mc 51b McMinn, Sampson, and Rasmussen, Phys. Rev. **84**, 963 (1951).

XIII. $Be^9(d\ d')Be^{9*}$

The energy of the first excited state is found to be 2.5 Mev (Bo 50d: $E_d=14$ Mev).

Bo 50d Boyer, MIT Prog. Rept. (LNSE), July (1950).

XIV. $B^{11}(d\ \alpha)Be^9$ $Q_m=8.016$

$Q=8.018\pm0.007$ Mev (Va 51: mag. spectrometer).

The energy of the first excited state is found to be 2.422±0.005 Mev (Va 51: $E_d=1.51$ Mev, mag. spectrometer). The alpha-group corresponding to this state has a natural half-width of less than 7 kev. No additional alpha-groups of more than 10 percent of the intensity of this group were observed which would correspond to excited states of Be^9 between 0 and 5 Mev (Va 51). The observation of $n-\alpha$ coincidences and the absence of $\alpha-\gamma$ coincidences indicate that the 2.4-Mev state decays mainly by neutron emission. A J of 2 or 3 would explain the small width (Di 52).

Va 51 Van Patter, Sperduto, Huang, Strait, and Buechner, Phys. Rev. **81**, 233 (1951).
Di 52 Dissanaike and Newton, Proc. Phys. Soc. (London) **65A**, 675 (1952).

TABLE I(9). Levels of Be^9 from $Be^9(p\ p')Be^{9*}$; $E_p=32$ Mev (Br 51e).

Be^{9*}	σ(θ) mb/sterad 90°	125°	160°
2.5±0.2	0.64±0.3	0.34±0.1	0.18±0.05
6.8±0.2	0.6	0.2	0.14
11.6±0.2	0.17	0.13	0.21

XV. $C^{12}(n\ \alpha)Be^9$ $Q_m=-5.708$ (not illustrated)

See C^{13}.

XVI. $B^{11}(n\ t)Be^9$ $Q_m=-9.561$ (not illustrated)

See B^{12}.

B^9

(not illustrated)

I. $Be^9(p\ n)B^9$ $Q_m=-1.851$

$E_{threshold}=-2.059\pm0.002$ Mev; $Q=-1.852\pm0.002$ (Ri 50e).

A measurement of the 585-kev resonance in sulfur using neutrons from this reaction gives a width for the B^9 ground state of <2 kev ($\tau>3\times10^{-19}$ sec) (St 51e).

The neutron spectrum at $E_p=3.8$ Mev shows a narrow group corresponding to the ground state of B^9 in addition to a continuous distribution of neutrons. No narrow levels have been observed for $B^{9*}\lesssim1.8$ Mev (Jo 50a).

Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
St 51e Stelson and Preston, Phys. Rev. **83**, 469 (1951).
Jo 50a Johnson, Ajzenberg, and Laubenstein, Phys. Rev. **79**, 187 (1950).
See also: Je 50c, Gu 51, Ha 52e.

II. $B^{10}(\gamma\ n)B^9$ $Q_m=-8.436$

$Q=-8.55\pm0.25$ (Sh 51d).

Sh 51d Sher, Halpern, and Mann, Phys. Rev. **84**, 387 (1951).
See also: Sh 51.

Be^{10}

I. $Be^{10}(\beta^-)B^{10}$ $Q_m=0.556$

The weighted mean end-point energy is 0.556±0.003 Mev (Li 51a). The mean half-life is $2.7\pm0.4\times10^6$ yr (Hu 49a): $\log ft=13.65$. The spectrum is of the D_2 type (Wu 50).

Li 51a Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
Hu 49a Hughes, Eggler, and Huddleston, Phys. Rev. **75**, 515 (1949).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
Wu 50 Wu, Revs. Modern Phys. **22**, 386 (1950).
See also: Ho 50b, Fe 50a, Bo 50e.

II. (a) $Li^7(t\ \alpha)He^6$ $Q_m=9.79$ $E_b=17.236$
(b) $Li^7(t\ 2n)Be^8$ $Q_m=8.759$
(c) $Li^7(t\ n)Be^9$ $Q_m=10.425$
(d) $Li^7(t\ n)He^5+He^4$ $Q_m=7.86$

Reaction (a) leads to two groups of α-particles, corresponding to the ground- and 1.7-Mev states of He^6, plus a continuum of neutrons and α-particles from the break-up of the excited state (De 52). Reaction (b) leads to a continuum of neutrons and α-particles, proceeding either through various states of Be^8 (Cu 52a) or by a direct four-body disintegration. Reaction (c)

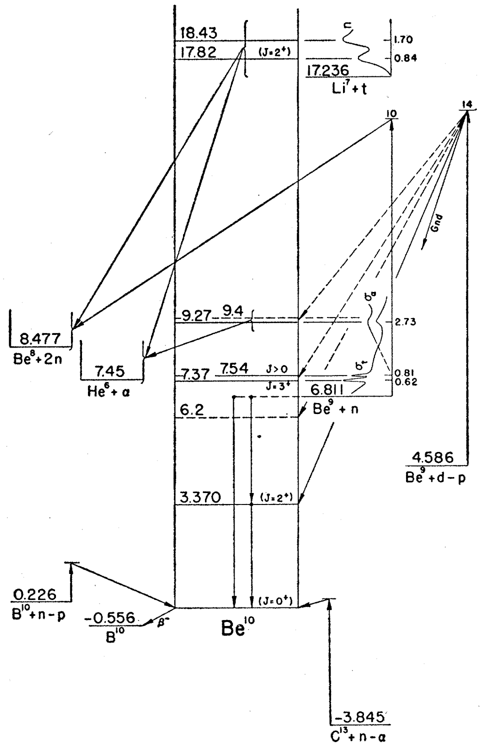

FIG. 10. Energy levels of Be^{10}: for notation, see Fig. 1.

should produce monochromatic neutrons, and, if excited states of Be^9 are formed, a continuum of α-particles and neutrons. Reaction (d) again would be expected to lead to a continuum of α-particles and neutrons.

The neutron yield (natural Li target) at 0° exhibits two broad resonances at $E_t=0.84$ and 1.70 Mev. An average total cross section of ~ 0.7 b is reported for the energy range $E_t=0.25$ to 2.0 Mev. The angular distributions are not isotropic (Cr 51b).

At $E_t=240$ kev, reaction (a) accounts for 20 percent of the disintegrations yielding α-particles at $\theta=90°$ (De 52). The ground-state α-particles are distributed as $1-(0.9\pm0.05)\cos^2\theta$ at $E_t=240$ kev, while those corresponding to the excited state of He^6 are nearly isotropic (Pe 52a). If these observations are ascribed to the 0.84-Mev resonance with $J=2$ even, formed by p-wave tritons, and emitting d-wave α-particles to the ground state and s-wave to the excited state, the assumption of a pure $^3P_2$ character for the compound state leads to $Y(\theta)=1-6/7\cos^2\theta$ (Ch 52b).

De 52 Dewan, Pepper, Allen, and Almqvist, Phys. Rev. **86**, 416 (1952).
Cu 52a Cüer and Magnac-Valette, Compt. rend. **234**, 1049 (1952).
Cr 51b Crews, Phys. Rev. **82**, 100 (1951).
Pe 52a Pepper, Almqvist, and Lorrain, Phys. Rev. **86**, 630A (1952).
Ch 52b Christy (to be published).
See also: Al 50i.

III. $Be^9(n\ \gamma)Be^{10}$ $Q_m=6.811$

The thermal cross section is 9.0 ± 0.5 mb (Hu 52e).

$Q=6.816\pm0.006$ (pair spectrometer: Bartholomew and Kinsey, private communication).

In addition to the ground-state transition, a 3.41 ±0.06-Mev γ-ray is observed, attributed to a cascade through the 3.37-Mev state. The intensity of the cascade is about 0.25 photon per capture and that of the ground state is 0.75 photon per capture (Ba 52f).

Hu 52e Hughes *et al.*, AECU 2040, (May 1952).
Ba 52f Bartholomew and Kinsey, Can. J. Phys. (to be published).
See also: Ki 51.

IV. $Be^9(n\ \alpha)He^6$ $Q_m=-0.64$ $E_b=6.811$

A resonance ($\sim$1 Mev wide) for production of He^6 occurs at $E_n=2.6$ Mev; the cross section is $\sim$50 mb (Al 47b). The cross section at $E_n=14$ Mev is 10 ± 1 mb (Ba 52e).

Al 47b Allen, Burcham and Wilkinson, Proc. Roy. Soc. (London) **192**, 114 (1947).
Ba 52e Battat and Ribe, Phys. Rev. **88**, 159A (1952).

V. $Be^9(n\ n)Be^9$ $E_b=6.811$

The epithermal cross section (free atoms) is 6.04 barns (Hi 49): the spin dependent scattering is <0.03 barn (Pa 52). From the fact that the scattering lengths for both quintet and triplet interactions are the same, positive (Sh 51b), and greater than the nuclear radius, it is concluded that two bound levels, with $J=1$ and 2, odd, may exist with binding energy $\lesssim 1.7$ Mev. The reported level at 6.2 Mev may correspond to one or both of these (R. G. Thomas, private communication).

In the region $E_n=0$ to 6 Mev, three resonances are reported, at 0.62, 0.81, and 2.73 Mev. The 0.62-Mev resonance has a width of 30 kev and a maximum cross section of 7 b ($\sigma_{max}-\sigma_{min}=3.7$ b): it is attributed to p-wave neutrons, forming a state with $J=3$ (Ad 49). The reduced width γ^2 is 0.017 of the sum-rule limit (Bo 51c). The resonance at 0.81 Mev is ≤ 11 kev wide and extends $\sim$1.3 barns above the background: it is attributed to neutrons of $l>0$, forming a state of $J>0$ (Bo 50f, Bo 51c). The third peak is located at 2.6, 2.73, 2.75, and 2.73 Mev, with $\sigma_{max}=2.5$, 3.4, 3.4, and 4.0 b by (Al 47b), (St 51d), (Ri 51c), and (Bo 51c), respectively. The large cross section ($\Delta\sigma=1.8$ b) and asymmetric shape suggests that two resonances are involved, a narrow one ($\sim$0.1 Mev) at 2.73 Mev and a much broader one at $\sim$2.85 Mev (Bo 51c).

The total cross section for 13- to 15-Mev neutrons (mean energy 13.9 Mev) is 1.41 ± 0.11 b (La 51b); (Co 52h) report $\sigma=1.53\pm0.03$ b at $E_n=14$ Mev.

Hi 49 Hibdon and Muehlhause, Phys. Rev. **76**, 100 (1949).
Pa 52 Palevsky and Smith, Phys. Rev. **86**, 604A (1952).
Sh 51b Shull and Wollan, Phys. Rev. **81**, 527 (1951).
Ad 49 Adair, Barschall, Bockelman, and Sala, Phys. Rev. **75**, 1124 (1949).
Bo 51c Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).

Bo 50f Bockelman, Phys. Rev. **80**, 1011 (1950).
Al 47b Allen, Burcham, and Wilkinson, Proc. Roy. Soc. (London) **192**, 114 (1947).
St 51d Stafford, Proc. Phys. Soc. (London) **64A**, 388 (1951).
Ri 51c Ricamo and Zunti, Helv. Phys. Acta **24**, 419 (1951).
La 51b Lasday, Phys. Rev. **81**, 139 (1951).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
See also: Am 46, Ha 52a, Hu 52e, Te 52.

VI. $Be^9(n\ n')Be^{9*}$

The cross section for γ-ray production is <14 mb at $E_n=2.5$ Mev (Gr 51a).

Gr 51a Grace, Beghian, Preston, and Halban, Phys. Rev. **82**, 969 (1951).

VII. $Be^9(n\ 2n)Be^8$ $Q_m=-1.666$ $E_b=6.811$

See (Ho 50b).

VIII. $Be^9(d\ p)Be^{10}$ $Q_m=4.586$

Recently reported values of the ground-state Q are:

$Q=4.585\pm0.008$ (St 51: mag. spectrometer),
$Q=4.591\pm0.008$ (Kl 52: mag. spectrometer),
$Q=4.55\ \pm0.03$ (Sa 51a: mag. spectrometer).

Recently reported values of the energy of the first excited state are:

3.372 ± 0.013 (Sa 51a: mag. spectrometer),
3.375 ± 0.010 (Bu 49e: mag. spectrometer, may be subjected to an upward revision of 9 kev: Van Patter, private communication),
3.360 ± 0.015 (Ra 49b: γ-ray energy including 20-kev Doppler correction).

At $E_d=14$ Mev, proton groups corresponding to levels at 3.3, 6.2, 7.6, 8.3, and 9.7 Mev are observed (Bo 50, Bo 50d). At $E_d=3.5$ Mev, $\theta=35°$, no groups corresponding to levels below the 3.37-Mev level appear with intensity greater than 5 percent of the ground-state group (Aj 52b).

The angular distribution of protons has been studied at $E_d=0.4$ Mev (ground state) by (De 52a), from $E_d=0.3$ to 0.8 Mev (ground- and 3.37-Mev states) by (Re 51a), from $E_d=1.0$ to 2.2 Mev (ground state) by (Ca 52), at $E_d=3.6$ Mev (both states) by (Fu 52), at $E_d=7.7$ Mev (both states) by (El 52) and at $E_d=14.5$ Mev (both states) by (Bl 52). At low energies, $E_d<2$ Mev, the distributions are exceedingly complex, with coefficients varying with energy. The complexities are considerably reduced if a relatively large contribution by stripping is assumed (Tr 52). The results at higher energies are dominated by the stripping process, involving p-wave neutron capture and hence $J=0$, 1, 2, or 3, even parity for both the ground state and the first excited state.

The angular correlation of protons and 3.37-Mev γ-rays, observed at $E_d=0.84$ and 0.91 Mev, involves terms in $\cos^2\theta$ and $\cos^4\theta$ and is consistent with $J=2$ for the excited state (Co 52d). The internal pair formation coefficient of the γ-radiation favors electric quadrupole radiation, but neither electric nor magnetic dipole can be excluded (Th 52, and R. J. Mackin, private communication).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Kl 52 Klema and Phillips, Phys. Rev. **86**, 951 (1952).
Sa 51a Salmon, Proc. Phys. Soc. (London) **64A**, 848 (1951).
Bu 49e Buechner and Strait, Phys. Rev. **76**, 1547 (1949).
Ra 49b Rasmussen, Hornyak, and Lauritsen, Phys. Rev. **76**, 581 (1949).
Bo 50 Boyer, Phys. Rev. **78**, 345A (1950).
Bo 50d Boyer, M.I.T. Progress Report (LNSE), July (1950).
Aj 52b Ajzenberg, Phys. Rev. **88**, 298 (1952).
De 52a De Jong and Endt, Physica **18**, 407 (1952).
Re 51a Resnick and Hanna, Phys. Rev. **82**, 463 (1951).
Ca 52 Canavan, Phys. Rev. **87**, 136 (1952).
Fu 52 Fulbright, Bruner, Bromley, and Goldman, Phys. Rev. (to be published).
El 52 El Bedewi, Proc. Phys. Soc. (London) **65A**, 64 (1952).
Bl 52 Black, Phys. Rev. **87**, 205A (1952).
Tr 52 True and Diesendruck, Phys. Rev. **87**, 381 (1952).
Co 52d Cohen, Shafroth, Class, and Hanna, Phys. Rev. **87**, 206A (1952).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
See also: Ha 51e.

IX. $B^{10}(n\ p)Be^{10}$ $Q_m=0.226$

See (Ho 50b).

X. $C^{13}(n\ \alpha)Be^{10}$ $Q_m=-3.845$

See C^{14}.

B^{10}

I. $Li^6(\alpha\ p)Be^9$ $Q_m=-2.132$ $E_b=4.453$

This reaction has not been observed: see (Ho 50b).

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

Slow neutron thresholds are reported for $E_\alpha\sim5.0$, 6.3, 7.2, and 8.5 Mev (Ha 39a).

Ha 39a Haxel and Stuhlinger, Z. Physik **114**, 178 (1939).

III. $Be^9(p\ \gamma)B^{10}$ $Q_m=6.585$

Resonances for capture radiation are listed in Table I(10). The first two resonances occur at $E_p=341.8$ and 485.0, respectively: a fit by two overlapping resonance curves yields the values cited. An earlier indication by (Ta 46) of a resonance at ~150 kev is not confirmed (Hu 52h). The 998-kev resonance decays mainly to the ground state: the angular distribution of the radiation is $Y(\theta)=(1+0.09\sin^2\theta)$ suggesting contribution of d-wave terms to the dominant s-wave component (De 49d). The reduced width is 0.026 of the sum-rule limit (Te 52). The 1087-kev resonance decays mainly to the 0.72-Mev state of B^{10}: the reduced width is 0.0011 of the sum-rule limit (Te 52).

In the range $E_p=2.4$ to 5.2 Mev, excitation curves for γ-rays of energy greater than ~6 Mev, and for γ-rays of energy greater than ~2 Mev have been reported (Ha 52e). The former shows a pronounced resonance

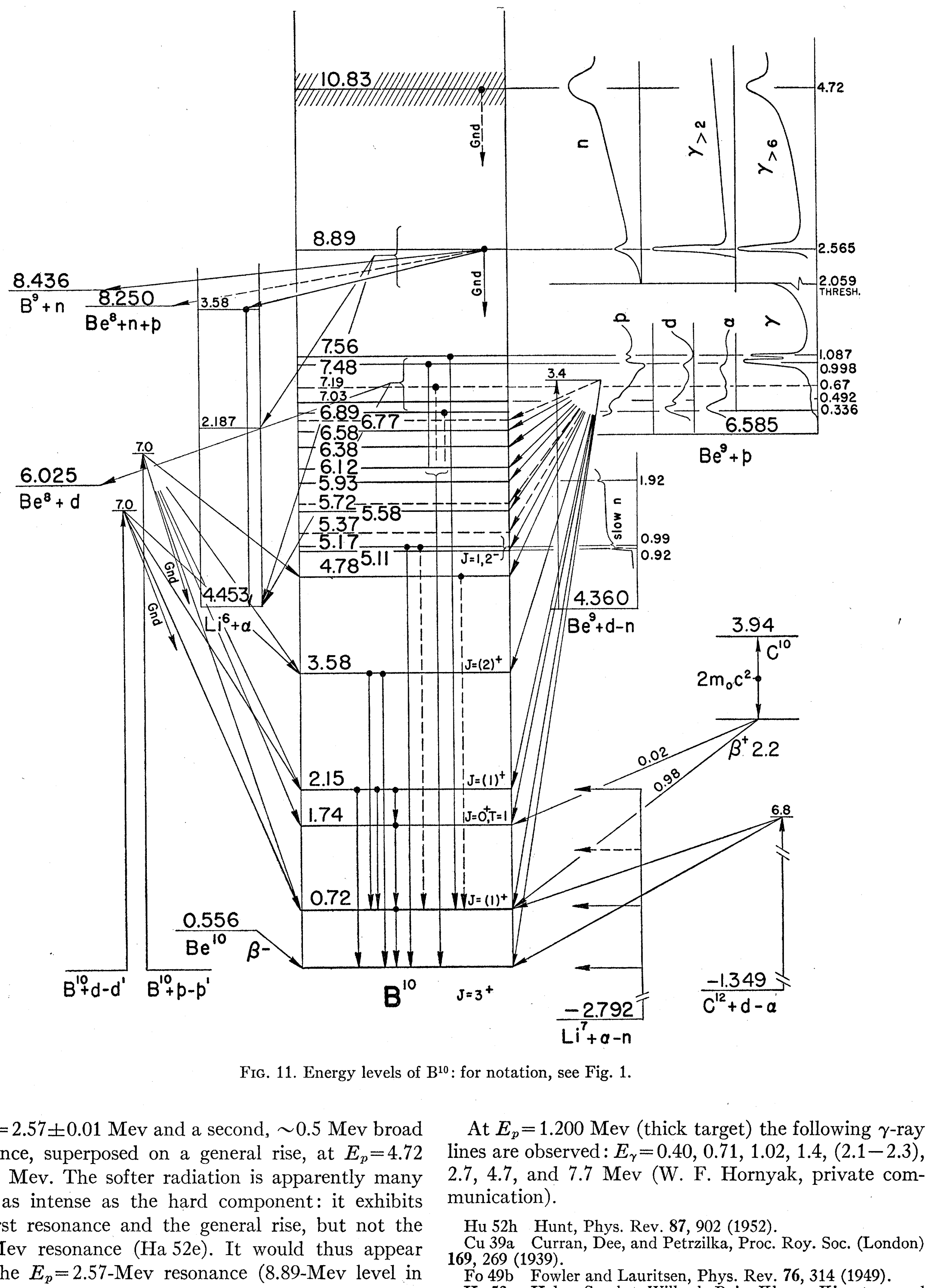

FIG. 11. Energy levels of B^{10}: for notation, see Fig. 1.

at $E_p=2.57\pm0.01$ Mev and a second, ~0.5 Mev broad resonance, superposed on a general rise, at $E_p=4.72\pm0.01$ Mev. The softer radiation is apparently many times as intense as the hard component: it exhibits the first resonance and the general rise, but not the 4.72-Mev resonance (Ha 52e). It would thus appear that the $E_p=2.57$-Mev resonance (8.89-Mev level in B^{10}) pertains not only to the (p α) and (p n) reactions (see below) but also to the capture reaction.

At $E_p=1.200$ Mev (thick target) the following γ-ray lines are observed: $E_\gamma=0.40$, 0.71, 1.02, 1.4, (2.1−2.3), 2.7, 4.7, and 7.7 Mev (W. F. Hornyak, private communication).

Hu 52h Hunt, Phys. Rev. **87**, 902 (1952).
Cu 39a Curran, Dee, and Petrzilka, Proc. Roy. Soc. (London) **169**, 269 (1939).
Fo 49b Fowler and Lauritsen, Phys. Rev. **76**, 314 (1949).
Ha 52e Hahn, Snyder, Willard, Bair, Klema, Kingston, and Green, Phys. Rev. **85**, 934 (1952).
Ta 46 Tangen, Kgl. Nord. Vid. Selsk. Skr. No. 1 (1946).

De 49d Devons and Hine, Proc. Roy. Soc. (London) **199**, 56, 73 (1949).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
See also: Ho 50b, Ca 51a.

IV. (a) $Be^9(p\ p)Be^9$ $E_b=6.585$
(b) $Be^9(p\ \alpha)Li^6$ $Q_m=2.132$
(c) $Be^9(p\ d)Be^8$ $Q_m=0.560$

The yield of elastically scattered protons, observed at $\theta=138°$, exhibits pronounced interference effects at the 0.33-, 0.998-, and 1.087-Mev resonances (see $Be^9(p\ \gamma)B^{10}$, above) (Th 49). Analysis of these data suggests assignment of $J=2$ (odd) to the 0.998-Mev level (7.48-Mev level of B^{10}, formed by s-wave protons) and $J=0$ (even) to the 1.087-Mev level (7.56 Mev in B^{10}, p-wave) (Co 49). Alpha-particle or deuteron emission from the latter level to the ground states of Li^6 or Be^8 are thus excluded (Th 49).

The α-particles and deuterons, observed at the same angle, show anomalies at $E_p=0.33$, 0.93 Mev for α-particles and at $E_p=0.33$, 0.44, and 0.93 Mev for deuterons (Th 49). The total cross section for α-particles exhibits peaks at 0.33, 0.68 (broad), and 0.94 Mev, while the deuterons show peaks at 0.33, 0.47, 0.68, and 0.94 Mev. The angular distributions are of the form $Y(\theta)=1+A_1\cos\theta+A_2\cos^2\theta$ with relatively large values for A_1, indicating strong interference between states of opposite parity. Since the large yield of the 0.33-Mev state indicates s-wave formation and since the 0.94–0.998 Mev state is probably also formed by s-wave protons, the evidence would suggest that the even-parity state (or states) in question may be one (or both) of those observed at $E_p=0.47$ and 0.68 Mev (Ne 51).

Reaction (b) exhibits a strong resonance at $E_p=2.56$ Mev: short-range α-particles and γ-rays are observed, corresponding to the reaction leading to the 3.58-Mev level in Li^6 and the subsequent γ-transition from this level to the ground state of Li^6. Alpha-groups to the ground and to the 2.187-Mev states of Li^6 do not appear to show resonance at $E_p=2.56$ Mev (Inglis and Malm, private communication). It is suggested that this behavior indicates isobaric spin $T=1$ for the $E_p=2.56$-Mev state (8.89 Mev in B^{10}) and that this state corresponds to either the 7.38-Mev or the 7.54-Mev states of Be^{10} (Ad 52a). (A spin $J=0$, even, assignment for the 8.89-Mev state of B^{10} would also prohibit transition to the ground state of Li^6.)

TABLE I(10). Resonances in $Be^9(p\ \gamma)B^{10}$.

E_p (kev)	Γ (kev)	$Y_{max}(\infty)$[a]	$\omega\Gamma_\gamma$ (ev)	B^{10*}
336.0±2[b]	175±5			6.887
492.0±3[b]	110±5			7.028
670[c]				7.19
998.0±4[d]	94	1.78	11	7.483
1087.0±2[d]	4	0.101	0.7	7.563
2565 ±5[e]	39±2			8.894

[a] Thick target yield in disintegrations/10^8 protons.
[b] (Hu 52h): absolute electrostatic analyzer.
[c] (Cu 39a).
[d] (Fo 49b).
[e] Values from $Be^9(p\ \alpha)Li^6$; shown to exhibit capture radiation by (Ha 52e).

TABLE II(10). Excited states of B^{10} from $Be^9(d\ n)B^{10}$.

A		B		C	
B^{10*} (kev)	Rel. intens.	B^{10*} (kev)	Rel. intens.	E_γ (kev)	Yield[a]
0	38	0	4.4		
760	43	720±60	4.1	716.6±1	13.7
1780	7	1750±60	0.9	1022 ±2	3.9
2220	24	2150±60	1.7	2151 ±16	1.2
				1433 ±5	2.5
				413.5±1	1.2
3680	26	3530±60	2.3	3604 ±30	0.9
				2871 ±15	2.4
		4780±40[b]		3970 ±80	[c]
		5140±40		5200 ±100	[c]
				4470 ±70	[c]
		5370±40(?)			
		5580±40			
		5720±40(?)			
		5930±40			
		6120±40			
		6380±40			
		6580±40			
		6770±40(?)			

A: Neutron spectra (photoplate), $\theta=15°$ to 140°, $E_d=0.94$ Mev, estimated relative errors: 50 kev (Pr 52a).
B: Neutron spectra (photoplate), $\theta=0°$ to 80°, $E_d=3.40$ Mev (Aj 51, Aj 52b).
C: Gamma-radiation: $E_d=1.2$ Mev, thick target (Ra 49b, Ra 50a).
[a] Probable error = 25 percent. Yield is in units of $10^{-6}\ \gamma/d$.
[b] Decay into $Li^6+\alpha$ is energetically possible for this level and for the higher excited states.
[c] At $E_d=1.5$ Mev, 300-kev target: relative intensities = 1:1.4:0.4; sum less than two percent of total γ-radiation (Ch 49c).

Th 49 Thomas, Rubin, Fowler and Lauritsen, Phys. Rev. **75**, 1612 (1949).
Co 49 Cohen, Phys. Rev. **75**, 1463A (1949) and Ph.D. thesis, California Institute of Technology (1949).
Ne 51 Neuendorffer, Inglis, and Hanna, Phys. Rev. **82**, 75 (1951).
Da 52 Day and Walker, Phys. Rev. **85**, 582 (1952).
Ad 52a Adair, Phys. Rev. **87**, 1041 (1952).

V. $Be^9(p\ n)B^9$ $Q_m=-1.852$ $E_b=6.585$

$E_{threshold}=2.059\pm0.002$; $Q=-1.852\pm0.002$ (Ri 50e).

A resonance at $E_p=2.56$ Mev is observed, superposed on a general rise to $E_p\sim4.5$ Mev (Ri 51, Ha 52e). The $(p\ n)$ resonance is appreciably broader than that observed at the same energy in the $(p\ \gamma)$ and $(p\ \alpha_2)$ reactions (Ha 52e). A second resonance is observed at $E_p=4.72$ Mev (see $Be^9(p\ \gamma)B^{10}$) corresponding to a broad (0.5-Mev) level in B^{10} at 10.83 Mev (Ha 52e).

The neutron yield is isotropic only very close to threshold. In the vicinity of the 2.56-Mev resonance, the yield shows maxima at 0° and 135° (center-of-mass). For $E_p=2.75$ to 3.4 Mev, the differential cross section shows a single maximum at 115° (Ri 51).

Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
Ri 51 Richards, Laubenstein, Johnson, Ajzenberg, and Browne, Phys. Rev. **81**, 316A (1951).
Ha 52e Hahn, Snyder, Willard, Bair, Klema, Kington, and Green, Phys. Rev. **85**, 934 (1952).

VI. $Be^9(d\ n)B^{10}$ $Q_m=4.360$

Recent neutron and gamma-ray results are summarized in Table II(10). The angular distributions of the

TABLE III(10). Slow neutron thresholds in $Be^9(d\ n)B^{10}$ (Bo 51b).

Threshold (Mev)	Q (Mev)	B^{10*} (Mev)
0.920 ± 0.002	-0.752 ± 0.016	5.11
0.985 ± 0.002	-0.805 ± 0.016	5.17
1.916 ± 0.004	-1.566 ± 0.017	5.93

neutrons from the ground state, the first four excited states and the 5.14-Mev doublet, observed at $E_d=3.40$ Mev, have been analyzed by the method of (Bu 51b). The results indicate even parity for the first five states and odd parity, $J=1$, or 2 for the levels at $\sim$5.14 Mev (Aj 52a, Aj 52b). At $E_d=0.94$ Mev, the angular distributions give some evidence for both stripping ($l_p=1$) and compound nucleus formation. If the contribution from the former is subtracted, the remainder has the form $Y(\theta)=1-\cos\theta$, for the ground state and first four excited states (Pr 52a). The relative intensities of neutron groups and γ-rays agree reasonably well (Pr 52a) with the decay scheme indicated on the B^{10} diagram (Aj 51).

There has been some question whether the γ-rays observed in the forward direction exhibit a Doppler shift (Ra 49b, Ra 50a). Recent work by (Cr 52b) and (Th 52) indicates that the 716.6-kev line is not shifted, suggesting that the lifetime of the 0.7-Mev state or of the higher states producing cascades to this state is $\gtrsim 3\times10^{-13}$ sec (Th 52).

On the basis of the neutron results, the intensities of the γ-ray transitions and the C^{10} decay, (Ri 52b) suggests $J=1^+$ for the 0.72, $J=1^+$ for the 2.15 and $J=2^+$ for the 3.58-Mev states of B^{10}. The fact that no direct γ-transition from the 1.74-Mev level to the ground state ($J=3^+$) has been observed is consistent with the evidence that the 1.74-Mev state is $J=0^+$ (Al 51i, Th 52). See also $B^{10}(d\ d')B^{10}$.

Observed thresholds for slow neutron production are listed in Table III(10) (Bo 51b). The fact that these levels were detectable by the neutron threshold method is evidence that s-wave neutrons are involved. The resulting level assignments are in agreement with the previously mentioned photoplate results (Aj 52a, Aj 52b).

At $E_d=3.0$ Mev, 6.0- and 6.7-Mev gamma-rays have been observed (Me 51a).

Pr 52a Pruitt, Hanna, and Swartz, Phys. Rev. **87**, 534 (1952).
Aj 51 Ajzenberg, Phys. Rev. **82**, 43 (1951).
Aj 52b Ajzenberg, Phys. Rev. **88**, 298 (1952).
Ra 49b Rasmussen, Hornyak, and Lauritsen, Phys. Rev. **76**, 581 (1949).
Ra 50a Rasmussen, Ph.D. thesis, California Institute of Technology (1950).
Ch 49c Chao, Lauritsen, and Rasmussen, Phys. Rev. **76**, 582 (1949).
Bu 51b Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).
Aj 52a Ajzenberg, Ph.D. thesis, U. of Wisconsin (1952).
Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Ri 52b Richards, University of Pittsburgh, Medium-Energy Nuclear Physics Conference (1952).
Al 51i Alburger, Phys. Rev. **83**, 184 (1951).
Bo 51b Bonner and Butler, Phys. Rev. **83**, 1091 (1951).
Me 51a Meyerhof, Rhoderick, and Mann, Phys. Rev. **83**, 203A (1951).
See also: Ev 49, Ho 50b, Tu 51a, Sc 51c, Al 51b, Co 51c, Co 51g, Sm 51a, Fa 51c, Su 51a, Hu 51g, Br 52b.

VII. $Be^{10}(\beta^-)B^{10}$ $Q_m=0.556$

See Be^{10}.

VIII. (a) $B^{10}(\gamma\ d)He^4+He^4$ $Q_m=-5.930$
(b) $B^{10}(\gamma\ np)He^4+He^4$ $Q_m=-8.155$

(not illustrated)

Events corresponding to these reactions have been observed in boron-loaded photographic emulsions at $E_\gamma=14.8$ to 17.6 and 24 Mev.

See (Go 50e, Nr 51g, Br 51j, Ch 52a, Ro 52c).

IX. $B^{10}(p\ p')B^{10*}$

A 718 ± 5 kev gamma-ray is observed, attributed to the first excited state of B^{10}. The cross section ($4\pi\sigma_{90°}$) for this radiation increases monotonically from 0.5 mb at $E_p=1.52$ Mev to 20 mb at 2.65 Mev (Da 52a).

Direct observation of the proton group (elect. analyzer) indicates a Q of -0.719 ± 0.003 Mev (limit of error) for the first excited state. This energy determination indicates that the value obtained from γ-ray measurements (see $Be^9(d\ n)B^{10}$) should not be corrected for Doppler effect (Cr 52b, Cr 52c).

Proton groups observed at $E_p=7$ Mev are listed in Table IV(10) (Bu 52b, Bu 52d).

Da 52a Day and Huus, Phys. Rev. **85**, 761A (1952).
Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).
Cr 52c Craig, Donahue, and Jones, Phys. Rev. (to be published).
Bu 52b Buechner, Browne, Elkind, Sperduto, Enge, and Bockelman, Phys. Rev. **87**, 237A (1952).
Bu 52d Buechner, University of Pittsburgh, Medium-Energy Nuclear Physics Conference, June (1952), and private communication.
See also: Co 52g.

X. $B^{10}(d\ d')B^{10*}$

Deuteron groups observed at $E_d=7$ Mev are listed in Table IV(10). The fact that no deuteron group corresponding to the 1.74-Mev state was observed at $E_d=6$ and 7 Mev is strong evidence (from isobaric spin con-

TABLE IV(10). B^{10} levels from $B^{10}(p\ p')B^{10*}$ and $B^{10}(d\ d')B^{10*}$ (Bu 52d).

B^{10*} (Mev)	Relative intensities[a] ($p\ p'$)	($d\ d'$)
0	100	100
0.72	6.5	10
1.74	1.0	<0.2
2.15	5	5
3.58	5	5
4.77	b	b

[a] $E_{d,p}=7$ Mev, $\theta=90°$. Ground-state deuterons are about half as intense as the protons.
[b] Proton and deutron groups reported, but intensity not specified.

siderations—see Ad 52a) that this state is the spin zero analog of the ground states of Be^{10} and C^{10} ($T_\zeta=0$ component of the $T=1$ multiplet) (Bu 52d). (See $Be^9(d\ n)B^{10}$.)

Bu 52d Buechner, University of Pittsburgh, Medium-Energy Nuclear Physics Conference, June (1952).
Ad 52a Adair, Phys. Rev. **87**, 1041 (1952).

XI. $B^{11}(\gamma\ n)B^{10}$ $Q_m=-11.459$ (not illustrated)

$Q=-11.50\pm0.25$ (Sh 51d).

Sh 51d Sher, Halpern, and Mann, Phys. Rev. **84**, 387 (1951).
See also: Sh 51.

XII. $C^{10}(\beta^+)B^{10}$ $Q_m=3.94$

The half-life is 19.1 ± 0.8 sec (Sh 49). Transitions are observed to the 1.74-Mev and to the 0.72-Mev states of B^{10} ($E_\gamma=1045$ and 720 kev) with a relative intensity of 1:50, indicating that both transitions are allowed [log ft=3.85 and 3.31, respectively]. Since the 1.74-Mev level is a $J=0^+$ state (see $B^{10}(d\ d')B^{10*}$, and $Be^9(d\ n)B^{10}$), the β^+ transition to that state is an example of an allowed 0^+ to 0^+ transition (Sh 52a).

Sh 49 Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949).
Sh 52a Sherr and Gerhart, Phys. Rev. **86**, 619A (1952).
See also: Bo 50e.

XIII. $C^{12}(d\ \alpha)B^{10}$ $Q_m=-1.349$

At $E_d=6.77$ Mev, $\theta=90°$, two α-particle groups are observed, corresponding to the ground state and to the 0.71-Mev level: no other levels appear <1.3 Mev (As 51).

As 51 Ashmore and Raffle, Proc. Phys. Soc. (London) **64A**, 754 (1951).

C^{10}

(not illustrated)

Mass of C^{10}

The mass difference $C^{10}-B^{10}$ is given by the positron end point, 2.2 ± 0.1 Mev, plus the γ-ray energy, 0.717 Mev, plus 1.02 Mev. *We adopt* $C^{10}-B^{10}=3.94\pm0.1$ Mev; mass defect$=18.94\pm0.1$ Mev.

I. $C^{10}(\beta^+)B^{10}$ $Q_m=3.94$

The decay is complex: see B^{10}.

II. $B^{10}(p\ n)C^{10}$ $Q_m=-4.72$

The threshold has not been observed; see (Sh 49).

B^{11}

I. $Li^7(\alpha\ \alpha')Li^{7*}$ $E_b=8.667$

The yield of γ-rays, attributed to this reaction, rises smoothly from $E_\alpha=2.3$ to 5.3 Mev (Sl 48b).

Sl 48b Slätis, Nature **161**, 899 (1948).
See also: Be 51, Sl 48c.

TABLE I(11). Resonances from $Li^7(\alpha\ \gamma)B^{11}$ (Be 51).

E_α (Mev)	Rel. yield[a]	$\omega\gamma$ (ev)[b]	B^{11*}
0.401	0.65	0.04	8.922
0.819 ± 0.001	5.6	0.6	9.188
0.958 ± 0.001	36	4.7	9.277

[a] Thick target yield, relative to $Li^7(p\ \gamma)Be^8=1000$ at $E_p=540$ kev.
[b] Partial width for γ-radiation times statistical weight factor.

II. $Li^7(\alpha\ n)B^{10}$ $Q_m=-2.792$ $E_b=8.667$

See (Ho 50b).

III. $Li^7(\alpha\ \gamma)B^{11}$ $Q_m=8.667$

Three resonances are reported (Be 51, see Table I(11)). At $E_\alpha=1$ Mev, the decay occurs predominantly via the 4.46-Mev level: the relative abundance of 4.8- and 4.46-Mev γ-rays varies with the angle of observation. The Doppler shift indicates a radiation time for both levels $<10^{-13}$ sec (Jo 52c).§

Be 51 Bennett, Roys, and Toppel, Phys. Rev. **82**, 20 (1951).
Jo 52c Jones and Wilkinson, Phil. Mag. **43**, 958 (1952).

IV. $Be^9(d\ d)Be^9$ $E_b=8.667$

At $E_d=8$ Mev, the angular distribution of elastically scattered deuterons exhibits a peak at $\theta=65°$, in addition to the forward peak (El 52).

El 52 El-Bedewi, Proc. Phys. Soc. (London) **65A**, 64 (1952).

V. $Li^7(\alpha\ p)Be^{10}$ $Q_m=-2.566$ $E_b=8.667$

See Ec 37.

VI. (a) $Be^9(d\ \alpha)Li^7$ $Q_m=7.151$ $E_b=8.667$
(b) $Be^9(d\ t)Be^8$ $Q_m=4.591$
(c) $Be^9(d\ 2\alpha)H^3$ $Q_m=4.687$

Reaction (a) leads to α-particle groups corresponding to states in Li^7 at 0, 0.48, 4.6, and 7.5 (?) Mev: the 4.6-Mev state yields a continuum of α-particles and tritons. Tritons leading to states of Be^8 at 0, 2.94, 4.09 (?), and 4.6 (?) Mev are observed in reaction (b): the subsequent disintegration of Be^8 leads to α-particle continua (see Be^8, Li^7). Additional α-particles may be formed in the reaction $Be^9(d\ n)B^{10*}\rightarrow Li^6+\alpha$. The direct three-body decay (reaction c) does not appear to occur.

The thick-target yield of ground-state α-particles (reaction a) is 25×10^{-9} α/d at $E_d=390$ kev (Gr 40). For angular distribution, see Li^7.

The thick target yield of ground-state tritons (reaction b) is 2×10^{-10} t/d at $E_d=212$ kev (Wi 37d). The yield rises rapidly in the region 0.2 to 1.0 Mev (Re 51a). The angular distributions suggest that compound nucleus formation does not play a major role in this reaction (see Be^8). The excitation function for produc-

§ *Note added in proof:* Study of angular correlations in the cascade γ-radiation lead to spin and parity assignments for seven levels from 2.1 to 9.3 Mev. The order and spacing are consistent with a single-particle model; see Jones and Wilkinson, Phys. Rev. **88**, 423 (1952).

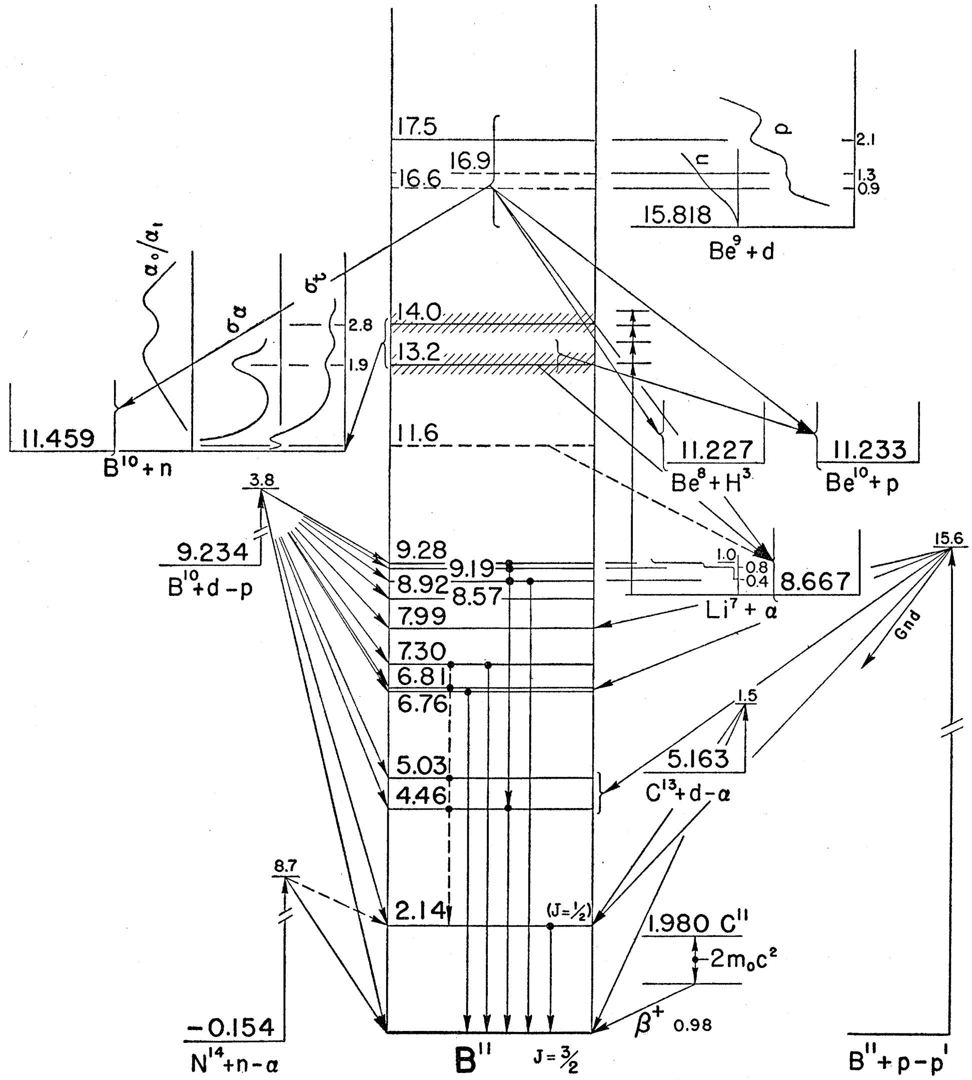

FIG. 12. Energy levels of B^{11}: for notation, see Fig. 1.

tion of H^3 from this reaction—and presumably also from $Be^9(d\ \alpha)Li^{7**}$ (see Li^7)—exhibits a steep rise at about $E_d=1.5$ Mev to a plateau of 0.23 ± 0.01 barn, extending from $E_d=2$ to 7.7 Mev (Wo 52).

Gr 40 Graves, Phys. Rev. **57**, 855 (1940).
Wi 37d Williams, Haxby, and Shepherd, Phys. Rev. **52**, 1031 (1937).
Re 51a Resnick and Hanna, Phys. Rev. **82**, 463 (1951).
Wo 52 Wolfgang and Libby, Phys. Rev. **85**, 437 (1952).
See also: Sa 52a, Fu 52.

VII. $Be^9(d\ p)Be^{10}$ $Q_m=4.585$ $E_b=15.818$

The yield of short- and long-range protons rises rapidly with energy from $E_p=0.2$ to 1 Mev. There is some suggestion of an anomaly in the long-range proton yield at about 0.7 Mev (Re 51a). (Ca 52) reports broad maxima in the $\theta=90°$ yield of long-range protons at ~0.9, (1.3), and 2.1 Mev.

The cross section (at 90°) is 0.043 ± 0.009 mb/sterad at 301 kev and 0.296 ± 0.059 mb/sterad at 440 kev (Sa 51a).

For angular distribution: see Be^{10}.

Re 51a Resnick and Hanna, Phys. Rev. **82**, 463 (1951).
Ca 52 Canavan, Phys. Rev. **87**, 136 (1952).
Sa 51a Salmon, Proc. Phys. Soc. (London) **64A**, 848 (1951).
See also: Fu 52.

VIII. $Be^9(d\ n)B^{10}$ $Q_m=4.360$ $E_b=15.818$

The fast neutron and γ-ray yields rise smoothly to $E_d=1.8$ Mev with some indication of a broad resonance at 1 Mev: see (Ho 50b). Thresholds for slow neutron production are observed: see B^{10}.

For angular distributions, see B^{10}.

See also: Ho 50b, Sm 51a, Al 51b, Su 51a, Co 51c, Co 51g, Tu 51a.

IX. $Be^9(\alpha\ d)B^{11}$ $Q_m=-8.016$ (not illustrated)

At $E_\alpha=21.7$ Mev, deuteron groups corresponding to levels of B^{11} at 0.65 ± 0.10 and 2.18 ± 0.10 Mev are reported (Mc 51b).

Mc 51b McMinn, Sampson, and Rasmussen, Phys. Rev. **84**, 963 (1951).

X. $B^{10}(n\ n)B^{10}$ $E_b=11.459$

The epithermal cross section (free) is 3.5 ± 0.2 b (Hu 52e). Broad maxima appear in the cross section at $E_n=1.9$ and 2.8 Mev, $\sigma\sim2.5$ b; an additional peak near 0.2 Mev may be indicated (Bo 51c). The cross section at $E_n=14$ Mev is 1.47 ± 0.03 b (Co 52h).

Hu 52e Hughes *et al.*, AECU 2040 (May, 1952).
Bo 51c Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
See also: Wi 51, Wa 51e.

XI. $B^{10}(n\ p)Be^{10}$ $Q_m=0.226$ $E_b=11.459$

The thermal cross section is <0.2 b (Hu 52e); the cross section for fast pile neutrons is 3 mb (Eg 48).

Hu 52e Hughes *et al.*, AECU 2040 (May, 1952).
Eg 48 Eggler, Hughes, and Huddleston, Phys. Rev. **74**, 1238 (1948).

XII. $B^{10}(n\ t)Be^8$ $Q_m=0.232$ $E_b=11.459$

See Be^8.

XIII. $B^{10}(n\ \alpha)Li^7$ $Q_m=2.792$ $E_b=11.459$

The thermal neutron absorption cross section for natural boron is 750 ± 10 b: for B^{10}, $\sigma_\alpha=3390$ b (Hu 52e).

Two α-particle groups are observed, corresponding to the ground and 478-kev excited states of Li^7. At low energies (0.01 to 1000 ev) the cross section follows the 1/v law. There is some suggestion of a resonance at $E_n=0.2$ Mev (Go 47a). A pronounced resonance exists at $E_n=1.9$ Mev with $\Gamma=400$ kev, $\sigma=0.5$ b (Pe 51c), which may actually be two resonances, at 1.81 ± 0.04 and 2.03 ± 0.04 Mev (St 50d, Bi 52). The ratio of transitions leading to the ground state and to the excited state of Li^7 varies markedly with energy. At thermal energies $\sigma(Li^7)/\sigma(Li^{7*})=0.0615\pm0.001$ (Ha 50e), 0.070 ±0.007 (Bi 52), 0.063 ± 0.009 (Rh 52), 0.0427 ± 0.0015 (Cu 51). The ratio rises monotonically to 2.3 at $E_n=1.9$ Mev and falls to 0.8 at 2.6 Mev (Pe 51c). At 1.8 Mev, (Bi 52) find a ratio of 1.7, followed by a decrease to ~1.5 near 2.5 Mev and a further rise to 1.8 at 3 Mev followed again by a decrease to 0.9 at 4 Mev. [The discrepancy between the two reports cited appears to be related to the effect of scattered neutrons degraded to the resonance energy and producing spurious peaks.]

Hu 52e Hughes *et al.*, AECU 2040 (May, 1952).
Go 47a Goldsmith, Ibser, and Feld, Revs. Modern Phys. **19**, 259 (1947).
Pe 51c Petree, Johnson, and Miller, Phys. Rev. **83**, 1148 (1951).

TABLE II(11). Proton groups from $B^{10}(d\ p)B^{11}$.

A: Q (Mev)	A: Intens.	B: Q (Mev)	B: $d\sigma$	B: B^{11*}
9.18 ± 0.05	1	9.235 ± 0.011	2	0
7.03 ± 0.06	0.3	7.097 ± 0.009	0.4	2.138
4.70 ± 0.06	0.8	4.776 ± 0.008	1.2	4.459
4.15 ± 0.08	0.6	4.201 ± 0.008	1.0	5.034
2.26 ± 0.07	16	2.477 ± 0.007	2	6.758
		2.427 ± 0.007	0.2	6.808
1.36 ± 0.07	13	1.937 ± 0.006	1.2	7.298
0.70 ± 0.10	0.8	0.667 ± 0.005	0.3	8.568
0.32 ± 0.10	large	0.309 ± 0.005	5	8.926
		0.045 ± 0.005	8	9.190
		-0.041 ± 0.005	4	9.276

A: $E_d=3.76$ Mev: relative intensities for $\theta=90°$ (Ba 50i).
B: $E_d=1.510$ Mev, $\theta=90°$: $d\sigma$ = approx. differential cross section in mb/sterad (Va 51a).

TABLE III(11). Gamma-rays from $B^{10}+d$.

A: E_γ	A: Y	B: E_γ	C: E_γ	C: Y
4.52 ± 0.1	34	4.43 ± 0.07	4.50 ± 0.05	0.9
		(6.51 ± 0.13)[a]	$(6.4\ \pm0.15)$[a]	1.0
6.71 ± 0.13	19	6.75 ± 0.13	$6.7\ \pm0.15$	0.8
		7.34 ± 0.20		
9.04 ± 0.18	12	8.93 ± 0.13	8.88 ± 0.06	1.0

A: $E_d=1.56$ Mev (Te 51a: pair spectrometer). Y is the yield in 10^6 quanta per microcoulomb.
B: $E_d=1.4$ Mev: the 6.5–6.75 Mev lines were not resolved (Ba 51f: internal conversion pairs).
C: $E_d=0.6$ Mev; Y is the relative yield (Ru 51a: pair spectrometer).
[a] Assigned to $B^{10}(d\ n)C^{11}$.

St 50d Stebler, Bichsel, and Huber, Helv. Phys. Acta **23**, 511 (1950).
Bi 52 Bichsel, Halg, Huber, and Stebler, Helv. Phys. Acta **25**, 119 (1952).
Ha 50e Hanna, Phys. Rev. **80**, 530 (1950).
Rh 52 Rhodes, Franzen, and Stephens, Phys. Rev. **87**, 141 (1952).
Cu 51 Cüer and Lonchamp, Compt. rend. **232**, 1824 (1951).
See also: Ro 49d, Ad 50, Wa 50e, Bi 51, Mi 51c.

XIV. $B^{10}(d\ p)B^{11}$ $Q_m=9.234$

Recent measurements of proton groups are summarized in Table II(11). A proton group corresponding to a level at 7.99 Mev is also reported (Bu 52d).

Recent γ-ray measurements are summarized in Table III(11). All of the lines indicated, except the 6.4-Mev line, are attributed to $B^{10}(d\ p)B^{11}$ on the basis of agreement with known proton groups and measured relative intensities. The 6.4-Mev γ-ray is attributed to $B^{10}(d\ n)C^{11}$ (Ru 51a, Ba 51f). Lower energy radiation, $E_\gamma=1.5$ and 2.2 Mev, has also been reported (see Ho 50b).

Study of the $p-\gamma$ coincidences indicates that the first two excited states (2.14 and 4.46 Mev) radiate directly to the ground state while the third, fifth, and sixth states (5.0, 6.8, and 7.3 Mev) decay predominantly by cascade transitions (Cu 50a, La 51c).

The $\gamma-p$ correlation for the 2.14-Mev level is isotropic ($I_{90°}/I_{180°}=1.0\pm10$ percent; $E_d\sim0.5$ Mev). Since the protons are anisotropic with respect to the deuteron beam (Th 49d), the level probably has $J=\frac{1}{2}$ (Th 51d).

For angular distribution: see C^{12}.

Ba 50i Bateson, Phys. Rev. **80**, 982 (1950).
Va 51a Van Patter, Buechner, and Sperduto, Phys. Rev. **82**, 248 (1951).
Bu 52d Buechner, University of Pittsburgh Medium-Energy Nuclear Physics Conference, June (1952).
Te 51a Terrell and Phillips, Phys. Rev. **83**, 703 (1951).
Ba 51f Bame and Baggett, Phys. Rev. **84**, 891 (1951).
Ru 51a Rutherglen, Rae, and Smith, Proc. Phys. Soc. (London) **64A**, 906 (1951).
Cu 50a Curling and Newton, Nature **166**, 339 (1950).
La 51c Landon, Phys. Rev. **82**, 304A (1951).
Th 49d Thirion, Compt. rend. **229**, 1007 (1949).
Th 51d Thirion, Compt. rend. **232**, 2418 (1951).
See also: Ph 52, Ca 52.

XV. (a) $B^{11}(\gamma\ \alpha)Li^7$ $Q_m=-\ 8.667$
(b) $B^{11}(\gamma\ t)Be^8$ $Q_m=-11.227$
(c) $B^{11}(\gamma\ t)He^4+He^4$ $Q_m=-11.131$
(not illustrated)

These reactions have been observed in boron-loaded photographic emulsions at $E_\gamma=14.8$ to 17.6 and 24 Mev. Whether the three-body reaction (c) occurs is not clear.

See (Go 50e, Ca 51d, Ch 52a, Ro 52c).

XVI. $B^{11}(p\ p')B^{11*}$

Inelastic scattering of 15.6-Mev protons on boron yields groups corresponding to levels at 2.2±0.3 (weak), 4.8±0.4 (strong), 6.5±0.3 (strong), and 7.8±0.4 Mev (weak) (Fu 48). A proton group corresponding to a level at 2.06 Mev has been observed at $E_p=7.4$ Mev (Co 52g).

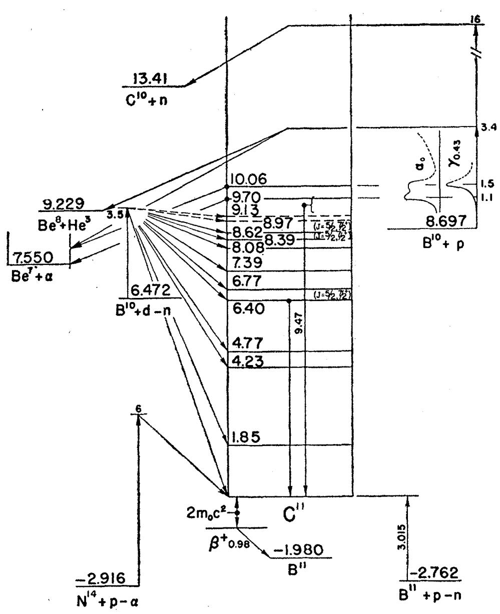

FIG. 13. Energy levels of C^{11}: for notation, see Fig. 1.

At $E_p=2.8$ Mev, a 2.13-Mev γ-ray is observed and is attributed to the first excited state (Day and Huus, private communication).

Fu 48 Fulbright and Bush, Phys. Rev. **74**, 1323 (1948).
Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).

XVII. $C^{11}(\beta^+)B^{11}$ $Q_m=1.980$

See C^{11}.

XVIII. $C^{13}(d\ \alpha)B^{11}$ $Q_m=5.163$

Recently reported Q-values for the reaction to the ground state are:

$Q=5.164\pm0.006$ (Li 51b: mag. spectrometer)
$Q=5.160\pm0.010$ (St 51: mag. spectrometer)

At $E_d=0.99$ Mev, $\theta=90°$, the cross section is 7 mb/sterad for the ground-state group. An α-particle group corresponding to a level at 2.107±0.017 Mev has been observed (Li 51b).

Li 51b Li and Whaling, Phys. Rev. **82**, 122 (1951).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).

XIX. $N^{14}(n\ \alpha)B^{11}$ $Q_m=-0.154$

Transitions to the 2.14-Mev excited state are observed‖; see N^{15}.

XX. $O^{16}(\gamma\ p\alpha)B^{11}$ $Q_m=-23.097$ (not illustrated)

See (Br 52a).

C^{11}

I. $C^{11}(\beta^+)B^{11}$ $Q_m=1.980$

The spectrum is simple. The half-life is 20.39±0.06 min: log ft = 3.59 (Fe 51b). There is some discrepancy between reported β-ray end points (0.985±0.005 Mev) and the value derived from the $B^{11}(p\ n)C^{11}$ threshold (0.958 Mev) (see Ho 50b).

Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
See also: Ho 50b.

II. $Be^9(He^3\ n)C^{11}$ $Q_m=7.563$ (not illustrated)

See C^{12}.

III. $B^{10}(p\ \gamma)C^{11}$ $Q_m=8.697$

The thick, B^{10} target yield of 9.47±0.12 Mev radiation is 3.4×10^{-10} γ/proton at $E_p=1.16$ Mev (Wa 50a).

Wa 50a Walker, Phys. Rev. **79**, 172 (1950).

IV. $B^{10}(p\ n)C^{10}$ $Q_m=-4.67$ $E_b=8.697$

C^{10} is produced in this reaction at $E_p=16$ to 18 Mev. The threshold has not been reported (Sh 49).

Sh 49 Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949).

‖ *Note added in proof:* Nine levels of B^{11} have been observed with 15-Mev neutrons: see (Li 52).

V. $B^{10}(p\ He^3)Be^8$ $Q_m=-0.532$ $E_b=8.697$

At $E_p=3.4$ Mev, $\theta=135°$, the cross section for the ground-state group is 1 mb/sterad (Cr 52b).

Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).

VI. $B^{10}(p\ \alpha)Be^7$ $Q_m=1.147$ $E_b=8.697$

Two alpha-groups, corresponding to the ground state and the 430-kev level of Be^7, are observed, The ground-state α-particles exhibit broad resonances at $E_p=1.1$ and 1.5 Mev, superposed on a continuous background. The differential cross section is 2 mb/sterad at $E_p=0.60$ Mev, $\theta=138°$ (Br 51a: see, however, Bu 50g). At $E_p=1.1$ Mev, $\theta=138°$, the differential cross section $=16\pm3$ mb/sterad, dropping to half this value at $E_p=1.6$ Mev (Br 51a). At $E_p=3.33$ Mev, $\theta=135°$, the differential cross section = 20 mb/sterad (Cr 52b).

The short-range alphas ($\theta=138°$) and 430-kev γ-rays from Be^{7*} ($\theta=90°$) exhibit only one resonance in the range 0 to 2.7 Mev, at 1.52 Mev, with a width of 0.25 Mev and peak cross section of 11 mb/sterad (Br 51a, Da 52a). At $E_p=3.33$ Mev, $\theta=135°$, $d\sigma=10$ mb/sterad for short-range α-particles (Cr 52b). At $E_p=1.79$ Mev, $\theta=90°$, the ground-state group is 2.2 times as intense as the short-range group (Va 50: $d\sigma(\alpha_0)=4.1$ mb/sterad).

Br 51a Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951).
Bu 50g Burcham and Freeman, Phil. Mag. **41**, 337 (1950).
Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A, (1952).
Da 52a Day and Huus, Phys. Rev. **85**, 761 (1952).
Va 50 Van Patter, Sperduto, Strait, and Buechner, Phys. Rev. **79**, 900 (1950).

VII. $B^{10}(p\ p)B^{10}$ $E_b=8.697$

The elastic scattering cross section at $\theta=138°$ rises from nearly the Rutherford value for $E_p<0.9$ Mev to 4 times Rutherford at $E_p=1.6$ Mev. Anomalies are associated with the resonance for $B^{10}(p\ \alpha)Be^7$, Be^{7*} at 1.5 Mev and that for $B^{10}(p\ \alpha)Be^7$ at 1.15 Mev (Br 51a). At $E_p=1.79$ Mev, $\theta=90°$, elastic protons are 10 times as numerous as ground-state α-particles from $B^{10}(p\ \alpha)Be^7$ (Va 50).

Br 51a Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951).
Va 50 Van Patter, Sperduto, Strait, and Buechner, Phys. Rev. **79**, 900 (1950).

VIII. $B^{10}(p\ p')B^{10}$ $E_b=8.697$

The cross section at $\theta=90°$ for 718-kev radiation from B^{10*} rises monotonically from 0.04 mb/sterad at $E_p=1.52$ Mev to 1.6 mb/sterad at 2.65 Mev (Da 52). At $E_p=2.191$ Mev, $\theta=135°$, the cross section for the corresponding proton group is ~3 mb/sterad (Cr 52c).

Da 52 Day and Walker, Phys. Rev. **85**, 582 (1952).
Cr 52c Craig, Donahue, and Jones, Phys. Rev. (to be published).

TABLE IV(11). Neutron groups from $B^{10}(d\ n)C^{11}$ (Jo 52a).

C^{11*}	Q	Rel. intens. in c.m. system, 0°	Ratio of intens. at 0° to $\phi°$ in c.m. system	$\phi°$ in c.m. system
0	$(6.472\pm0.011)^a$	1.1	1.1	84.3°
1.85	4.62 ± 0.06	0.3	0.8	84.8
4.23	2.24 ± 0.06	1.4	1.6	85.8
4.77	1.70 ± 0.06	1.0	1.9	87.1
6.40	0.07 ± 0.04	5.9	3.5	87.4
6.77	-0.30 ± 0.04	1.0	2.1	88.5
7.39	-0.92 ± 0.04	0.2	0.8	89.2
8.08	-1.61 ± 0.02	0.2	1.3	91.1
8.39	-1.92 ± 0.02	5.0	12.2	92.0
8.62	-2.15 ± 0.02	9.2	8.3	94.2
8.97^b	-2.50 ± 0.02^b	0.3^b		
9.13^b	-2.66 ± 0.02^b	0.3^b		

a Calculated Q_m.
b Assignment to C^{11} uncertain.

IX. $B^{10}(d\ n)C^{11}$ $Q_m=6.472$

Neutron results (photoplate) are summarized in Table IV(11) (Jo 52a: $E_d=3.40$, 3.64 Mev; $\theta=0°$ and 80°). The relatively high intensity of low energy groups and the strongly forward distribution in several cases are consistent with the assumption of a stripping process: levels at 6.40, 8.39, and 8.62 Mev are probably formed by s-wave proton capture and have even parity and $J=5/2$ or $7/2$ (Jo 52a; H. T. Richards, private communication). Apparently the reaction proceeds at least partly through stripping even for $E_d=0.8$ to 1.6 Mev (Ri 52). A 6.4±0.15-Mev (Ru 51a), 6.51±0.13-Mev (Ba 51f), γ-ray, observed when B^{10} is bombarded with deuterons, is assigned to C^{11} (see $B^{10}(d\ p)B^{11}$).

The close similarity between the levels of C^{11} observed in the experiment of (Jo 52a) and those of B^{11}, observed in $B^{10}(d\ p)B^{11}$, is strong evidence for the validity of the hypothesis of charge-symmetry of nuclear forces.

Jo 52a Johnson, Phys. Rev. **86**, 302 (1952).
Ri 52 Risser and Burke, Phys. Rev. **85**, 742 (1952).
Ru 51a Rutherglen, Rae, and Smith, Proc. Phys. Soc. (London) **64A**, 906 (1951).
Ba 51f Bame and Baggett, Phys. Rev. **84**, 891 (1951).
See also: Hu 51g, Te 51a.

X. $B^{11}(p\ n)C^{11}$ $Q_m=-2.762$

The threshold is 3.015 ± 0.003 Mev; $Q=-2.762\pm0.003$ (Ri 50e).

Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).

XI. $C^{12}(n\ 2n)C^{11}$ $Q_m=-18.711$ (not illustrated)

The threshold is ~21.5 Mev (Sh 45).

Sh 45 Sherr, Phys. Rev. **68**, 240 (1945).
See also: Sh 51e.

XII. $C^{12}(\gamma\ n)C^{11}$ $Q_m=-18.711$ (not illustrated)

The threshold is ≤18.7 Mev (Mc 49); 18.7 to 19.4 Mev (Ba 45).

Mc 49 McElhinney, Hanson, Becker, Duffield, and Diven, Phys. Rev. **75**, 542 (1949).
Ba 45 Baldwin and Koch, Phys. Rev. **67**, 1 (1945).

XIII. $C^{12}(p\ d)C^{11}$ $Q_m = -16.486$ (not illustrated)

See N^{13}.

XIV. $N^{14}(p\ \alpha)C^{11}$ $Q_m = -2.916$

See O^{15}.

B^{12}

I. $B^{12}(\beta^-)C^{12}$ $Q_m = 13.370$

The spectrum is complex—see C^{12}.

II. $Be^9(\alpha\ p)B^{12}$ $Q_m = -6.880$

At $E_\alpha = 21.7$ Mev, proton groups are observed with Q values -6.92 ± 0.05, -7.87 ± 0.05, -8.57 ± 0.05, and -10.74 ± 0.10, corresponding to levels at 0.95, 1.65, and 3.82 Mev (Mc 51b).

Mc 51b McMinn, Sampson, and Rasmussen, Phys. Rev. **84**, 963 (1951).

III. $B^{11}(n\ \gamma)B^{12}$ $Q_m = 3.361$

$\sigma_{\text{thermal}} < 0.05$ barn (Wa 50e).

Wa 50e Way, Fano, Scott, and Thew, Circular of the Natl. Bureau of Stands. 499, September 1 (1950), Supplements (1) April, 1951; (2) November, 1951; (3) June, 1952.

IV. $B^{11}(n\ n)B^{11}$ $E_b = 3.361$

Observed resonances are listed in Table I(12) (Bo 51c). The epithermal scattering cross section (free) is 3.76 b (Wa 50e). The total cross section at $E_n = 14$ Mev is 1.40 ± 0.03 b (Co 52h).

Bo 51c Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).

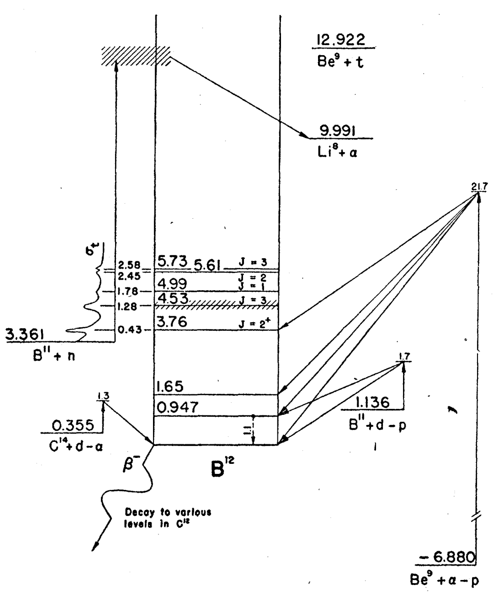

FIG. 14. Energy levels of B^{12}: for notation, see Fig. 1.

TABLE I(12). Resonances in $B^{11}(n\ n)B^{11}$ (Bo 51c).

E_{res} (Mev)	Γ (kev)[a]	l_n	Θ^2	J	B^{12*}
0.43	40	1	0.036	2	3.76
1.28	130	1	0.033	3	4.53
		2	0.28		
1.78	65	1	0.012	1	4.99
		2	0.056		
2.45	120	1	0.017	2	5.61
		2	0.053		
		3	0.82		
2.58	60	1	0.0082	3	5.73
		2	0.025		
		3	0.26		

[a] Widths corrected for variation of level shift with energy.
l_n = Incoming wave.
$\Theta^2 = 2\ \text{Ma}\ \gamma^2/3\hbar^2$, fraction of the sum-rule limit.

Wa 50e Way, Fano, Scott, and Thew, Circular of the Natl. Bureau of Stands. 499, September 1 (1950), Supplements (1) April, 1951; (2) November, 1951; (3) June, 1952.
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
See also: Hi 49, Bo 50f, Wi 50b, Wi 51, Wa 51e, Te 52.

V. $B^{11}(n\ \alpha)Li^8$ $Q_m = -6.630$ $E_b = 3.361$

See (Ho 50b).

VI. $B^{11}(d\ p)B^{12}$ $Q_m = 1.136$

The ground-state Q is 1.136 ± 0.004 Mev. A second proton group yields a level energy of 0.947 ± 0.005 Mev. At $E_d = 1.5$ Mev, $\theta = 90°$, the excited state group is 1/5 as intense as the ground-state group (Bu 50d).

Bu 50d Buechner, Van Patter, Strait, and Sperduto, Phys. Rev. **79**, 262 (1950).
See also: Hu 49j.

VII. $C^{12}(n\ p)B^{12}$ $Q_m = -12.588$ (not illustrated)

See (Je 48c).

VIII. $C^{14}(d\ \alpha)B^{12}$ $Q_m = 0.355$

The cross section at $E_d = 0.75$ Mev is $\sim$1.7 mb. The yield rises to 1.3 Mev more steeply than does that for $B^{11}(d\ p)B^{12}$ (Hu 50e).

Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).

IX. $N^{15}(n\ \alpha)B^{12}$ $Q_m = -7.627$ (not illustrated)

See (Je 48c).

C^{12}

I. $Be^9(\alpha\ n)C^{12}$ $Q_m = 5.708$

The reaction exhibits a broad resonance at $E_\alpha = 1.4$ Mev (see C^{13}). At $E_\alpha = 1.4$ Mev, only two neutron groups are observed, corresponding to the ground state and a state at 4.45 Mev. In the forward direction, the excited state is 0.4 times as intense as the ground-state group; at 90°, the ratio is 1.6 (Br 50). These data are consistent with the assumption that the C^{13*} state involved is formed by p-wave α-particles, $J = 5/2^+$, and the C^{12*} state has $J = 2$, even or odd (Ha 51e). At

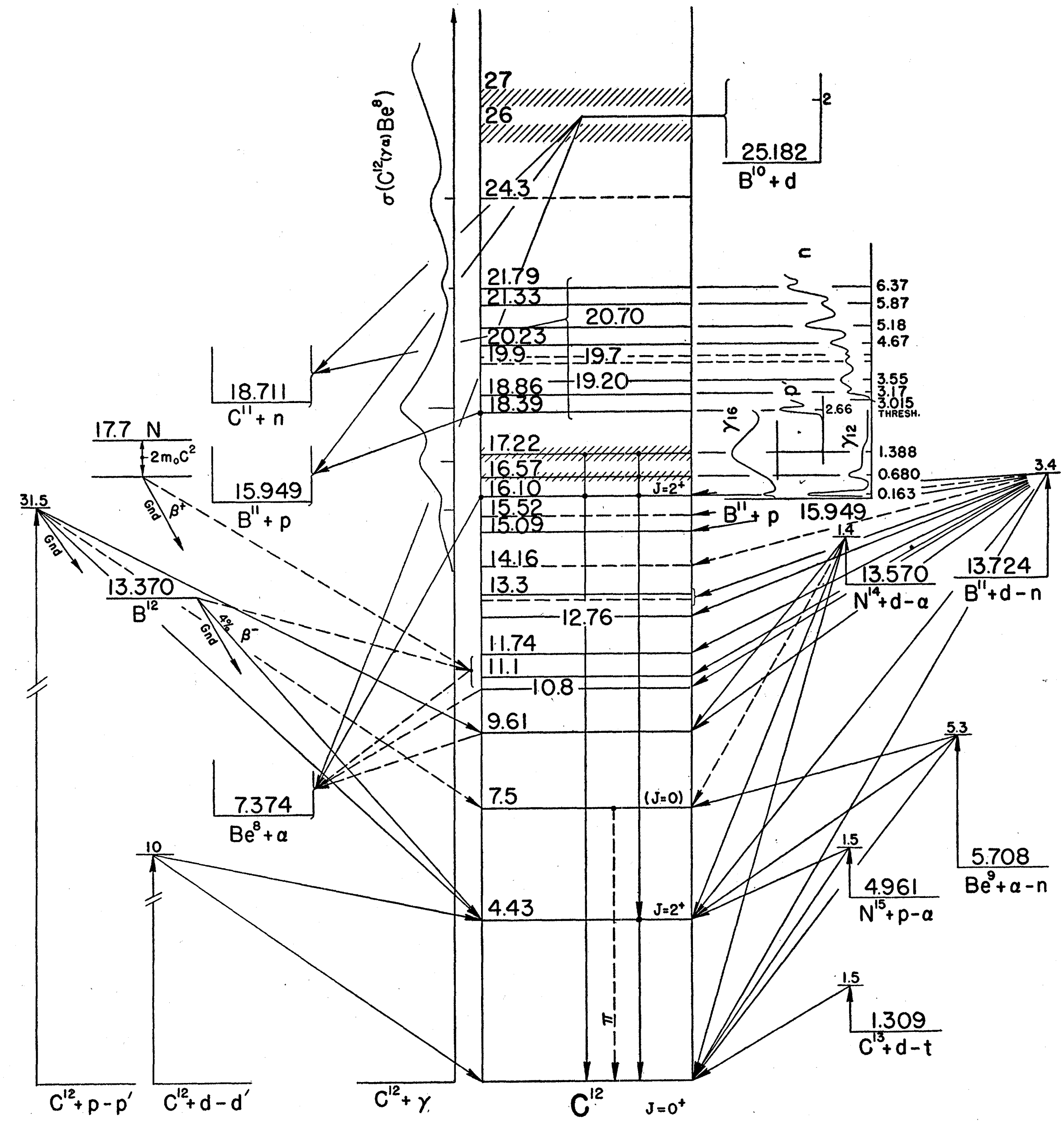

FIG. 15. Energy levels of C^{12}: for notation, see Fig. 1.

$E_\alpha = 5.3$ Mev (thin target), groups corresponding to levels at 0, 4.2, and 7.5 Mev are observed. In the forward direction the group to the 4.2-Mev level is eight times as intense as the group to the 7.5-Mev level: in the backward direction the 4.5-Mev level group is twice as intense as the ground-state group (Gu 52).

Recent measurements of the γ-ray energy ($E_\alpha = 5.3$ Mev) are:

$E_\gamma = 4.45 \pm 0.09$ (Te 50: pair spectrometer)
$E_\gamma = 4.44 \pm 0.03$ (Be 50f: NaI crystal)
$E_\gamma = 4.40 \pm 0.05$ (Pr 50b: NaI crystal)
$E_\gamma = 4.37 \pm 0.07$ (Ar 51d: internal pairs)
$E_\gamma = 4.47 \pm 0.04$ (Al 52: pair spectrometer)

According to (Te 50), no radiation is present in the range 7–11 Mev with an intensity greater than 0.5 percent of the intensity of the 4.5-Mev line ($E_\alpha = 5.3$ Mev): (Ar 51d) place an upper limit of 0.2 percent at $E_\gamma = 7.5$ Mev. (Pr 50b), on the other hand, report a line at 7.2 Mev of about 1 percent strength. No line near 2.5 to 3 Mev has been reported in recent literature: (Ar 51b) place an upper limit of one-third of the 4.5-Mev line intensity.

In a cloud-chamber investigation of the internally-formed pairs, 72 pairs corresponding to a transition energy of 4.4±0.5 Mev have been observed. The angular correlation of the pairs is consistent with electric quadrupole radiation. In addition, the observation of 7.0 ±0.6-Mev pairs (7 cases) suggests that the 7.0-Mev state has $J=0$, from which the ground-state transition by γ-radiation would be forbidden. The 2.5-Mev cascade transition to the 4.45-Mev state which would compete with the nuclear pairs would be expected to be only ~10 percent as intense as the 4.45-Mev radiation and may have escaped detection (Ha 52f, and private communication).

Slow neutron thresholds corresponding to levels at 9.5, 10.3, and 10.8 Mev have been reported; see (Ho 50b).

Br 50 Bradford and Bennett, Phys. Rev. **78**, 302 (1950).
Ha 51e Haefner, Revs. Modern Phys. **23**, 228 (1951).
Gu 52 Guier, Bertini, and Roberts, Phys. Rev. **85**, 426 (1952).
Te 50 Terrell, Phys. Rev. **80**, 1076 (1950).
Be 50f Bell and Jordan, Phys. Rev. **79**, 392 (1950).
Pr 50b Pringle, Roulston, and Standil, Phys. Rev. **78**, 627 (1950).
Ar 51d Artemov and Vlasov, Dokl. Akad. Nauk, SSSR, **77**, (No. 2) 225–227 (1951); Phys. Abstr. 6450 (1951).
Al 52 Alburger, Phys. Rev. (to be published).
Ha 52f Harries and Davies, Proc. Phys. Soc. (London) **65A**, 564 (1952).
See also: Gu 50, Ho 50b, Br 51d.

II. $Be^9(He^3\ n)C^{11}$ $Q_m=7.563$ $E_b=26.274$ (not illustrated)

A 20-minute positron activity, observed at $E(He^3)=21$ Mev, is attributed to this reaction (Do 52).

Do 52 Donovan, Kundu, Long, and Pool, Phys. Rev. **88**, 158A (1952).

III. $B^{10}(d\ p)B^{11}$ $Q_m=9.234$ $E_b=25.182$

The yield of ground-state protons exhibits two broad resonances in the range $E_d=0.7$ to 2.0 Mev (Ph 50). At $E_d=1.51$ Mev, $\theta=90°$, the differential cross section is about 2 mb/sterad (Va 51a: see B^{11}). The angular distribution of ground-state protons has been studied in the range $E_d=1$ to 4 Mev by (Re 50): for $E_d<3$ Mev, entering s- and p-waves are indicated, while d-wave contributions are indicated for higher energies. Angular distributions for the four most energetic proton groups, observed at $E_d=0.3$ Mev, are reported by (En 52).

Ph 50 Phillips, Phys. Rev. **79**, 240 (1950).
Va 51a Van Patter, Buechner, and Sperduto, Phys. Rev. **82** 248 (1951).
Re 50 Redman, Phys. Rev. **79**, 6 (1950).
En 52 Endt, Paris, Jongerius, and Valcky, Physica **18**, 423 (1952).

IV. $B^{10}(d\ n)C^{11}$ $Q_m=6.472$ $E_b=25.182$

A broad, low resonance appears at $E_d=0.9$ Mev for production of neutrons in the forward direction (Bu 51a). The angular distribution has a maximum at $\theta=35°$ to 40°, suggesting a stripping process (Ri 52). See also C^{11}.

Bu 51a Burke and Risser, Phys. Rev. **83**, 211 (1951).
Ri 52 Risser and Burke, Phys. Rev. **85**, 742 (1952).
See also: Tu 51a, Hu 51g.

V. $B^{10}(d\ \alpha)Be^8$ $Q_m=17.809$ $E_b=25.182$

A resonance for both ground-state and 2.9-Mev excited state α-particles appears at $E_d=1.05$ Mev (Wh 51b).

Wh 51b Whitehead, Phys. Rev. **82**, 553 (1951).

VI. $B^{10}(\alpha\ d)C^{12}$ $Q_m=1.348$ (not illustrated)

See Cr 49c.

VII. $B^{11}(p\ p')B^{11*}$ $E_b=15.949$

A resonance for 2.13-Mev γ-radiation from the first excited state of B^{11} appears at $E_p=2.662$ Mev, of width $\Gamma=51$ kev. The capture radiation (see $B^{11}(p\ \gamma)C^{12}$) does not appear to exhibit a resonance in this region: $\sigma_{capt}\lesssim 0.002$ mb (Day and Huus, private communication).

VIII. $B^{11}(p\ \alpha)Be^8$ $Q_m=8.575$ $E_b=15.949$

A resonance occurs for ground-state α-particles and for those leading to the 2.9-Mev excited state of Be^8 (Mc 40a, Ub 42, Whaling and Wenzel, private communication) at the same energy as the $B^{11}(p\ \gamma)$ resonance: 162.8±0.5 kev (Mo 49a). The ground-state α-particle yield drops to essentially zero above resonance, while the resonance for short-range α-particles is superimposed on a considerable exponentially rising background. Both groups are anisotropic at resonance, and the short-range group is symmetric just above resonance (J. A. Jacobs, private communication). (Ha 39) gives the distribution for the long-range group at resonance as $Y(\theta)=1+0.7\cos^2\theta$ and finds that the coefficient for the short-range α-particles varies with bombarding energy.¶

The $\alpha-\alpha$ correlation has been studied: see Be^8.

Mc 40a McLean, Young, Whitson, Plain, and Ellett, Phys. Rev. **57**, 1083A (1940).
Mo 49a Morrish, Phys. Rev. **76**, 1651 (1949).
Ub 42 Ubisch, Kgl. Nor. Vid. Selsk. Forh. **XV**, 71 (1942).
Ha 39 Haxby, Allen, and Williams, Phys. Rev. **55**, 140 (1939).
See also: Te 52.

IX. $B^{11}(p\ \gamma)C^{12}$ $Q_m=15.949$

The first resonance occurs at $E_p=162.8\pm0.5$ kev (Mo 49a) and has a width $\Gamma=5.0\pm1$ kev (see Ho 50b). A recent report by (Hu 52g) gives $E_p=163.8\pm0.3$ kev and $\Gamma=7.4\pm0.6$ kev for the first resonance (absolute elect. analyzer). Resonances reported by (Hu 52a, and private communication) are given in Table II(12). The second resonance is also reported by (Co 52e) who find $E_{res}=670\pm15$ kev, $\Gamma=390$ kev after correction

¶ *Note added in proof:* Recent observations on the anisotropy of the ground-state group indicate $J=2^+$ for the resonance with a mixing ratio $t=2.4\pm0.1$ (see Sec. IX), and interference with a broad $J=1^-$ state. See (Th 52c).

TABLE II(12). Resonances in $B^{11}(p\ \gamma)C^{12}$ (Hu 52a).

E_p (Mev)	Γ (kev)	σ_{12}[a]	σ_{16}[b]
0.163	5	138	5.5
0.680	322	48.5	<2.3
1.388	1270	18	35.1

[a] 4π times 90° resonance cross section for 12-Mev radiation, in units of 10^{-6} barn.
[b] 4π times 90° resonance cross section for 16-Mev radiation, in units of 10^{-6} barn.

for variation of the penetration factors. The discrepancy in Γ may reflect the influence of the 1.388-Mev resonance which was not observed by (Co 52e) (Day, private communication).

The cascade radiation exhibits all three resonances, while the ground-state transition exhibits only the 163- and 1388-kev resonances: a resonant contribution of as little as 2.3×10^{-6} barn to the 16-Mev radiation at $E_p=680$ kev would have been detectable (Day and Huus, private communication). That both the cascade and ground-state radiations exhibit resonance at $E_p=163$ kev is confirmed by Day, by Kern, and by Nelson (private communications).

The angular distribution of the 12-Mev γ-ray with respect to the proton beam is given by $1+A\cos^2\theta$ where A appears to vary with bombarding energy, from 0.19 at $E_p=150$ kev to 0.25 at $E_p=180$ kev (thick target). At $E_p=170$ kev, $A=0.23\pm0.04$ (Hu 52b and E. B. Nelson, private communication; see also Ke 51a). The ground-state transition (16 Mev) is approximately isotropic, although a variation of as much as 10 percent is not excluded (Ke 51a, $E_p\sim200$ kev). It is pointed out by (Ar 51c) that since the 12-Mev radiation is clearly anisotropic, the 16-Mev radiation must come from a different level, if it is in fact isotropic. At $E_p=700$ kev (thin target) the γ-ray distribution contains a ($0.16\cos\theta$) term, indicating interference between levels of opposite parity (Kern *et al.*, private communication).**

The angular correlations of the resonant cascade radiation have been measured with the following results (notation of Bi 51d):

$$W(\theta_1, 0)=1+(0.39\pm0.15)\cos^2\theta_1 \quad \text{(Hu 52b)}$$
$$W(\pi/2, \theta_2)=1-(0.2\pm0.1)\cos^2\theta_2 \quad \text{(Hu 52b)}$$
$$W(\pi/2, \pi/2, \phi)=1+(0.365\pm0.06)\cos^2\phi \quad \text{(Le 52)}$$

Since the 16-Mev C^{12*} state in question is also a resonance for α-particles; (see $B^{11}(p\ \alpha)Be^8$), it must either have odd J and odd parity or even J, even parity. Formation by s-waves is ruled out by the anisotropy of the γ-rays and α-particles, and d-waves seem unlikely on the ground of the low penetration expected. The possible states with p-waves are then $J=0^+$ or 2^+, of which the first is again excluded by the observation of anisotropy. There are good reasons for believing that the 4.4-Mev state has $J=2^+$ (see e.g. $N^{15}(p\ \alpha)C^{12}$), and hence that the present transitions are properly described as $2^+(MD)2^+(EQ)0^+$ (Ha 51e, Bi 51d). The observed angular distribution of α-particles and 12-Mev γ-rays and the first two correlations cited above are consistent with this scheme, and yield a ratio of $t\sim7/3$ for the relative participation of channel spins 1 and 2 (Ha 51e, Ch 52b, Hu 52b). The last correlation result requires a ratio of unity (Le 52) which is not outside the limits permitted by the first two correlations, but implies spherical symmetry for the α- and γ-angular distributions (Ch 52b).

** *Note added in proof:* Glättli and Stoll (Helv. Phys. Acta **25**, 455 (1952)) find a 19 percent anisotropy for the 16-Mev radiation, independent of bombarding energy from $E_p=150$ to 500 kev. The anisotropy of the 12-Mev radiation exhibits a minimum at $E_p\sim300$ kev.

Mo 49a Morrish, Phys. Rev. **76**, 1651 (1949).
Hu 52g Hunt and Jones (to be published).
Co 52e Cochran, Ryan, Givin, Kern, and Hahn, Phys. Rev. **87**, 672 (1952).
Hu 52a Huus and Day, Phys. Rev. **85**, 761 (1952).
Hu 52b Hubbard, Nelson, and Jacobs, Phys. Rev. **87**, 378 (1952).
Ke 51a Kern, Moak, Good, and Robinson, Phys. Rev. **83**, 211 (1951).
Ar 51c Arfken, Biedenharn, and Rose, Phys. Rev. **84**, 89 (1951).
Bi 51d Biedenharn, Arfken, and Rose, Phys. Rev. **83**, 586 (1951).
Ha 51e Haefner, Revs. Modern Phys. **23**, 228 (1951).
Le 52 Lewis, Phil. Mag. **43**, 690 (1952).
Ch 52b Christy (to be published).
See also: Wa 50a, Ho 50b, Ca 51a, Te 52.

X. $B^{11}(p\ n)C^{11}$ $Q_m=-2.762$ $E_b=15.949$

$E_{\text{threshold}}=3.015\pm0.003$ Mev; $Q=-2.762$ (Ri 50e).

Resonances appear in the forward neutron yield at $E_p=3.17$, 3.55 (broad), 4.0 to 4.4 (two levels), and 4.67 Mev. The $\theta=0°$ differential cross section at $E_p=3.55$ Mev is 5.44 ± 0.5 mb/sterad. The angular distribution is isotropic at this resonance (Wi 52, Wi 52b, and private communication). Resonances at $E_p=3.7$, 5.18, 5.87, and 6.37 Mev are reported by (Bl 51a) who used a stacked-foil technique, counting the C^{11} formed. The total cross section at $E_p=3.7$ Mev is ~55 mb (Bl 51a).

Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
Wi 52 Willard, Bair, and Kington, Phys. Rev. **87**, 206A (1952).

TABLE III(12). Neutron groups from $B^{11}(d\ n)C^{12}$ (Jo 52a).

Q	C^{12*}
(13.740±0.014)[a]	0
(9.30 ±0.02)[a]	4.44
4.1 ±0.1	9.6
2.9 ±0.1	10.8
2.6 ±0.1	11.1
2.00 ±0.08	11.74
0.98 ±0.08	12.76
0.53 ±0.05[b]	13.21[b]
0.38 ±0.05[b]	13.36[b]
−0.42 ±0.05(?)	14.16(?)
−1.35 ±0.03	15.09
−1.78 ±0.03(?)	15.52(?)
−2.33 ±0.03	16.07

[a] Q values from other disintegration data.
[b] May be one level at 13.3 Mev.

Wi 52b Willard and Bair, Phys. Rev. **86**, 629 (1952).
Bl 51a Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).

XI. $B^{11}(d\ n)C^{12}$ $Q_m=13.724$

Neutron groups observed by the photographic emulsion technique at $E_d=3.4$ Mev, $\theta=0°$ and $80°$, are listed in Table III(12). No group corresponding to a level at 7 Mev was resolved, although a weak [<10 percent] group might have evaded detection (see Gi 49). A considerable background appears for neutron energies corresponding to 11.5–16.3 Mev excitation which may be associated with further particle emission or with unresolved levels (Jo 52a).

A single γ-ray, of energy 4.5 ± 0.1 Mev (4.44 ± 0.05 Mev: Ru 51a) is observed; the yield at $E_d=1.56$ Mev from a thick, 100 percent B^{11} target is 2.7×10^{-6} γ/d. The absence of higher energy (~9.7 Mev) radiation may be associated with the α-particle instability of this level (Te 51a, Ru 51a).

A possible threshold for slow neutron production at $E_d=3.4$ Mev may be associated with a level at 16.6 Mev (Tu 51a).

Gi 49 Gibson, Proc. Phys. Soc. (London) **62A**, 586 (1949).
Jo 52a Johnson, Phys. Rev. **86**, 302 (1952).
Ru 51a Rutherglen, Rae, and Smith, Proc. Phys. Soc. (London) **64A**, 906 (1951).
Te 51a Terrell and Phillips, Phys. Rev. **83**, 703 (1951).
Tu 51a Tucker, Phys. Rev. **83**, 473 (1951).

XII. $B^{12}(\beta^-)C^{12}$ $Q_m=13.370$

The Fermi plot is straight from $E_\beta=6$ Mev to the end point at 13.43 Mev: deviations below 6 Mev may indicate transitions to levels at ~7 and ~11 Mev (~five percent total) (Ho 50). Observation of $\beta-\gamma$ coincidences with an end point of ~4.7 g/cm^2 in carbon indicates 4 ± 1 percent transitions to the 4.44-Mev level (Ve 51b).

The half-life is 0.025 ± 0.002 sec (see Ho 50b); log ft=4.17 for the ground-state transition.

Ho 50 Hornyak and Lauritsen, Phys. Rev. **77**, 160 (1950).
Ve 51b Vendryes, Compt. rend. **233**, 391 (1951).
See also: Ve 51a.

XIII. $C^{12}(\gamma\ n)C^{11}$ $Q_m=-18.711$ (not illustrated)

The cross section exhibits a resonance at $E_\gamma=22.9$ Mev, of half-width 2.8 Mev. The peak cross section is 13.1 mb, the integrated cross section [to ~27 Mev] 46 Mev-mb (Ha 51b, Ka 51a). On the high energy side, the yield exhibits a tail, roughly proportional to E_γ^{-3}, extending to over 60 Mev (Sa 51). Integrated cross sections of 148 and 86 Mev-mb are quoted by (La 48b) and (Ma 51d), respectively.††

Ha 51b Haslam, Johns, and Horsley, Phys. Rev. **82**, 270 (1951).
Ka 51a Katz and Cameron, Can. J. Phys. **29**, 518 (1951).
Sa 51 Sagane, Phys. Rev. **84**, 587 (1951).

†† *Note added in proof:* Discontinuities in the activation curve are attributed to levels of C^{12} at 19.35, 19.69, 20.06, 20.47, 20.74, 21.37, and 22.6 Mev (Katz *et al.*, private communication).

TABLE IV(12). Inelastic proton groups from C^{12}; $E_p=31.5$ Mev (Br 51e).

Q (Mev)	$d\sigma(90°)$ (mb/sterad)	$d\sigma(160°)$ (mb/sterad)
-4.3 ± 0.2	$1.5\ \pm0.2$	0.34 ± 0.05
-7.5 ± 0.4	0.16 ± 0.1	0.12 ± 0.06
-9.5 ± 0.2	0.90 ± 0.2	0.19 ± 0.1
-11 to -17	$2.8\ \pm0.4$	$2.7\ \pm0.4$

La 48b Lawson and Perlman, Phys. Rev. **74**, 1190 (1948).
Ma 51d Marshall, Phys. Rev. **83**, 345 (1951).
See also: Le 50a, Ko 51, La 52, Ed 52a.

XIV. $C^{12}(\gamma\ p)B^{11}$ $Q_m=-15.949$ (not illustrated)

The cross section exhibits a maximum at $E_\gamma=21.5$ ±0.5 Mev, 1.7 ± 0.5 Mev wide. The peak cross section is 34 ± 8 mb: the integrated cross section [to 24 Mev] is 63 ± 16 Mev-mb (Ha 51f). The angular distribution of protons at $E_\gamma=23$ Mev has the form $1+(\sin\theta+0.25\sin\theta\cos\theta)^2$, indicating interference of a one percent quadrupole component with the dominant dipole absorption (Ha 52g).

At higher energy, the reaction $C^{12}(\gamma\ p\alpha)Li^7$ also occurs (Br 52a).

Ha 51f Halpern and Mann, Phys. Rev. **83**, 370 (1951).
Ha 52g Halpern, Mann, and Rothman, Phys. Rev. **87**, 164 (1952).
Br 52a Brinkworth, Goward, and Wilkins, A.E.R.E. Memo G/M 130 (April, 1952).
See also: Ma 50h.

XV. $C^{12}(\gamma\ 3\alpha)$ $Q_m=-7.278$

Some 2500 stars, observed in photographic emulsions bombarded with bremsstrahlung spectra, with peak energies up to 70 Mev, and with $Li^7(p\ \gamma)Be^8$ γ-rays, have been analyzed. The cross section exhibits pronounced maxima at about 17.2, 18.3, 21.9, 24.3, and 29.4 Mev, and considerable but not conclusive evidence of partially resolved finer structure corresponding to sharp states of C^{12}. The mean cross section for the $Li^7(p\ \gamma)Be^8$ lines, 14.8 and 17.6 Mev, is 0.14 ± 0.025 mb (Go 52a and private communication). A value of 0.175 ± 0.025 mb is reported by (Gl 52).

The character of the α-spectrum at $E_\gamma=17.6$ Mev suggests that electric quadrupole and magnetic dipole radiations, leading to states in C^{12} with $J=2^+$ and $J=1^+$, are mainly involved (Te 51b: see Be^8).

Go 52a Goward and Wilkins, A.E.R.E. Memo G/M 127, (March, 1952).
Gl 52 Glättli, Seippel, and Stoll, Helv. Phys. Acta, **25**, 491 (1952).
Te 51b Telegdi, Phys. Rev. **84**, 600 (1951).
See also: Ch 50b, Te 50c, Wi 50d, Ch 51b, Wi 51c, Wi 51f, Na 52a, Ed 52, Go 52.

XVI. $C^{12}(n\ n')C^{12*}$ (not illustrated)

Observation of α-particles resulting from inelastic scattering of high energy neutrons in carbon gives evidence for α-emitting levels at 10.3 ± 0.25, 11.3 ± 0.25, and 13.05 ± 0.25 Mev (Titterton, private communication).

XVII. $C^{12}(p\ p')C^{12}$

Proton groups reported by (Br 51e) are shown in Table IV(12). At $E_p=8$ Mev, a single γ-ray is observed, $E_\gamma=4.5$ Mev (Go 51h). Other recent determinations of the energy of the first level are: 4.59 Mev (Co 52g), 4.40 Mev (Ba 52c), and 4.47 Mev (Ar 52b). The average of earlier determinations (see Ho 50b) is 4.6 ± 0.2 Mev for the first level, and 10.0 ± 0.4 Mev for the third.

The angular distribution of inelastically scattered protons, observed at $E_p=7.3$ Mev, exhibits strong fore-and-aft asymmetry (Go 52b).

Br 51e Britten, Princeton Univ. Rept, NYO 971, June (1951).
Go 51h Gove, Phys. Rev. **84**, 1059 (1951).
Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).
Ba 52c Baker, Dodd, and Simmons, Phys. Rev. **85**, 1051 (1952).
Ar 52b Arthur, Allen, Bender, Hausman, McDole, Diana, Rhodes, and Barjon, Phys. Rev. **87**, 237A (1952).
Go 52b Gove and Stoddart, Phys. Rev. **86**, 572 (1952).
See also: Ho 50b, Rh 50, Br 51, St 52b.

XVIII. $C^{12}(d\ d')C^{12*}$

At $E_d=10$ Mev, $\theta=90°$, an inelastically scattered group with $Q=-4.41$ Mev is observed with about twice the intensity of the elastic group (Ke 51b).

Ke 51b Keller, Niedner, Wang, and Shull, Phys. Rev. **81**, 481 (1951).
See also: Bo 50d.

XIX. $C^{13}(d\ t)C^{12}$ $Q_m=1.309$

Recently reported Q-values are:

$Q=1.310\pm0.006$ (St 51: mag. spectrometer)
$Q=1.310\pm0.003$ (Li 51b: mag. spectrometer)

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Li 51b Li and Whaling, Phys. Rev. **82**, 122 (1951).

XX. $N^{12}(\beta^+)C^{12}$ $Q_m=17.7$

The decay proceeds primarily via an allowed transition to the ground state. Delayed α-particles with a total energy of ~4 Mev are also observed, suggesting that a state of C^{12} in the region 11 to 12 Mev is involved (Al 50g).

Al 50g Alvarez, Phys. Rev. **80**, 519 (1950).

XXI. $N^{14}(d\ \alpha)C^{12}$ $Q_m=13.570$

The Q-value obtained from the best current Q's of $N^{14}(d\ p)N^{15}$, $N^{14}(n\ \gamma)N^{15}$ and $N^{15}(p\ \alpha)C^{12}$ is 13.568 ±0.010 (Van Patter, private communication). Two other α-particle groups have Q-values of 9.137 ± 0.006 and 3.955 ± 0.003, giving level energies of 4.431 ± 0.013 and 9.613 ± 0.012 Mev. The 9.6-Mev level appears to have a breadth >10 kev, probably associated with its α-particle instability (Ma 51).

A group corresponding to a level at 7.6 Mev with an intensity ~10 percent of the group to the 4.4-Mev level, is also reported (Ho 40).

The angular distributions of the ground- and 4.4-Mev state groups have been obtained at $E_d=7.9$ Mev. Both exhibit a minimum at $\theta=77°$ in addition to other complexities (Gi 52).

A 4.4-Mev γ-ray (not resolved) is reported by (Te 51a). (See N^{15}: $N^{14}(d\ p)N^{15}$.)

Ma 51 Malm and Buechner, Phys. Rev. **81**, 519 (1951).
Ho 40 Holloway and Moore, Phys. Rev. **58**, 847 (1940).
Gi 52 Gibson and Thomas, Proc. Roy. Soc. (London) **210**, 543 (1952).
Te 51a Terrell and Phillips, Phys. Rev. **83**, 703 (1951).

XXII. $N^{15}(p\ \alpha)C^{12}$ $Q_m=4.961$

Recently reported Q-values are:

$Q=4.961\pm0.006$ (Li 51a: mag. spectrometer)
$Q=4.960\pm0.007$ (St 51: mag. spectrometer)
$Q=4.960\pm0.006$ (Co 51d: mag. spectrometer)

The short-range α-particles have a Q of 0.529 ± 0.008 Mev, yielding a level energy of 4.432 ± 0.010 Mev (Sc 52). The γ-ray energy, after a Doppler correction of 20 kev, is 4.443 ± 0.020 Mev (Th 52). A value 4.45 ±0.04 Mev is quoted by (Ca 51a).

The angular distributions of short-range α-particles and $\alpha-\gamma$ correlations establish that the 4.4-Mev level has $J=2^+$ or $J>4$ (see O^{16}).

Li 51a Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Co 51d Collins, McKenzie, and Ramm, Nature **167**, 682 (1951).
Sc 52 Schardt, Fowler, and Lauritsen, Phys. Rev. **86**, 527 (1952).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Ca 51a Carver and Wilkinson, Proc. Phys. Soc. (London) **64A**, 199 (1951).

XXIII. $O^{16}(\gamma\ \alpha)C^{12}$ $Q_m=-7.149$ (not illustrated)

For bombarding energies of about 18 Mev, most of the disintegrations lead to the ground state (Na 52a).

Some 66 stars, produced by 23-Mev bremsstrahlung irradiation of photographic emulsions have been analyzed by (Go 50h). About 50 percent of the disintegrations appear to involve a level of C^{12} at 9.7 Mev, which subsequently disintegrates by α-particle emission to the ground state of Be^8. The remainder apparently lead to excited states of Be^8, again via C^{12*} (see Be^8).

Na 52a Nabholz, Stoll, and Wäffler, Phys. Rev. **86**, 1043 (1952).
Go 50h Goward and Wilkins, Proc. Phys. Soc. (London) **63A**, 1171 (1950).

N^{12}

(not illustrated)

Mass of N^{12}

From the $C^{12}(p\ n)N^{12}$ results, the $N^{12}-C^{12}$ mass difference is given as 17.7 ± 0.1 Mev. This value is in good agreement with that derived from the N^{12} β^+ decay (17.6 ± 0.2 Mev) (Al 49a).

We adopt: $N^{12}-C^{12}=17.7\pm0.1$ Mev; mass defect: 21.2 ± 0.1 Mev

I. $N^{12}(\beta^+)C^{12}$ $Q_m=17.7$

The half-life is 0.0125 ± 0.001 sec; $E_\beta(\max)=16.6\pm0.2$ Mev (Al 49a). The decay is complex: N^{12} decays both to the ground state and to α-unstable excited states of C^{12}(Al 50g). Log ft = 4.18 for the ground-state transition (Fe 51b).

Al 49a Alvarez, Phys. Rev. **75**, 1815 (1949).
Al 50g Alvarez, Phys. Rev. **80**, 519 (1950).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).

II. $C^{12}(p\ n)N^{12}$ $Q_m=-18.5$

The threshold is $E_p=20.0\pm0.1$ Mev (Al 49a).

Al 49a Alvarez, Phys. Rev. **75**, 1815 (1949).

III. $N^{14}(\gamma\ 2n)N^{12}$ $Q_m=-30.9$

The integrated cross section is $5.5\pm2\times10^{-4}$ Mev-b (Pa 52a).

Pa 52a Panofsky and Reagan, Phys. Rev. **87**, 543 (1952).

C^{13}

I. $Be^9(\alpha\ n)C^{12}$ $Q_m=5.708$ $E_b=10.656$

Resonances are reported at $E_\alpha=1.5$ Mev, $\sigma=0.13$ barn, $J=3/2$ or $5/2$ and 4.4 Mev, $\sigma=0.32$ b (states at 11.7 and 13.7 Mev). The thick-target yield at $E_\alpha=5.3$ Mev is $\sim7\times10^{-5}$ n/α. Additional resonances for $E_\alpha>5$ Mev probably exist but have not been well resolved (see Ho 50b).‡‡

Limited angular distribution data at $E_\alpha=1.4$ Mev are consistent with the assumption of $J=5/2^+$ for the 11.7-Mev state of C^{13} (Ha 51e). The angular distribution of neutrons at $E_\alpha=30$ Mev is strongly forward (Al 51b: threshold detector). It appears, however, that after account is taken of the effect of center-of-mass motion on the energy spectrum, the distribution can be made to agree with that expected from a statistical distribution of compound states (Co 51c, Wo 50a).

TABLE I(13). Proton groups from $B^{10}(\alpha\ p)C^{13}$.

A Q (Mev)	B Q (Mev)	C Q (Mev)	C Intens.	D Q (Mev)	E Q (Mev)	F Q (Mev)	C^{13*}
(4.1)	4.07 ±0.2	4.08 ±0.12	10		3.8	4.08	0
3.3		3.35 ±0.25	1			3.35	0.7?
	(0.85)	0.65 ±0.15	100	0.63	(0.75)	(0.72)	
0.5	0.31	0.15 ±0.15	50	0.00	0.24	0.18	3.9
0.1	0.07						
−0.8	−0.31	−0.57 ±0.15		−0.55	−0.22	−0.5	4.6
−1.86	−1.57			−1.75		−1.7	5.8

A: (Li 37): Q_0 estimated from masses.
B: (Cr 49c): $E_\alpha=6.64$ and 7.45 Mev, isotopic targets, Al absorbers, proportional counter. $Q=0.85$ group is from B^{11}; $Q=-0.3$ group could be from $B^{10}(\alpha\ d)C^{12}$. Ground-state group highly asymmetric.
C: (Pe 50a): Po α's, photoplate, 4000 tracks; angular distributions reported.
D: (Sl 51): Po α's, photoplate, 200 tracks; $Q=0.63$ group very strong.
E: (Fr 51c): Po α's, isotopic targets, magnetic analysis, "poor" geometry. $Q=0.75$ group from B^{11}, $Q=-0.22$ observed only at $\theta=90°$.
F: Average of quoted values.

‡‡ *Note added in proof:* The yield of γ-rays exhibits a strong resonance at $E_\alpha=1.9$ Mev, $\Gamma\sim200$ kev, and a weaker one at $E_\alpha=2.7$ Mev (N. P. Heydenburg, private communication).

Ha 51e Haefner, Revs. Modern Phys. **23**, 228 (1951).
Al 51b Allen, Nechaj, Sun, and Jennings, Phys. Rev. **81**, 536 (1951).
Co 51c Cohen, Phys. Rev. **81**, 632 (1951).
Wo 50a Wolfenstein, Phys. Rev. **78**, 322A (1950).
See also: Ho 50b.

II. $Be^9(\alpha\ p)B^{12}$ $Q_m=-6.880$ $E_b=10.656$

See B^{12}.

III. $Be^9(\alpha\ d)B^{11}$ $Q_m=-8.016$ $E_b=10.656$

See B^{11}.

IV. (a) $Be^9(\alpha\ \alpha'n)Be^8$ $Q_m=-1.666$ $E_b=10.656$
(b) $Be^9(\alpha\ n)3He^4$ $Q_m=-1.570$

Observation of slow neutrons, not accompanied by γ-rays, starting at $E_\alpha=4.9$ Mev, may be associated with one of these reactions (Bj 38). However, there remains some controversy concerning the existence of these neutrons (see Ho 50b): in some of the experiments in which Pb shielding was used, inelastic scattering can account for part of the effect (Ho 51). No Pb was used, however in the original experiments of (Bj 38) or in the recent work of (Gi 51) who report $\sim$1.5 n/sec/mC/ev in the range 1–20 ev from a Ra−Be source delivering $\sim$15000 n/sec/mC.

Bj 38 Bjerge, Proc. Roy. Soc. (London) **164**, 243 (1938).
Ho 51 Houtermans and Teucher, Z. Physik **129**, 365 (1951).
Gi 51 Giegerl and Broda, Nature **167**, 399 (1951).
See also: Ho 50b.

V. $B^{10}(\alpha\ p)C^{13}$ $Q_m=4.071$

Fluctuations in quoted Q values, cited in Table I(13), for this experiment are so large that only a qualitative consistency can be claimed. The ground-state group appears well established: it is quite low in intensity and strongly asymmetric (weak at 0°). The $Q=3.35$ group is still weaker: the possibility of contamination is not ruled out. The third group, $Q=0.7$ does not appear with B^{10} targets: it is certainly from $B^{11}(\alpha\ p)C^{14}$ ($Q_m=0.781$). The fourth and fifth, unresolved in most work, appear to be associated with the known levels at 3.68 and 3.89 Mev: the two negative Q values may indicate levels at 4.6 and 5.8 Mev.

A 3.8-Mev gamma-ray is observed at $E_\alpha=1.4$ Mev (Be 51).

Be 51 Bennett, Roys, and Toppel, Phys. Rev. **82**, 20 (1951).
Li 37 Livingston and Bethe, Revs. Modern Phys. **9**, 245 (1937).
Cr 49c Creagan, Phys. Rev. **76**, 1769 (1949).
Pe 50a Perkin, Phys. Rev. **79**, 175 (1950).
Sl 51 Slatis, Hjalmar, and Carlsson, Phys. Rev. **81**, 641; **82**, 753 (1951).
Fr 51c Frye and Wiedenbeck, Phys. Rev. **82**, 960 (1951).

VI. $B^{11}(d\ n)C^{12}$ $Q_m=13.723$ $E_b=18.671$

Broad low resonances appear at $E_d=1.1$ and 1.6 Mev for production in the forward direction of neutrons of all

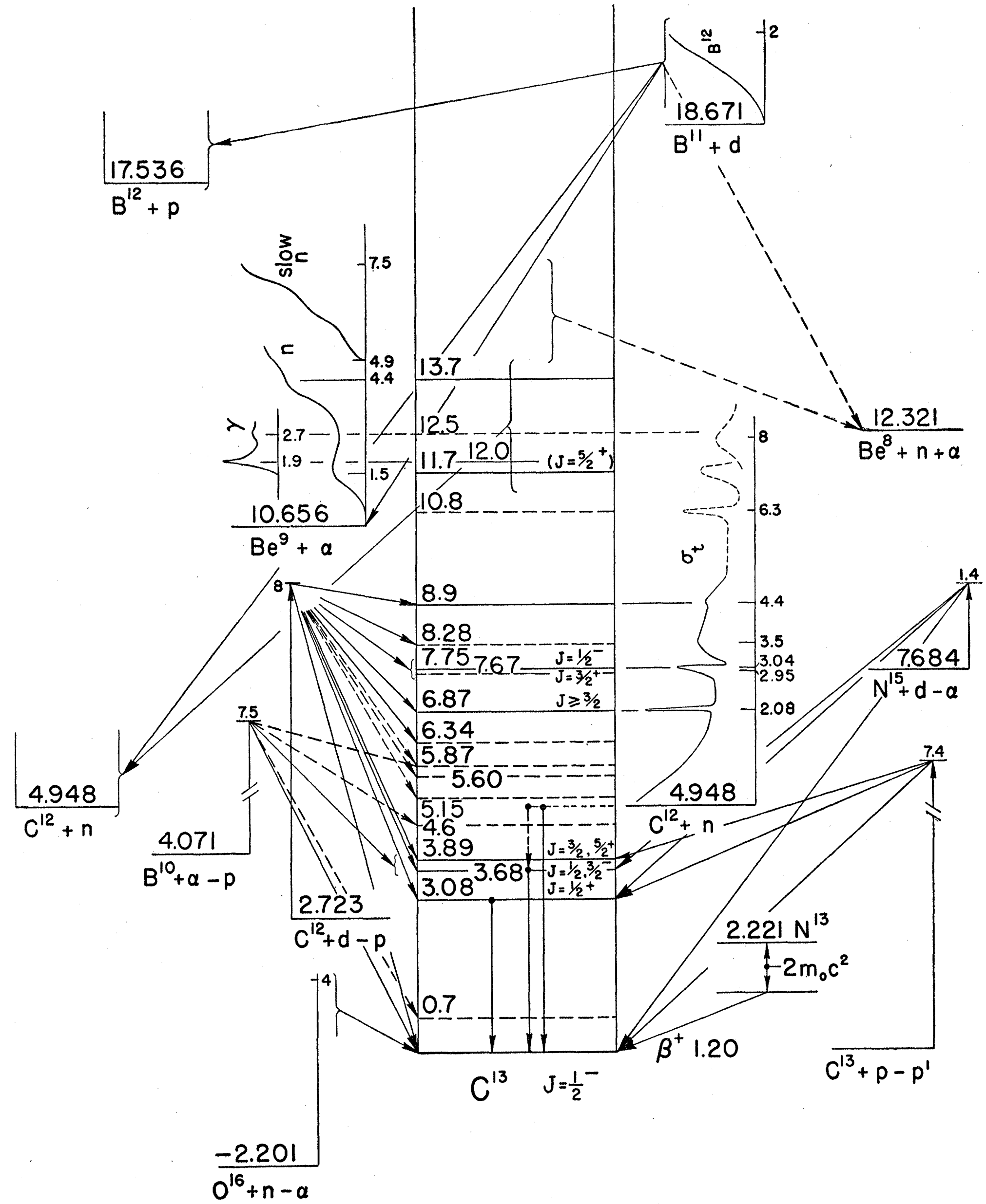

FIG. 16. Energy levels of C^{13}: for notation, see Fig. 1.

energies. The angular distributions exhibit a maximum at 0° (Bu 51a).

Bu 51a Burke and Risser, Phys. Rev. **83**, 211 (1951).
See also: Hu 51g, Tu 51a, Sm 51a.

VII. $B^{11}(d\ p)B^{12}$ $Q_m=1.136$ $E_b=18.671$

The thin target yield rises smoothly from $E_d=0.3$ to 1.8 Mev with no evidence of resonances. At 1.47 Mev the yield is 10^7 β/microcoulomb, $\sigma=4$ mb (Hu 49j): see B^{12}.

Hu 49j Hudspeth and Swann, Phys. Rev. **76**, 1150 (1949).

VIII. $B^{11}(d\ \alpha)Be^9$ $Q_m=8.015$ $E_b=18.671$

At $E_p=1.510$ Mev, $\theta=90°$, the intensity of the ground state and of the excited state α-groups are ~ 10 and 5 percent, respectively, of the intensity of the elastically scattered deuterons (Va 51).

Va 51 Van Patter, Sperduto, Huang, Strait, and Buechner, Phys. Rev. **81**, 233 (1951).

IX. $B^{11}(d\ d)B^{11}$ $E_b=18.671$

See (Va 51).

TABLE II(13). C^{13*} states determined from $C^{12}+d$ proton groups.

A	B
3.086±0.006	3.11
3.686±0.011	3.683
	3.884
	(5.15)
	(5.60)
	(5.87)
	6.34
	6.91
	7.54
	7.82
	8.02
	8.28
	8.84

A: E_d=1.51 Mev, θ=90° (St 51, Va 51a) and Van Patter (private communication): mag. spectrometer.
B: E_d=8 Mev, θ=15° to 160°. (Ro 50d, Ro 51j, Ro 51k: photoplate).

X. $C^{12}(n\ n)C^{12}$ $E_b=4.948$

The epithermal scattering cross section is 4.70±0.05 b (free atoms: Hu 52e).

No resonances with a width >5 kev appear in the scattering cross section in the energy range $E_n=20$ to 1360 kev (Mi 50c). The course of the cross-section curve in this range can be accounted for by the broad *s*-state at 3.09-Mev excitation (Th 52b). A resonance, <10 kev wide, exists at 2.08 Mev, $\sigma\geq 2.7$ b, corresponding to a level at 6.87 Mev in C^{13} with $J\geq\frac{3}{2}$ (Bo 51c). A structure at 3.0 Mev (Bo 51c, Ri 51e) is attributed to strong interference between a resonance at this energy with $J=\frac{3}{2}$ and either potential scattering or another resonance, possibly that at 3.5 Mev (Ri 50d, Ri 51c), of the same spin (Bo 51c). The angular distributions have been measured in the range $E_n=2.6$ to 4.15 Mev by (Hu 52d), who find by a partial-wave analysis a $D_{\frac{3}{2}}$ resonance at $E_n=2.95$ Mev and an $S_{\frac{1}{2}}$ resonance at $E_n=3.04$ Mev. The rise in cross section at 3.5 Mev does not appear to be a resonance (Hu 52d). Another maximum appears at $E_n=4.4$ Mev (Fr 50b) and a further broad resonance is reported at about 8 Mev (Ne 52). There is evidence of a resonance at ~6.3 Mev and some indication that the structure near 8 Mev is complex (Henkel, private communication). Precise cross-section values are quoted for several energies by (La 50a).

The total cross section for 14-Mev neutrons is 1.279 ±0.004 barns (Po 52a), 1.32±0.02 barns (Co 52h).

Hu 52e Hughes *et al.*, AECU 2040 (1952).
Mi 50c Miller, Phys. Rev. **78**, 806 (1950).
Th 52b Thomas, Phys. Rev. (to be published).
Bo 51c Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).
Ri 51e Ricamo, Nuovo cimento **8**, 893 (1951).
Ri 50d Ricamo, Zünti, Baldinger, and Huber, Helv. Phys. Acta **23**, 508 (1950).
Ri 51c Ricamo and Zünti, Helv. Phys. Acta **24**, 419 (1951).
Hu 52d Huber, Baldinger, and Budde, Helv. Phys. Acta **25**, 444 (1952).
Fr 50b Freier, Fulk, Lampi, and Williams, Phys. Rev. **78**, 508 (1950).
Ne 52 Nereson, Phys. Rev. **87**, 221 (1952).
La 50a Lampi, Freier, and Williams, Phys. Rev. **80**, 853 (1950).
Po 52a Poss, Salant, Snow, and Yuan, Phys. Rev. **87**, 11 (1952).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
See also: Am 46, Hi 49, Br 50f, Ba 50g, La 51b, Sh 51b, Wa 51e.

XI. $C^{12}(n\ \gamma)C^{13}$ $Q_m=4.948$

The thermal capture cross section in graphite is 4.7 mb (Wa 50e).

$Q=4.949\pm0.006$ Mev (pair spectrometer: Bartholomew and Kinsey, private communication).

In addition to the 4.95-Mev ground-state transition, a γ-ray is reported with an energy of 3.68±0.05 Mev and an intensity of 0.3 photon per capture. If a 3.9-Mev γ-ray occurs, its intensity is <0.06 photon per capture; an upper limit of 0.1 photon per capture can be placed on a 3.1-Mev γ-ray (Ba 52f).

The thermal capture cross section is about five times smaller than would be expected from the known characteristics of the 3.09-Mev level to which it is attributed (see $C^{12}(n\ n)C^{12}$). This deficit can be accounted for by a large contribution from the external region to the transition moment, opposite in sign to the internal contribution (Th 52b).

Wa 50e Way, Fano, Scott, and Thew, Natl. Bur. of Stds. Circ. 499, (September, 1950) and supplements.
Ba 52f Bartholomew and Kinsey, Can. J. Phys. (to be published).
Th 52b Thomas, Phys. Rev. (to be published).
See also: Wi 50a, Ki 51.

XII. $C^{12}(n\ n)3\alpha$ $Q_m=-7.277$ $E_b=4.948$ (not illustrated)

485 stars, attributed to this reaction, have been observed in boron-loaded photoplates exposed to neutrons with E_n up to 24 Mev. The 2.94-, 4.05-, 7.5- and 10.0(?)-Mev states of Be^8 are believed to be involved in the events (Pe 51b).

Pe 51b Perkin, Phys. Rev. **81**, 892 (1951).

XIII. $C^{12}(n\ 2n)C^{11}$ $Q_m=-18.711$ $E_b=4.948$ (not illustrated)

See (Ho 50b, Je 49e).

TABLE III(13). Levels of C^{13} from $C^{12}(d\ p)C^{13}$.

C^{13*}	l_n	J	Reference
0	1	1/2, 3/2⁻	(Ro 51j, Bl 52)
3.09	0	1/2⁺	(Ro 51j, Bl 52)
3.68	1	1/2, 3/2⁻	(Ro 51k)
3.89	2	3/2, 5/2⁺	(Ro 51k, Bl 52)

TABLE IV(13). Resonances in $C^{12}(p\ \gamma)N^{13}$ (Se 51c).

E_{res} (Mev)	Γ (kev)	Y_{max}[a]	$\omega\Gamma_\gamma$ (ev)	σ_{res} (mb)
0.45	35	7.5±0.5	0.67	0.127
1.698±0.005[b]	70±10	11.0±0.8	1.39	0.035

[a] Disintegrations per 10^{10} protons, thick C^{12} target.
[b] Observed E_{res} = 1693 ±0.005 corrected for penetration factor.

XIV. $C^{12}(d\,p)C^{13}$ $Q_m = 2.723$

Recently reported values for the ground-state Q are

$Q = 2.732 \pm 0.006$ (Kl 52: mag. spectrometer)
$Q = 2.716 \pm 0.005$ (St 51: mag. spectrometer)

Measurements on the proton groups are summarized in Table II(13). Angular distributions of the protons, analyzed by the method of (Bu 51b), indicate the level assignments shown in Table III(13).

A 3082±7-kev (Doppler corrected) γ-ray is observed when C^{12} is bombarded with ~1.5-Mev deuterons. The lifetime of the radiating state is $<3\times10^{-13}$ sec. The transition is *ED*, in agreement with the angular distribution results and the known spin of C^{13} (Th 52). At $E_d = 3$ Mev, γ-ray lines are observed with $E_\gamma = 3.06 \pm 0.06$ and 3.65 ± 0.05 Mev and with intensity ratio 30:1 (Meyerhof, scintillation spect., private communication).

Kl 52 Klema and Phillips, Phys. Rev. **86**, 951 (1952).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Bu 51b Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).
Va 51a Van Patter, Buechner, and Sperduto, Phys. Rev. **82**, 248 (1951).
Ro 50d Rotblat, Harwell, Conf. Report (1950).
Ro 51j Rotblat, Nature **167**, 1027 (1951).
Ro 51k Rotblat, Phys. Rev. **83**, 1271 (1951).
Bl 52 Black, Phys. Rev. **87**, 205A (1952).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
See also: Go 51i, Bo 50, Me 51a, Be 50i, Al 51n, Bl 51, Ha 51e, Gi 50b, Br 52, Br 52b.

XV. $C^{13}(\gamma\,n)C^{12}$ $Q_m = -4.948$

See (Se 49a).

XVI. $C^{13}(p\,p')C^{13}$§§

At $E_p = 7.4$ Mev, $\theta = 90°$, proton groups corresponding to levels at 3.14 and 4.03 Mev are observed (Co 52g).

Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).

XVII. $N^{13}(\beta^+)C^{13}$ $Q_m = 2.221$

See N^{13}.

XVIII. $N^{15}(d\,\alpha)C^{13}$ $Q_m = 7.684$

$Q = 7.681 \pm 0.006$ (Ma 51: mag. spectrometer).

At $E_d = 1.4$ Mev, alpha-groups are observed corresponding to states in C^{13} at 0, 3.083 ± 0.005 and 3.677 ± 0.005 Mev. No group corresponding to a possible level at 0.8–1.0 Mev is observed with an intensity >10 percent of the intensity of the ground-state group (Ma 51).

Ma 51 Malm and Buechner, Phys. Rev. **81**, 519 (1951).

XIX. $O^{16}(n\,\alpha)C^{13}$ $Q_m = -2.201$

$Q = 2.38 \pm 0.16$ (Hu 51f).*

Hu 51f Huber, Baldinger, and Proctor, Helv. Phys. Acta **24**, 302 (1951).

§§ *Note added in proof:* Levels at 3.0 and 3.7 Mev are reported: see (Li 52).

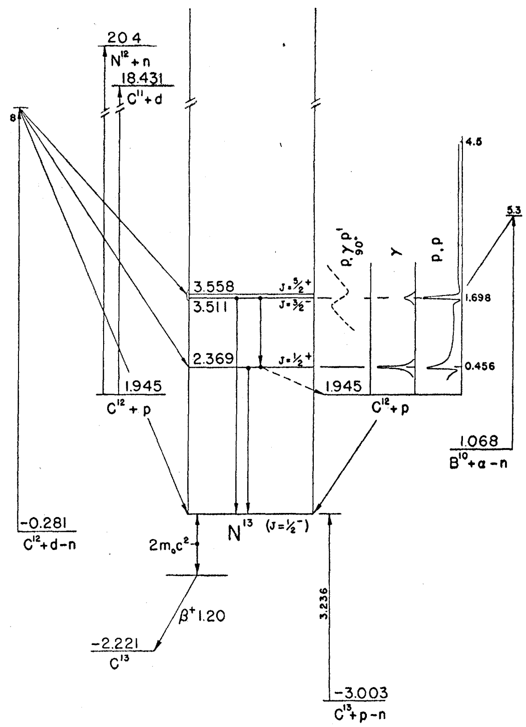

FIG. 17. Energy levels of N^{13}: for notation, see Fig. 1.

N^{13}

I. $N^{13}(\beta^+)C^{13}$ $Q_m = 2.221$

The half-life is 10.1 ± 0.1 min (see Ho 50b); E_β (max) $= 1.202 \pm 0.005$ Mev (Ho 50). The positron spectrum is simple: the Fermi plot is straight down to <0.15 Mev. Log ft = 3.67 (Fe 51b).

Ho 50 Hornyak and Lauritsen, Phys. Rev. **77**, 160 (1950).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
See also: Ho 50b.

II. $B^{10}(\alpha\,n)N^{13}$ $Q_m = 1.068$

See N^{14}.
See also: Ro 52a.

III. $C^{12}(p\,\gamma)N^{13}$ $Q_m = 1.945$

Pronounced resonances exist at $E_p = 456 \pm 2$ kev, $\Gamma = 35$ kev (Fo 49b) and 1697 ± 12 kev, $\Gamma = 74 \pm 9$ kev (Va 49). Reaction constants reported by (Se 51c, Se 51e) are given in Table IV(13). The reduced width γ^2 for the first resonance is of the order of the Wigner sum-rule limit for *s*-wave protons. This large width and the difference in boundary conditions at the nuclear surface account quantitatively for the displacement between this and the 3.10-Mev $S_{\frac{1}{2}}$ state of C^{13} (Th 51a, Eh 51, Th 52b). The parameters obtained from these data and from the neutron scattering on C^{12}, are: reduced width $\Theta_\lambda^2 \equiv 2\ Ma\gamma^2/3\hbar^2 = 0.5$ of the sum-rule limit, $a = 4.9\times10^{-13}$ cm, $E_\lambda(C^{13}) = 1.3$ Mev, and $E_\lambda(N^{13}) = 1.1$ Mev with respect to the observed ground states

TABLE V(13). Level parameters obtained from $C^{12}(p\ p)C^{12}$ (Ja 52b).

Level:	1/2+	3/2−	5/2+
E_r (Mev)[a]	2.369	3.511	3.558
Γ (kev)[a]	31	55	61
E_λ (Mev)[a]	0.951	3.516	3.612
$2\ Ma\gamma^2/3\hbar^2$	0.54	0.031	0.21

[a] All quantities are in center-of-mass coordinates: E_r and E_λ are measured from the ground state of N^{13}; an interaction radius $a=4.77\times10^{-13}$ cm was used.

(Th 52b) (compare $C^{12}(p\ p)C^{12}$). (Te 52) give a reduced width of 0.18 of the sum-rule limit.

The radiation from the 1.70-Mev resonance goes directly to the ground state: no cascades are observed. The angular distribution has the form $Y(\theta)=1-A\cos^2\theta$, where A has the following values:

at $E_p=1.682$ Mev	$A=0.473$
1.723	0.568
1.749	0.618

The variation of A suggests interference with another level: the absence of a measurable $(\cos\theta)$ term indicates like parity. The data can be fitted by the assumption of d-wave formation of a $J=\frac{3}{2}^+$ level (see, however, $C^{12}(p\ p)C^{12}$) with interference from an s-wave background (Da 51, Da 51b). On the assumption that the resonance is in fact formed by p-waves, a reduced width $\Theta^2=0.04$ of the sum-rule limit is obtained ($\Gamma=70$ kev). The large value of the partial width for radiation ($\omega\Gamma_\gamma=1.4$ ev) indicates considerable overlap of the initial and final wave functions, suggesting that the $P_{\frac{3}{2}}$ state is related to the ground state ($1\ p$) rather than to a higher ($2\ p$) configuration (Th 52b).

Consideration of the cross section at $E_p\sim100$ kev (see Ho 50b and Fo 51) and of the capture cross section in $C^{12}(n\ \gamma)C^{13}$ leads to an estimate of $\Theta^2=0.02$ for the reduced width of the ground states of N^{13} and C^{13} (Th 52b).

In the range $E_p=1.2$ to 2.5 Mev, a gamma-ray whose energy varies with bombarding energy as $E_\gamma=12/13$ $(E_p-0.48)$ is observed. At $\theta=90°$, the cross section has a maximum at $E_p\sim1.6$ Mev, $\sigma\sim0.003$ mb, and a minimum at $E_p=1.75$ Mev. At $\theta=0°$, the intensity at $E_p=1.6$ Mev is <10 percent of the 90° value while that at 1.75 Mev is $\sim\frac{1}{2}$ of the 90° value. The radiation clearly represents a transition to the 2.37-Mev level ($E_p=0.46$ Mev) which presumably decays preferentially by proton emission. It is possible that the peculiar excitation function results from interference between nonresonant and resonant (at $E_p=1.7$ Mev) p-wave capture radiation (To 52 and H. Woodbury, private communication).

Fo 49b Fowler and Lauritsen, Phys. Rev. **76**, 314 (1949).
Va 49 Van Patter, Phys. Rev. **76**, 1264 (1949).
Se 51c Seagrave, Ph.D. thesis, California Institute of Technology (1951).
Se 51e Seagrave, Phys. Rev. **84**, 1219 (1951).
Th 51a Thomas, Phys. Rev. **81**, 661 (1951).
Eh 51 Ehrman, Phys. Rev. **81**, 412 (1951).
Th 52b Thomas, Phys. Rev. (to be published).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
Da 51 Day and Perry, Phys. Rev. **81**, 662 (1951).
Da 51b Day, Ph.D. thesis, California Institute of Technology (1951).
Fo 51 Fowler, Phys. Rev. **81**, 655 (1951).
To 52 Tollestrup, Day, and Woodbury, Phys. Rev. **85**, 760A (1952).
See also: Ho 50b.

IV. $C^{12}(p\ p)C^{12}$ $E_b=1.945$

Anomalies appear at 0.46 and 1.7 Mev (Go 51, Ja 52a: $\theta_{cm}=106°$, 128°, 149°, and 169°). Analysis of the data indicates that the low energy anomaly is due to s-wave protons ($J=\frac{1}{2}^+$; $E_p=0.461\pm0.003$ Mev; $\Gamma=34$ kev) (Go 51, Ja 51b, Wa 52a, Ja 52b.) A $J=\frac{3}{2}^-$ state ($E_p=1.698$ Mev; $\Gamma=60$ kev) and a $J=5/2^+$ state ($E_p=1.748$ Mev; $\Gamma=66$ kev) are necessary to account for the higher energy data (Ja 52b). The parameters describing these three levels are given in Table V(13). The large reduced widths of the two even parity levels suggests that the single-particle model is valid here, while the comparative narrowness of the $J=\frac{3}{2}^-$ level may indicate appreciable excitation of the core (Ja 52b: see, however, Th 52b).

The differential cross section at 32 Mev is 3.0 ± 0.4 mb/sterad at 90° and 0.29 ± 0.05 mb/sterad at 160° (Br 51).

See also: C^{12}.

Go 51 Goldhaber and Williamson, Phys. Rev. **82**, 495 (1951).
Ja 52a Jackson, Galonsky, Eppling, Hill, Goldberg, and Cameron, Phys. Rev. (to be published).
Ja 51b Jackson and Galonsky, Phys. Rev. **84**, 401 (1951).
Wa 52a Warters and Milne, Phys. Rev. **85**, 761A (1952).
Ja 52b Jackson and Galonsky, Phys. Rev. (to be published).
Br 51 Britten, Phys. Rev. **82**, 295 (1951).
See also: Wh 50f, Ko 51a, Ba 52c, Th 52b.

V. $C^{12}(p\ d)C^{11}$ $Q_m=-16.486$ $E_b=1.945$

The differential cross sections at 90° and 160°, $E_p=32$ Mev, are ~1.3 and ~1.1 mb/sterad, respectively. If one assumes isotropy, $\sigma_t=15$ mb (Br 51, Br 51e).

Br 51 Britten, Phys. Rev. **82**, 295 (1951).
Br 51e Britten, Princeton University Report NYO 971, June (1951).

VI. $C^{12}(p\ n)N^{12}$ $Q_m=-18.5$ $E_b=1.945$

The threshold is $E_p=20.0\pm0.1$ Mev (Al 49a).

Al 49a Alvarez, Phys. Rev. **75**, 1815 (1949).

VII. $C^{12}(p\ pn)C^{11}$ $Q_m=-18.711$ $E_b=1.945$

See (Ch 47c, Mc 48).

VIII. $C^{12}(d\ n)N^{13}$ $Q_m=-0.281$

The threshold is $E_d=0.328\pm0.003$ Mev; $Q=-0.281\pm0.003$ (Bo 49c).

Neutron groups corresponding to excited states of N^{13} at 2.29 ± 0.12 (Gr 49a), 2.38 ± 0.05 Mev (El 51c) and 3.48±0.12 (Gr 49a), 3.53±0.05 Mev (El 51c) have been observed.

Angular distributions of neutrons corresponding to the first three states of N^{13}, analyzed by the method of (Bh 52), are not inconsistent with $J=\frac{1}{2}$, or $\frac{3}{2}$, odd for the ground state, $J=\frac{1}{2}$, even for the 2.4-Mev state and $J=\frac{3}{2}$, or 5/2, even for the 3.5-Mev state(s) (El 51c; see, however, $C^{12}(p\ p)C^{12}$).

Bo 49c Bonner, Evans, and Hill, Phys. Rev. **75**, 1398 (1949).
Gr 49a Grosskreutz, Phys. Rev. **76**, 482 (1949).
El 51c El Bedewi, Middleton, and Tai, Proc. Phys. Soc. (London) **64A**, 1055 (1951).
Bh 52 Bhatia, Huang, Huby and Newns, Phil. Mag. **43**, 485 (1952).
See also: Hu 51g, He 51a, Sm 51a.

IX. $C^{13}(p\ n)N^{13}$ $Q_m=-3.003$.

$E_{\text{threshold}}=3.236\pm0.003$ Mev; $Q=-3.003\pm0.003$ (Ri 50e).

Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
See also: Ad 50b.

X. $N^{14}(n\ 2n)N^{13}$ $Q_m=-10.545$ (not illustrated)

See N^{15}.

XI. $N^{14}(\gamma\ n)N^{13}$ $Q_m=-10.545$ (not illustrated)

The threshold is $E_\gamma=10.7\pm0.2$ Mev (see Ho 50b).

XII. $N^{14}(d\ t)N^{13}$ $Q_m=-4.288$ (not illustrated)

The threshold is $E_d=6.8\pm0.1$ Mev (Bo 42).

Bo 42 Borst, Phys. Rev. **61**, 106A (1942).

C^{14}

I. $C^{14}(\beta^-)N^{14}$ $Q_m=0.155$

The mean of reported end points is 155±1 kev (Li 51a). The half-life is 5400±200 years (Ma 51e): log ft=9.03. It is not entirely clear whether the spectrum deviates from the allowed shape (see Ho 50b, Je 52, Mc 52a). A half-life value of 5568±30 years is reported by (An 51).

Since the parities of C^{14} and N^{14} are both even (see $C^{13}(d\ p)C^{14}$ and $C^{13}(d\ n)N^{14}$), it is not obvious why the half-life of C^{14} should be so large. It may be that a strong L-forbiddenness (transition $^1S_0$ to $^3D_1$) is involved (see, e.g., No 51, Ge 51, and Bo 50c).

Li 51a Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
Ma 51e Manov and Curtiss, J. Research Natl. Bur. Standards **46**, 328 (1951).
An 51 Anderson and Libby, Phys. Rev. **81**, 64 (1951).
See also: Bo 50c, Ho 50b, Fe 51b, Fu 51a, Ge 51, No 51, Je 52, Mc 52a.

II. $B^{11}(\alpha\ p)C^{14}$ $Q_m=0.781$

$Q=0.75\pm0.01$ (Fr 51c: magnetic spectrometer).

Fr 51c Frye and Wiedenbeck, Phys. Rev. **82**, 960 (1951).
See also: Ho 50b, Pe 50a.

III. $C^{13}(d\ p)C^{14}$ $Q_m=5.944$

Recently reported Q-values are:

$Q=5.940\pm0.004$ (Li 51b: magnetic spectrometer)
$Q=5.948\pm0.008$ (St 51: magnetic spectrometer)

The angular distribution of ground-state protons at $E_d=4$ Mev indicates capture of p-wave neutrons: the parity of C^{14} is therefore the same as N^{14} (see $C^{13}(d\ n)N^{14}$) and is even, since C^{13} is odd (Br 52).

A proton group corresponding to a level at 6.093 ±0.009 Mev (Sp 50, Van Patter: private communication) has been observed. At $E_d=1.507$ Mev, $\theta=90°$, the group corresponding to this level is three times as intense as the ground-state group. In the region from 5.2 to 6.1 Mev in C^{14} no level has been observed with a proton group intensity >20 percent of the intensity of the 6.1-Mev group (Sp 50).

A 6110±30 kev γ-ray has been observed (Th 52: see also Ba 51b). The internally-formed positron distribution suggests that the 6.10-Mev line is electric dipole radiation; $E2$ and $M1$ cannot be excluded, however. A marked rise in the positron intensity associated with a transition energy ~4.1 Mev may indicate a nuclear pair emitting state at that energy in C^{14} (Th 52).

Li 51b Li and Whaling, Phys. Rev. **82**, 122 (1951).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Br 52 Bromley and Goldman, Phys. Rev. **86**, 790 (1952).
Sp 50 Sperduto, Holland, Van Patter, and Buechner, Phys. Rev. **80**, 769 (1950).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Ba 51b Baggett and Bame, Phys. Rev. **84**, 154 (1951).
See also: Ha 51e, Ko 52b.

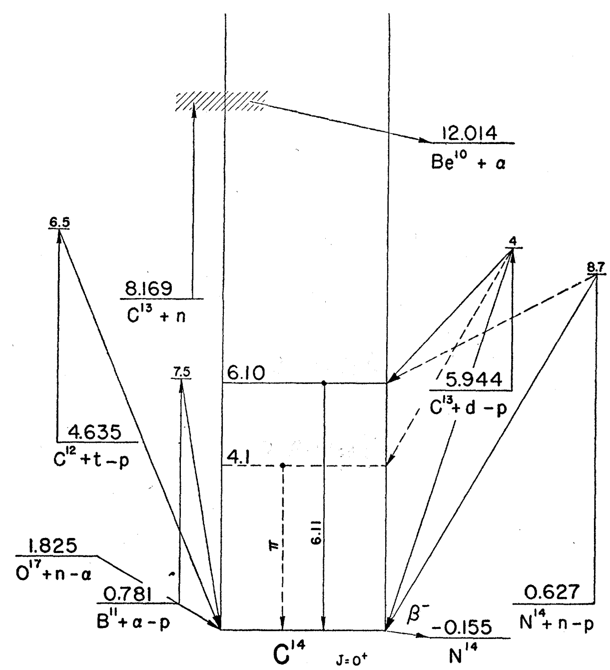

FIG. 18. Energy levels of C^{14}: for notation, see Fig. 1.

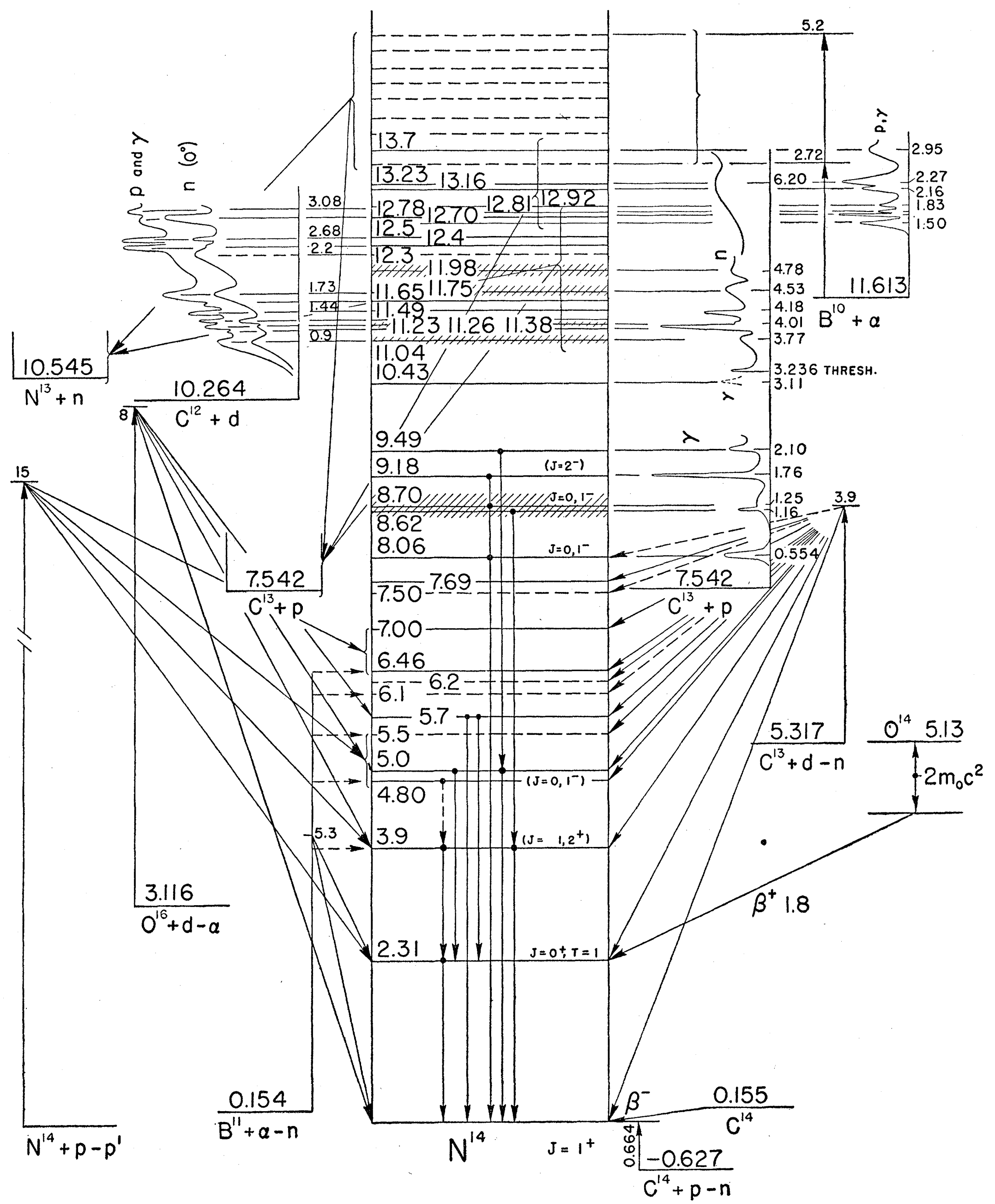

FIG. 19. Energy levels of N^{14}: for notation, see Fig. 1.

IV. $C^{12}(t\ p)C^{14}$ $Q_m = 4.635$

This reaction has been observed with 6.5-Mev tritons (Po 51).

Po 51 Pool, Kundu, Weiler, and Donaven, Phys. Rev. **82**, 305 (1951).

V. $C^{13}(n\ n)C^{13}$ $E_b = 8.169$

The coherent scattering cross section is 4.5 ± 0.6 b; the total is 5.5 ± 1.0 b (bound atoms, epithermal neutrons) (Ko 52).

Ko 52 Koehler and Wollan, Phys. Rev. **85**, 491 (1952).
See also: Hu 52e.

VI. $C^{13}(n\ \gamma)C^{14}$ $Q_m = 8.169$

The thermal cross section is listed as 0.1 b by (Wa 50e) and as 1.0 ± 0.3 mb by (Hu 52e).

Wa 50e Way *et al.*, Circular of the Nat. Bur. of Standards 499 (1950), and supplements 1 (April, 1951), 2 (November, 1951) and 3 (June, 1952).
Hu 52e Hughes *et al.*, AECU 2040 (1952).

VII. $C^{13}(n\ \alpha)Be^{10}$ $Q_m=-3.845$ $E_b=8.169$

Production of Be^{10} has been observed with pile neutrons (Hu 47).

Hu 47 Hughes, Eggler, and Huddleston, Phys. Rev. **71**, 269 (1947).

VIII. $N^{14}(n\ p)C^{14}$ $Q_m=0.627$

$Q=0.610\pm0.010$ Mev (Me 50a: prop. counter)
$Q=0.609\pm0.005$ (Is 50: ioniz. in air)
$Q=0.630\pm0.006$ (Fr 50: ioniz. in argon).

Some transitions to the 6.1-Mev state are observed (St 51b).

Me 50a Meyer, Z. Physik **128**, 451 (1950).
Is 50 Ishiwari and Yuasa, Memoires of the College of Science, U. of Kyoto **26A**, 1 and 2 (1950).
Fr 50 Franzen, Halpern, and Stephens, Phys. Rev. **77**, 641 (1950).
St 51b Stetter and Bothe, Z. Naturforsch. **6A**, 61 (1951).
See also: Be 50d, Ho 50b, Bo 51d, Jo 51a.

IX. $O^{17}(n\ \alpha)C^{14}$ $Q_m=1.825$

The isotopic cross section is 0.46 ± 0.11 b for thermal neutrons (Ma 47).

Ma 47 May and Hincks, Can. J. Research **25**, 77 (1947).
See also: Hi 46.

N^{14}

I. $B^{10}(\alpha\ n)N^{13}$ $Q_m=1.068$ $E_b=11.613$

Steps in the thick target yield are observed at $E_\alpha\sim1.5$, ~2.3 and ~2.7 Mev (N. P. Heydenburg, private communication). Nine resonances are reported for $E_\alpha=2.7$ to 5.2 Mev (Sz 39).

Sz 39 Szalay, Z. Physik **112**, 29 (1939).

TABLE I(14). Resonances[a] in $B^{10}(\alpha\ p)C^{13*}$.

E_α (Mev)	Γ (kev)	Rel. intens.	N^{14*}
1.50	30	10.5	12.70
1.63	25	15	12.78
1.68	15	6.5	12.81
1.83	40	6.5	12.92
2.16	20	10	13.16
2.27	130	14	13.23
(2.95)	(~200)	9.5	(13.72)

[a] Estimated from curve supplied by Dr. Heydenburg.

TABLE II(14). Resonances in $C^{12}(d\ p)C^{13}$ and $C^{12}(d\ n)N^{13}$ (Ph 50b).

E_R (Mev)	Width (kev)	γ's	σ (bn)[a] n's	long p's	N^{14*}
0.91	200	0.12	0.08	0.36	11.04
1.13	30	0	0?	0.1	11.23
1.16	200	0.15	0.05	0.30	11.26
1.30	80	0.15	0.07	0.16	11.38
1.435	5.5	0.3	0.01	0.2	11.49
1.62	20	0	0.07	···	11.65
1.73	200	0.6	0.07	···	11.75

[a] Estimated relative cross sections, integrated over all angles.

II. $B^{10}(\alpha\ p)C^{13}$ $Q_m=4.071$ $E_b=11.613$

Resonances for 3.9-Mev γ-rays (from C^{13*}) are listed in Table I(14) (N. P. Heydenburg, private communication).

For angular distributions, see C^{13}.

See also: Ho 50b, Pe 50a.

III. $B^{10}(\alpha\ d)C^{12}$ $Q_m=1.348$ $E_b=11.613$

See (Cr 49c).

IV. $B^{11}(\alpha\ n)N^{14}$ $Q_m=0.154$

At $E_\alpha=5.3$ Mev, the neutron spectrum from a thick, isotopic B^{11} target exhibits a maximum at $E_n=2$ to 3 Mev. Gamma-radiation of energy 2.2 ± 0.2 Mev is observed with an intensity ~9 percent of the neutron yield (Be 50h).

For slow neutron thresholds, see (St 39).

Be 50h Beghian, Grace, and Halban, Proc. Phys. Soc. (London) **63A**, 913 (1950).
See also: St 39, Ho 50b.

V. (a) $C^{12}(d\ p)C^{13}$ $Q_m=2.723$ $E_b=10.264$
(b) $C^{12}(d\ n)N^{13}$ $Q_m=-0.281$

Resonances for ground-state protons, 3.1-Mev γ-rays (from C^{13*}) and neutrons are given in Table II(14) (Ph 50b). Additional resonances for γ-rays occur at $E_d=2.2$?, 2.49, 2.68, 2.90, and 3.08 Mev. Forward neutrons exhibit similar resonances, but with some significant differences possibly associated with strong variations in angular distribution (Ba 48).

The angular distributions at the lower resonances for long-range protons (Ph 50b) and neutrons (Bo 49a) are complex, involving terms as high as $P_4(\cos\theta)$ with coefficients which vary markedly with energy (Ph 50b). It would appear that interference between close resonances plays a major role, rendering analysis rather difficult. At $E_d=2$ to 3 Mev, the forward neutrons become

TABLE III(14). Resonances in $C^{13}(p\ n)N^{13}$ (Willard *et al.*).

E_R (Mev)	Γ (kev)	Rel. intens.	N^{14*}
3.77	(~100)	6	11.04
4.01	22	23	11.27
4.05	(≤150)	7	(11.30)
4.18	35	11	11.42
4.53	(~150)	9	11.75
4.78	(>100)	8	11.98

TABLE IV(14). Resonances in $C^{13}(p\ \gamma)N^{14}$ (Se 52).

E_p (Mev)	Γ (kev)	Y_{max}[a]	$\omega\Gamma_\gamma$ (ev)	σ_R(mb)	N^{14*}
0.55[b]	32.5 ± 1	0.9	8.6	1.44	8.06
1.16	6 ± 2	0.12	1.3	0.56	8.62
1.25	500	1.13	12.8	0.062	8.70
1.76[c]	2.1 ± 0.2	1.15	14.8	12.0	9.18
2.10	45 ± 3	0.48	6.15	1.96	9.49

[a] Disintegrations per 10^8 protons; thick target, pure isotope.
[b] 0.554 ± 0.002 (Fo 49b).
[c] 1.754 ± 0.003, $\Gamma=2.5\pm0.5$ (Da 51).

TABLE V(14). Gamma-radiation from $C^{13}(p\ \gamma)N^{14}$ (Wo 52b and private communication).

E_p (Mev)	N^{14*}	E_γ (Mev)[a]						
0.55	8.06	**8.03**,			4.1,	2.32,	1.63	
1.16	8.62	8.6,	**4.7**		3.94,	2.35,	1.66	
1.25	8.70	**8.7**,	4.7,		3.92,	2.33,	1.60,	0.75
1.76	9.18	**9.17**,	6.6,	2.72				
2.10	9.49		5.09,	**4.41**,	2.78,	2.32,		

[a] Energy values are ± one or two percent: the most intense components are in bold face in the table.

relatively prominent, suggesting that a stripping process may be of importance in this region.

The $E_d=1.435$-Mev resonance for γ-rays and long-range protons also appears in the neutron yield (Fa 52).

Ph 50b Phillips, Phys. Rev. **80**, 164 (1950).
Ba 48 Bailey, Freier, and Williams, Phys. Rev. **73**, 274 (1948).
Bo 49a Bonner, Evans, Harris, and Phillips, Phys. Rev. **75**, 1401 (1949).
Fa 52 Famularo, Thompson, and Bonner, Phys. Rev. **85**, 742 (1952).
See also: Sm 51a, Tu 51a, Ko 52c.

VI. (a) $C^{12}(d\ d)C^{12}$ $E_b=10.264$
(b) $C^{12}(d\ d')C^{12*}$

See (Gu 47, Ke 51b).

VII. $C^{12}(d\ \alpha)B^{10}$ $Q_m=-1.349$ $E_b=10.264$

See B^{10}.

VIII. $C^{13}(p\ n)N^{13}$ $Q_m=-3.003$ $E_b=7.542$

The threshold is 3.236 ± 0.003 Mev; $Q=-3.003$ (Ri 50e).

Resonances for neutrons at $\theta=0°$ observed by Willard, Bair, and Kington (private communication) are reported in Table III(14). (Bl 51a), using a stacked foil technique, find resonances at $E_p=4.0$, 4.90, and 6.20 Mev.

Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
Bl 51a Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).
See also: Ad 50b.

TABLE VI(14). Neutron groups from $C^{13}(d\ n)N^{14}$.

A: Q (Mev)	A: N^{14*}	B: N^{14*}
5.17 ± 0.05	0	
2.98 ± 0.05	2.19	2.23
1.70 ± 0.05	3.47?	
1.30 ± 0.05	3.87	3.85
0.27 ± 0.05	4.90	4.80
		4.97
		5.5?
		5.78
		6.1?
		6.2?
		6.45
		7.00
		7.50?
		7.69
		8.09

A: $E_d=1.43$ Mev, $\theta=0°$ and 90° (Ma 50d).
B: $E_d=3.89$ Mev, $\theta=0°$, 20°, 45°, 80° (Be 52b and private communication).

IX. $C^{13}(p\ \gamma)N^{14}$ $Q_m=7.542$

Resonances reported by (Se 52) are given in Table IV(14). The widths of the 0.55- and 1.25-Mev resonances indicate s-wave capture (Se 52). (Te 52) give a reduced width $\gamma^2=0.12$ of the sum-rule limit for the former. That the 0.55-Mev resonance is formed by s-waves is confirmed by the observed isotropy of the radiation (De 49d). At the 1.76-Mev resonance, the angular distribution is $Y(\theta)=1-0.48\cos^2\theta$, consistent with $J=1$, even or 2, even or odd. The strength of the radiation suggests that it is electric dipole, consistent with $J=2$, odd (Da 51, Da 51b). In this case, the angular distribution would indicate either a $d_{\frac{5}{2}}$ incoming proton in $j-j$ coupling or a ${}^3F_2$ compound state in $L-S$ coupling (Ch 52b). An additional level, at $E_p=3.11$ Mev, $\Gamma\sim30$ kev is observed by Willard, Bair, and Kington (private communication).

The γ-ray spectrum varies markedly with bombarding energy, proceeding predominantly to the ground state at the 0.55, 1.25, and 1.76-Mev resonances, mainly to excited states at the other two; see Table V(14) (Wo 52b and private communication).

The cross section at $E_p=129$ kev is $5\pm1\times10^{-9}$ b; about 80 percent of transitions go to the ground state (Wo 52a)

Se 52 Seagrave, Phys. Rev. **85**, 197 (1952).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
De 49d Devons and Hine, Proc. Roy. Soc. (London) **199**, 56, 73 (1949).
Da 51 Day and Perry, Phys. Rev. **81**, 662 (1951).
Ch 52b Christy (to be published).
Fo 49b Fowler and Lauritsen, Phys. Rev. **76**, 314 (1949).
Wo 52b Woodbury, Day, and Tollestrup, Phys Rev. **85**, 760 (1952).
Da 51b Day, Ph.D. thesis, California Institute of Technology (1951).
Wo 52a Woodbury and Fowler, Phys. Rev. **85**, 51 (1952).
See also: Fo 51, Wa 51, Ca 51a.

X. $C^{13}(d\ n)N^{14}$ $Q_m=5.317$

Recently reported neutron groups are exhibited in Table VI(14). The angular distribution of the ground-state group, analyzed by the method of (Bu 51b), indicates capture of p-wave protons: the parity of N^{14} is therefore even, since C^{13} is odd (see $C^{12}(d\ p)C^{13}$) (Br 52, Br 52b: $E_d=4$ Mev, Be 52b; $E_d=3.9$ Mev). The angular distribution of neutrons corresponding to the 2.23 and 3.85-Mev states indicates p-wave capture: $J=0$, 1, or 2, even. The angular distribution of the combined neutrons from the 4.80- and 4.97-Mev states indicates s-capture to the dominant 4.80-Mev state and possibly p-capture to the 4.95-Mev state: $J=0$ or 1, odd for the 4.80-Mev state and $J=0$, 1 or 2, even (?) for the 4.97-Mev level (Be 52b and private communication.)

Gamma-rays observed from deuteron bombardment of C^{13} are reported in Table VII(14). The 6.1-Mev radiation is assigned to C^{14} because it appears at $E_d=650$ kev, below the threshold for the present reaction (see $C^{13}(d\ p)C^{14}$) (Th 52). The 725-kev radiation appears also to occur in $C^{13}(p\ \gamma)N^{14}$ (see above): it may result from a cascade, for example between the 4.8- and 3.9-Mev levels (R. E. Benenson, private communication).

Bu 51b Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).
Br 52 Bromley and Goldman, Phys. Rev. **86**, 790 (1952).
Br 52b Bromley, Univ. of Rochester Report, NYO3211 (June 1952).
Be 52b Benenson, Phys. Rev. **87**, 207A (1952).
Ma 50d Mandeville and Swann, Phys. Rev. **79**, 787 (1950).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Ba 51b Baggett and Bame, Phys. Rev. **84**, 154 (1951).
See also: Me 51a.

XI. $C^{14}(p\ n)N^{14}$ $Q_m = -0.627$

The threshold is $E_p = 664 \pm 9$ kev (Sh 49a).

Sh 49a Shoupp, Jennings, and Sun, Phys. Rev. **75**, 1 (1949).

XII. $C^{14}(\beta^-)N^{14}$ $Q_m = 0.155$

See C^{14}.

XIII. $N^{14}(\gamma\ n)N^{13}$ $Q_m = -10.545$ (not illustrated)

The cross section for N^{13} production exhibits a small maximum at $E_\gamma \sim 13$ Mev, followed by a larger one, $\sigma = 2.84$ mb, at $E_\gamma = 24.2$ Mev (Jo 51b). The integrated cross section is 17 Mev-mb (Ed 52a: based on $C^{12}(\gamma\ n)C^{11} = 47$ Mev-mb).

Jo 51b Johns, Horsley, Haslam, and Quinton, Phys. Rev. **84**, 856 (1951).
Ed 52a Edwards and MacMillan Phys. Rev. **87**, 377 (1952).
See also: Ho 52, La 52.

XIV. $N^{14}(\gamma\ pn)C^{12}$ $Q_m = -12.489$ (not illustrated)

This reaction has been observed at $E_\gamma = 100$ Mev: see (Ga 50b). See also: (Jo 51b, Ho 52).

XV. $N^{14}(\gamma\ d)3He^4$ $Q_m = -17.542$ (not illustrated)

This reaction has been observed at $E_\gamma \sim 25$ Mev. In some cases, it proceeds through the ground state of Be^8: see (Go 51e, Li 52a, Br 52a).

XVI. $N^{14}(\gamma\ \alpha)B^{10}$ $Q_m = -11.613$ (not illustrated)

See (Mi 50b).

XVII. $N^{14}(\gamma\ \alpha p)Be^9$ $Q_m = -18.197$ (not illustrated)

See (Li 52a, Br 52a).

XVIII. $N^{14}(\gamma\ 2\alpha)Li^6$ $Q_m = -16.065$ (not illustrated)

See (Wi 50, Wi 50d).

XIX. $N^{14}(p\ p')N^{14*}$

Levels are reported at 2.35 and 3.95 Mev by (Co 52g: $E_p = 7.4$ Mev), and at 5.1 ± 0.4 and 6.7 ± 0.4 Mev by (Fu 48: $E_p = 15$ Mev).‖‖

‖‖ *Note added in proof:* Preliminary results on inelastic scattering of 7.0- and 7.6-Mev protons and deuterons from N^{14} show proton and deuteron groups from the 3.95-Mev level and a proton group from the 2.31-Mev level. An inelastic deuteron group from the 2.31-Mev level has thus far not been observed. This may be additional evidence that the 2.31-Mev level is the $T=1$ state analogous to the $C^{14}-O^{14}$ ground states (see $O^{16}(d\ \alpha)N^{14}$) (Bockelman, Browne, and Buechner, private communication).

TABLE VII(14). Gamma-rays from $C^{13}+d$.

A E_γ (kev)	Yield	B E_γ (kev)	Yield	Assignment
725±4	1.3			N^{14}(?)
1638±8	2			N^{14}
2310±12	8			N^{14}
3381±13	3.7	3400±150	4.9	N^{14}
5052±25	3.2	5040±90	3.4	N^{14}
5690±50	1.4			N^{14}
6110±30	4.6	6100±100	4.3	C^{14}

A: Th 52: magnetic lens spectrometer. Energies are not corrected for possible Doppler shifts of 4 to 10 kev. Yields are in $10^{-6}\ \gamma/d$ for thick C^{13} target at $E_d = 1.21$ Mev: the first three are subject to ~ 25 percent uncertainty.
B: Ba 51b; pair spectrometer. The 5.69-Mev line is not resolved. Yields in $10^{-6}\ \gamma/d$ for thick C^{13} target at $E_d = 1.65$ Mev.

Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).
Fu 48 Fulbright and Bush, Phys. Rev. **74**, 1323 (1948).

XX. $O^{14}(\beta^+)N^{14}$ $Q_m = 5.13$

The decay proceeds by emission of 1.8 ± 0.1 Mev positrons, followed by a $2.3_{-0.1}^{+0.3}$ Mev γ-ray. The direct ground-state transition is less than 5 percent if it exists at all. The half-life is 76.5 ± 2 sec (Sh 49); log ft = 3.52 (Fe 51b). Since O^{14} and the 2.3-Mev level of N^{14} almost certainly have zero spin, the O^{14} decay appears to be an example of strong Fermi interaction.

Sh 49 Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
See also: No 51.

XXI. $O^{16}(d\ \alpha)N^{14}$ $Q_m = 3.116$

Recently reported Q-values are:

$Q = 3.112 \pm 0.006$ (St 51: mag. spectrometer)
$Q = 3.119 \pm 0.005$ (Li 51a: mag. spectrometer)
$Q = 3.113 \pm 0.0035$ (Cr 52b: elect. analyzer)

At $E_d = 7.73$ Mev, groups of α-particles corresponding to the ground state and to excited states at 3.98 ± 0.04 and 5.06 ± 0.05 Mev are observed (Bu 51f: photoplate). At $E_d = 6.77$, $\theta = 90°$, three groups, yielding level energies of 3.95, 5.01, and 5.7 Mev are reported: no sign of groups corresponding to 2.3-, 3.4-, or 6.1-Mev excitation was found (As 51: magnetic an-

TABLE I(15). Resonances in $B^{11}(\alpha\ n)N^{14}$ (see Ho 50b).

E_{res} (Mev)	N^{15*}
1.90	12.38
2.67	12.95
3.20	13.34
3.60	13.63
4.17	14.05
4.50	14.29
4.79	14.50
5.07	14.71

Table II(15). Resonances in $C^{13}(d\,n)N^{14}$ (Ri 50c).

E_R (Mev)[a]	Γ (kev)	σ (mb)[b]	N^{15*}
0.58	100	6.6	16.65
0.85	400	24	16.89
1.55	100	63	17.49
1.78	500	80	17.69

[a] Corrected for penetration factor.
[b] 4π times forward cross section, ±50 percent.

Table III(15). Resonances in $C^{14}(p\,n)N^{14}$ (Ro 51h).

E_p (kev)	Γ (kev)	Y_{max}[a]	N^{15*}
1165±2	8±1	21	11.294
1310±3	43±5	17	11.430
1664±4	38±10	2.0	11.760
1789±4	18±5	0.9	11.877
1883±4	15±5	2.0	11.964
2024±4	18±5	16	12.096
2079±4	55±10	36	12.147
2272±4	22±5	~4	12.328
2451±10	45±20	~1.6	12.495

[a] Relative yields.

alyzer). At $E_d=2$ Mev, $\theta=90°$, no group >2 percent of the ground-state group is observed up to 2.8-Mev excitation (Va 52b). The absence of the 2.3-Mev level in all these observations is consistent with the assumption that it is the isobaric spin $T=1$ state analogous to the $C^{14}-O^{14}$ ground states (Ad 52a).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Li 51a Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).
Bu 51f Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **209**, 478 (1951).
As 51 Ashmore and Raffle, Proc. Phys. Soc. (London) **64A**, 754 (1951).
Va 52b Van de Graaff, Sperduto, Buechner, and Enge, Phys. Rev. **86**, 966 (1952).
Ad 52a Adair, Phys. Rev. **87**, 1041 (1952).

O^{14}

(not illustrated)

Mass of O^{14}

The β-decay energy, 1.8±0.1 Mev, added to the 2.31-Mev γ-ray energy gives a mass 5.13 Mev above N^{14}: mass defect = 12.13±0.1 Mev. This value leads to a threshold of 6.34 Mev for $N^{14}(p\,n)O^{14}$, which is consistent with the observed value of 6.0±0.5 Mev.

I. $O^{14}(\beta^+)N^{14}$ $Q_m=5.13$

See N^{14}.

II. $N^{14}(p\,n)O^{14}$ $Q_m=-5.91$

The threshold is $E_p=6.0\pm0.5$ Mev (Sh 49).

Sh 49 Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949).

Table IV(15). Resonances in $N^{14}(n\,n)N^{14}$.

A: E_{res} (kev)	A: Γ (kev)	A: σ(b)[a]	A: l_n[b]	A: J[c]	B: E_{res} (kev)	B: Γ (kev)[d]	B: σ(b)[a]	B: l_n[b]	B: J[c]	N^{15*}
433		(2.6)	>0	>1/2	430	3.5	4.8	1, 2	>1/2	11.235
					492	7.5	0.1			11.293
640	40	1.0	0	$1/2^+$	639	43	1.06	0	$1/2^+$	11.430
1000	45	1.7	0	$3/2^+$	998	46	1.68	0	$3/2^+$	11.765
1120		(1.3)	>0	3/2, 5/2	1120	19	2.00	1, 2	5/2	11.879
					1188	≤3.2	≥1.07		>1/2	11.943
					1211	13	0.61	1	$1/2^-$	11.964
1350		(1.3)			1350	22	1.70	1, 2	5/2	12.094
1420		(0.4)			1401	54	0.81	1	$3/2^-$	12.142
					1595	22	1.54	1, 2	5/2	12.323
					1779	24	0.74	1, 2	5/2	12.494

A: (Jo 51a).
B: (Hi 52).
[a] Difference between peak and minimum near resonance energy, less reaction cross section. Values in parenthesis estimated from published curve.
[b] Most probable value of incoming orbital angular momentum.
[c] Most probable value of total angular momentum and parity of compound state.
[d] Some of these widths are taken from the $C^{14}(p\,n)N^{14}$ reaction.

C^{15}

(not illustrated)

Mass of C^{15}

The end point of the β-spectrum is 8.8±0.05 Mev. Assuming that the transition is to the ground state of N^{15}, this value yields a mass defect of 13.3±0.5 Mev. The Q for $C^{14}(d\,p)C^{15}$ is estimated to be >−1.2 Mev. The calculated mass defect obtained from this Q is <14.5 Mev. Since there is no known level below ~5.3 Mev in N^{15}, the 8.8-Mev betas are probably due to the transition to the ground state of N^{15}. *We adopt:* $C^{15}-N^{15}$ = 8.8±0.5 Mev; mass defect = 13.3±0.5 Mev

I. $C^{15}(\beta^-)N^{15}$ $Q_m=8.8$

The maximum β^- energy is 8.8±0.5 Mev. There is evidence of 5.5-Mev delayed γ-radiation. This radiation is presumably due to partial decay of C^{15} to either or both of the N^{15} states at ~5.3 Mev. The half-life is 2.4±0.3 sec (Hu 50a, Hu 50e, Hu 52) (log ft of ground-state transition = 5.27 (Fe 51b), assuming transitions to ground state only).

Hu 50a Hudspeth, Swann, and Heydenburg, Phys. Rev. **77**, 736 (1950).
Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).
Hu 52 Hudspeth, Rose, and Heydenburg, Phys. Rev. **85**, 742A (1952).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).

II. $C^{14}(d\,p)C^{15}$ $Q_m=0.0$

The threshold is $E_p<1.4$ Mev: $Q>-1.2$ Mev (Hu 50e).

Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).

III. $C^{14}(n\,\gamma)C^{15}$ $Q_m=2.2$

The capture cross section is $<10^{-3}$ mb (Ya 51).

Ya 51 Yaffe and Stevens, Can. J. Phys. **29**, 186 (1951); Phys. Rev. **79**, 893 (1950).

N^{15}

I. $B^{11}(\alpha\ n)N^{14}$ $Q_m = 0.154$ $E_b = 10.988$

A large number of resonances for $E_\alpha = 1.8$ to 9 Mev have been reported (see Ho 50b). The means of those for $E_\alpha < 5.1$ Mev, and the corresponding level energy are given in Table I(15).

II. $B^{11}(\alpha\ p)C^{14}$ $Q_m = 0.781$ $E_b = 10.988$

See C^{14}.

III. $C^{12}(\alpha\ p)N^{15}$ $Q_m = -4.961$

At $E_\alpha = 21$ Mev, $\theta = 90°$, proton groups corresponding to states at 0, 5.4, and 6.5 Mev are observed (Bu 51).

Bu 51 Bullock, McMinn, Rasmussen, and Sampson, Phys. Rev. **83**, 212A (1951).
See also: Bu 51c.

IV. $C^{12}(t\ p)C^{14}$ $Q_m = 4.635$ $E_b = 14.841$

See (Po 51).

V. $C^{13}(d\ n)N^{14}$ $Q_m = 5.317$ $E_b = 16.150$

Resonances for forward neutrons with $E_n > 3$ Mev are given in Table II(15) (Ri 50c).

For angular distributions, see N^{14}.

Ri 50c Richardson, Phys. Rev. **80**, 850 (1950).

VI. $C^{13}(d\ p)C^{14}$ $Q_m = 5.944$ $E_b = 16.150$

Resonances for ground-state protons appear at $E_d = 0.65$ and 1.55 Mev (see Ho 50b). The thick (C^{13}) target yield is reported as 4.6×10^{-6} γ/d at $E_d = 1.65$ Mev by (Ba 51b) and as 4.3×10^{-6} γ/d at $E_d = 1.2$ Mev by (Th 52).

For angular distributions, see C^{14}.

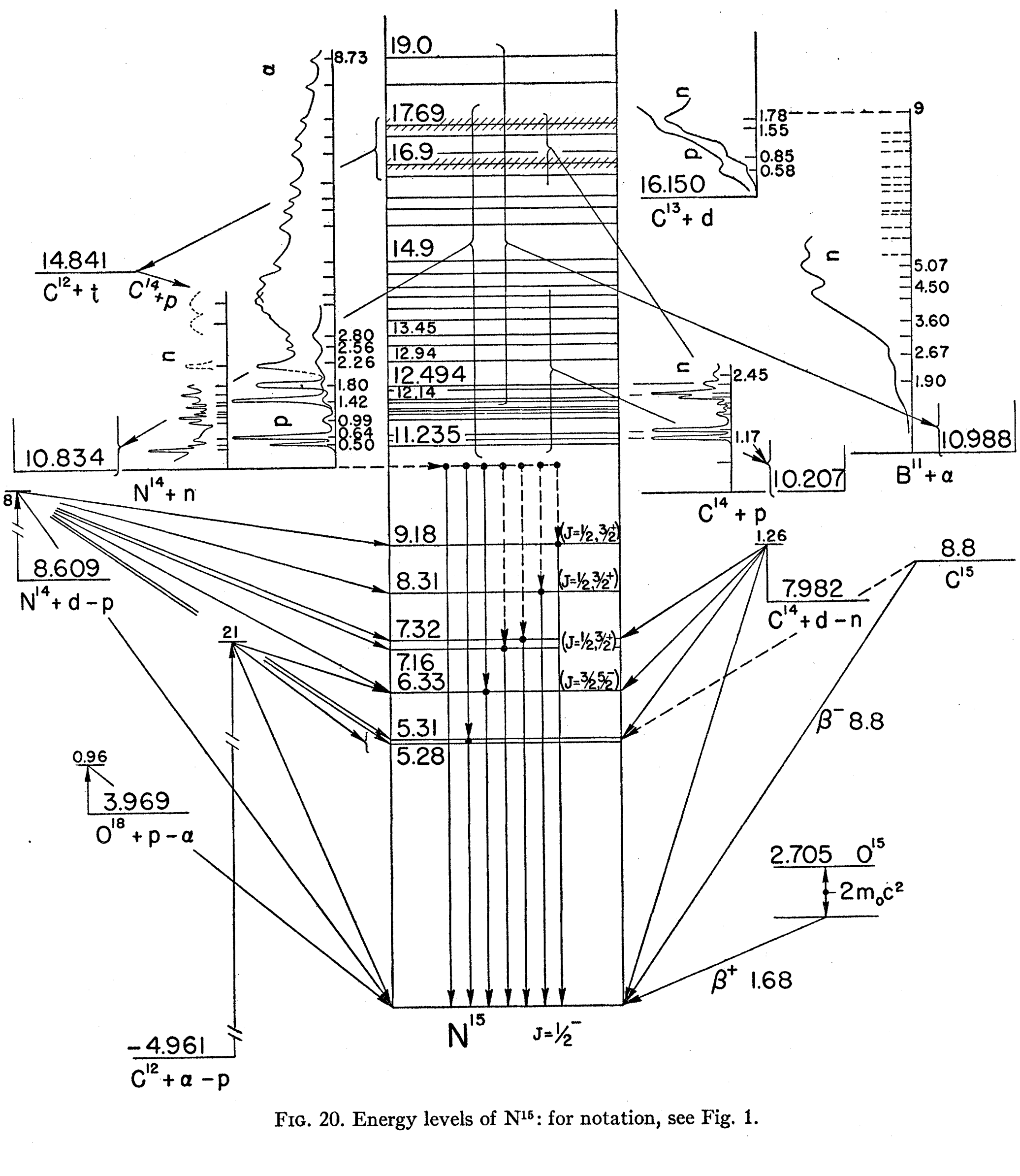

FIG. 20. Energy levels of N^{15}: for notation, see Fig. 1.

TABLE V(15). Resonances in $N^{14}(n\ \alpha)B^{11}$.

A E_n (kev)	A σ (mb)	B E_n (kev)	C E_n (kev)	D N^{15*}
1415±50	35	1380±90	1380	12.16
1800±15	150	1780±110	1850	12.514
2260±50	150	2210±120	2280	12.94
2560±50	80			13.22
2750±50	85		2840	13.40
(3550)	(150)		3700†	14.26
			4080	14.62
			4380†	14.90
			5150†	15.62
			5480†	15.89
			5730†	16.13
			6080	16.47
			6680	17.04
			7040†	17.30
			7460	17.78
			8160	18.43
			8730	18.97

A: Direct determinations: the first two values are from (Jo 50b), $Li^7(p\ n)$ neutrons, the remainder are from (Bo 51d), $H^2(d\ n)$ neutrons.
B: (St 48a): continuous neutron spectrum, pulse-height analysis. Computed with $Q=-0.24$.
C: (St 51b): continuous neutron spectrum, pulse-height analysis. Computed with $Q=-0.28$. Resonances marked "†" may also lead to 2.1-Mev state of B^{11}.
D: The first five values are from Column A, the rest are from (St 51b).

TABLE VI(15). Resonances in $N^{14}(n\ p)C^{14}$.

A E_n (kev)	A Γ (kev)	A σ (mb)	B E_n (kev)	C E_n (kev)	D N^{15*}
499±5	30	120	480±50	500	11.300
640±7	55	200	640±40	710	11.431
993±12	60	20			11.761
1415±15		190	1430±90	1400	12.155
			1770±110	1740	12.47
2260±50		30	2190±120	2220	12.94
2800±50		30			13.45

A: Direct method: the first four values are from (Jo 50b), $Li^7(p\ n)$ neutrons. The last two values are from (Bo 51d), $H^2(d\ n)$ neutrons. Cross sections are estimated from published curves.
B: (St 48a): continuous neutron spectrum, pulse-height analysis. Computed with $Q=0.63$.
C: (St 51b): continuous neutron spectrum, pulse-height analysis. Computed with $Q=0.60$. In addition, the following resonances for formation of C^{14} in the ~6 Mev state are reported: $E_n=6.05$, (6.67), and 6.90 Mev (N^{15} levels: 16.47, 17.04, and 17.30 Mev).
D: Computed mainly from Column A.

Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Ba 51b Baggett and Bame, Phys. Rev. **84**, 154 (1951).
See also: Ho 50b.

VII. $C^{13}(d\ \alpha)B^{11}$ $Q_m=5.163$ $E_b=16.150$

The yield rises smoothly from $E_d=0.4$ to 0.9 Mev (Cu 50). At $E_d=0.99$ Mev, $\theta=90°$, the differential cross section is 7 mb/sterad (Li 51b).

Cu 50 Curling and Newton, Nature **165**, 609 (1950).
Li 51b Li and Whaling, Phys. Rev. **82**, 122 (1951).

VIII. $C^{13}(d\ t)C^{12}$ $Q_m=1.309$ $E_b=16.150$

The differential cross section at $E_d=0.99$ Mev, $\theta=90°$, is 2 mb/sterad (Li 51b).

Li 51b Li and Whaling, Phys. Rev. **82**, 122 (1951).

IX. $C^{14}(d\ n)N^{15}$ $Q_m=7.982$

At $E_d=1.26$ Mev, $\theta=0°$ and 90°, neutron groups corresponding to levels at 5.34, 6.32, and 7.46 Mev are observed (Hu 50e).

Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).

X. $C^{14}(p\ n)N^{14}$ $Q_m=-0.627$ $E_b=10.207$

Recently reported resonances are given in Table III(15). The location of levels and the relative yields are in good agreement with those obtained from the inverse reaction (Ro 51h).

Ro 51h Roseborough, McCue, Preston, and Goodman, Phys. Rev. **83**, 1133 (1951).
See also: Sh 49a.

XI. $C^{15}(\beta^-)N^{15}$ $Q_m=8.8$

See C^{15}.

XII. $N^{14}(n\ n)N^{14}$ $E_b=10.834$

The coherent scattering cross section is 11.1±0.3 b (Pe 52b), 11.0±0.5 b (Hu 52e); the total scattering cross section is 11.4±0.5 b (bound atoms, epithermal neutrons) (Hu 52e, Me 49b). The large value of σ_s suggests a level below the binding energy (Me 49b).

Resonances reported for $E_n=0.4$ to 1.8 Mev are given in Table IV(15). Above $E_n=2$ Mev, a sharp maximum is observed at 2.22 Mev and broad maxima at 3.1 and 3.55 Mev (levels at 12.90, 13.7, and 14.2 Mev) (Ri 51d). The total cross section at $E_n=14$ Mev is 1.7±0.1 b (Po 52a), 1.59±0.03 b (Co 52h).

The angular distribution, determined from the energy distribution of recoils, exhibits pronounced anisotropy at $E_n=0.30$ and 0.70 Mev (Ba 50g).

Pe 52b Peterson and Levy, Phys. Rev. **87**, 462 (1952).
Hu 52e Hughes *et al.*, AECU 2040 (1952).
Me 49b Melkonian, Phys. Rev. **76**, 1750 (1949).
Ri 51d Ricamo and Zünti, Helv. Phys. Acta **24**, 302 (1951).
Po 52a Poss, Salant, Snow, and Yuan, Phys. Rev. **87**, 11 (1952).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
Ba 50g Baldinger, Huber, Ricamo, and Zünti, Helv. Phys. Acta **23**, 503 (1950).
Jo 51a Johnson, Petree, and Adair, Phys. Rev. **84**, 775 (1951).
Hi 52 Hinchey, Stelson, and Preston, Phys. Rev. **86**, 483 (1952).
See also: Ri 50d, Wa 50e, Ad 50, Sh 51b.

XIII. $N^{14}(n\ \alpha)B^{11}$ $Q_m=-0.154$ $E_b=10.834$

Resonances for this reaction and for the $N^{14}(n\ p)C^{14}$ reaction have been determined in two ways: by observation of the variation in yield of α-particles as the incident neutron energy is varied, and by observation of the distribution of total pulses sizes (α-particles and B^{11} recoils) in a nitrogen-filled ionization chamber irradiated with continuous-spectrum neutrons. Absolute energy values obtained by the latter method may be subject to some uncertainty in the conversion of number of ion pairs to energy, particularly for the recoil particle (see, e.g., Bo 51d). In addition, the computed neutron energies involve the Q-value as an additive constant. Table V(15) exhibits recently reported values obtained by both methods (see also Ho 50b).

Bo 51d Bollmann and Zünti, Helv. Phys. Acta **24**, 517 (1951).
Jo 50b Johnson and Barschall, Phys. Rev. **80**, 818 (1950).
St 48a Stebler and Huber, Helv. Phys. Acta **21**, 59 (1948).
St 51b Stetter and Bothe, Z. Naturforsch. **6a**, 61 (1951).
See also: Ho 50b, Fe 51a, Te 52.

XIV. $N^{14}(n\ p)C^{14}$ $Q_m=0.627$ $E_b=10.834$

The thermal cross section is 1.70 ± 0.05 b (see Hu 52e, Wa 50e, Ro 49d): the total absorption cross section is 1.78 ± 0.05 b (Hu 52e). The large value of the cross section indicates a relatively close resonance, possibly below the neutron binding energy (Fe 51a). Recently reported resonances, obtained by two methods (see $N^{14}(n\ \alpha)B^{11}$), are given in Table VI(15).

Hu 52e Hughes *et al.*, AECU 2040 (1952).
Wa 50e Way, Fano, Scott, and Thew, Circular of the National Bureau of Standards 499 (1950).
Ro 49d Ross and Story, Repts. on Prog. in Phys. (London) **12**, 291 (1949).
Fe 51a Feld, Phys. Rev. **82**, 308 (1951).
Jo 50b Johnson and Barschall, Phys. Rev. **80**, 818 (1950).
Bo 51d Bollmann and Zünti, Helv. Phys. Acta **24**, 517 (1951).
St 48a Stebler and Huber, Helv. Phys. Acta **21**, 59 (1948).
St 51b Stetter and Bothe, Z. Naturforsch. **6a**, 61 (1951).

XV. $N^{14}(n\ \gamma)N^{15}$ $Q_m=10.834$

Gamma-rays observed with a pair spectrometer are listed in Table VII(15) together with the N^{15} levels with which they are presumed to be associated. The cross section is ≤ 160 mb, based on $\sigma_{n\gamma}(Be^9)=9$ mb. The ground-state transition is surprisingly weak compared to the cascades (Ki 51). (Hu 52e) quote 100 ± 50 mb for the thermal cross section.

Ki 51 Kinsey, Bartholomew, and Walker, Can. J. Phys. **29**, 1 (1951).
Hu 52e Hughes *et al.*, AECU 2040 (1952).

XVI. $N^{14}(n\ 2n)N^{13}$ $Q_m=-10.545$ $E_b=10.834$ (not illustrated)

See (Je 50b, Wa 50f, Co 51).

XVII. $N^{14}(n\ t)C^{12}$ $Q_m=-4.007$ $E_b=10.834$

See (Co 41a).

XVIII. $N^{14}(d\ p)N^{15}$ $Q_m=8.609$

Recent ground-state Q-values are:

$Q=8.615\pm0.009$ (St 51: magnetic spectrometer)
$Q=8.613\pm0.011$ (Mi 52: magnetic spectrometer)

Recently reported proton groups are given in Table VIII(15) (Ma 50i). Gamma-rays observed in bombardment of nitrogen by deuterons are listed in Table IX(15).

Analysis of the angular distributions at $E_d=8$ Mev indicates the following assignments for levels of N^{15} (Gi 52):

TABLE VII(15). Gamma-radiation from $N^{14}(n\ \gamma)N^{15}$ (Ki 51).

E_γ	Rel. intens.	N^{15*}
10.816 ± 0.015	1.00	
9.156 ± 0.030	0.09	9.156
8.278 ± 0.016	0.19	8.278
7.356 ± 0.012	0.56	7.356
7.164 ± 0.012	0.19	7.164
6.318 ± 0.010	0.9	6.325
5.554 ± 0.010	1.5	5.275
5.287 ± 0.010	2.3	5.275
4.485 ± 0.010	0.8	6.325

TABLE VIII(15). Proton groups from $N^{14}(d\ n)N^{15}$ (Ma 50i).[a]

Q	N^{15*}
8.615 ± 0.010	0
3.339 ± 0.005	5.276 ± 0.006
3.310 ± 0.005	5.305 ± 0.006
2.287 ± 0.005	6.328 ± 0.006
1.451 ± 0.005	7.164 ± 0.006
1.306 ± 0.005	7.309 ± 0.006
0.300 ± 0.005	8.315 ± 0.006

[a] $E_d=1.41$ Mev, $\theta=90°$.

TABLE IX(15). Gamma-radiation from $N+d$.

E_γ (Mev)[a]	Yield[b]	Assignment
2.4		
(4.4 ± 0.3)	(4)	C^{12}
5.33 ± 0.11	15	N^{15} or O^{15}
(6.4 ± 0.5)	(2)	N^{15} or O^{15}
7.40 ± 0.15	11	N^{15}
8.46 ± 0.17	5	N^{15}

[a] The 2.4-Mev line is a mean value from earlier determinations (see Ho 50b). The remaining values are from (Te 51a), $E_d=1.56$ Mev, pair spectrometer.
[b] Yields are in 10^6 γ/microcoulomb (Te 51a).

Ground state	$J=1/2$, $3/2$ or $5/2$ odd
5.3-Mev pair	J large
6.3-Mev	$J=3/2$ or $5/2$ odd
7.2-Mev pair	$J=1/2$ or $3/2$ even (one or both)
8.32-Mev	$J=1/2$ or $3/2$ even
9.22-Mev	$J=1/2$ or $3/2$ even

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Mi 52 Mileikowsky and Whaling, Phys. Rev. (to be published).
Ma 50i Malm and Buechner, Phys. Rev. **80**, 771 (1950).
Te 51a Terrell and Phillips, Phys. Rev. **83**, 703 (1951).
Gi 52 Gibson and Thomas, Proc. Roy. Soc. (London) **210**, 543 (1952).
See also: In 50a, Ho 50b.

XIX. $N^{14}(t\ pn)N^{15}$ $Q_m=2.352$ (not illustrated)

See (Cu 52a).

XX. $O^{15}(\beta^+)N^{15}$ $Q_m=2.705$

See O^{15}.

XXI. $O^{18}(p\ \alpha)N^{15}$ $Q_m=3.969$

$Q=3.97\pm0.05$ (Fr 50c: magnetic analyzer)
$Q=3.96\pm0.04$ (Se 51b: magnetic analyzer)

TABLE X(15). Resonances from $N^{14}(p\ \gamma)O^{15}$.

E_R (Mev)	$Y_{max}(\infty)$[b]	Γ (kev)	$\omega\Gamma_\gamma$ (ev)	σ_R (mb)	O^{15*}
0.277[a]	0.35±0.03	<2[a]	0.02	>0.15	7.606
0.70 ±0.03	0.2 ±0.07	100±30	0.02	0.001	8.00
1.064±0.002	5.5 ±0.1	4.8±1	0.63	0.37	8.340
1.55 ±0.02	1.2 ±0.2	50±20	0.16	0.006	8.79
1.748±0.005	1.5 ±0.3	11±3	0.21	0.03	8.978
1.815±0.004	3.7 ±0.3	7±1.5	0.52	0.11	9.041
2.356±0.008	15±2	14±4	2.4	0.21	9.546
2.489±0.007	21±1	11±3	3.3	0.35	9.670
2.60 ±0.05	300±50	1270±50	46	0.05	9.77

[a] (Ta 46). Other values from (Du 51).
[b] Contribution to the thick-target yield, in positrons/10^{10} protons.

TABLE XI(15). Neutron groups from $N^{14}(d\ n)O^{15}$ (Ev 52).

Q (Mev)	O^{15*}	l_p	Assignment
5.15±0.16	0	1	$J=5/2, 3/2, 1/2$, odd
−0.14±0.11	5.29±0.17	2	$J=7/2, 5/2, 3/2, 1/2$, even
−1.04±0.06	6.19±0.16	1	$J=5/2, 3/2, 1/2$, odd
−1.69±0.08	6.84±0.16	0	$J=3/2, 1/2$, even
−2.33±0.09	7.48±0.16	1	$J=5/2, 3/2, 1/2$, odd
−3.27±0.09	8.42±0.16	1	$J=5/2, 3/2, 1/2$, odd
−3.91±0.07	9.06±0.16	1	$J=5/2, 3/2, 1/2$, odd

TABLE I(16). Resonances in $N^{15}(p\ \alpha)C^{12}$ (Sc 52).

E_R (kev)	Γ (kev)	$\sigma_0(b)$[a]	$\sigma_1(b)$[b]	O^{16*}
338[c]	94	0.075		12.427
429±1	0.9		0.3	12.512
898±1	2.2		0.8	12.952
1050[d]	~150	0.5	0.015	13.094
1210±3[e]	22.5[e]	0.6	0.3	13.244

[a] 4π times differential cross section at 90° and 138° for ground-state α-particles.
[b] 4π times differential cross section at 90° and 138° for 4.4-Mev state α-particles.
[c] Corrected for s-wave penetration factor.
[d] From $N^{15}(p\ \gamma)O^{16}$.
[e] Values for α_1.

At $E_p=960$ kev, no α-group corresponding to a N^{15} level <3.5 Mev is observed with intensity >10 percent of the ground-state transition (Se 51b).

Fr 50c Freeman, Proc. Phys. Soc. (London) **63**, 668 (1950).
Se 51b Seed, Phil. Mag. **42**, 566 (1951).
See also: Mi 50e.

O^{15}

I. $O^{15}(\beta^+)N^{15}$ $Q_m=2.705$

The maximum positron energy is 1.683±0.005 Mev; the half-life, 118.0±0.6 sec. The Kurie plot is linear down to ~300 kev, indicating a simple allowed transition (Br 50d) (log ft=3.57: Fe 51b).

Br 50d Brown and Perez-Mendez, Phys. Rev. **78**, 649 (1950).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
See also: Ho 50b.

II. $C^{12}(\alpha\ n)O^{15}$ $Q_m=-8.448$

O^{15} activity has been observed with 16-Mev α-particles (Ki 39).

Ki 39 King, Henderson, and Risser, Phys. Rev. **55**, 1118 (1939).

III. $N^{14}(p\ \alpha)C^{11}$ $Q_m=-2.916$ $E_b=7.347$

The excitation function shows a smooth rise from $E_p=4.5$ to 6 Mev (Ba 39a).

Ba 39a Barkas, Phys. Rev. **56**, 287 (1939).

IV. $N^{14}(p\ \gamma)O^{15}$ $Q_m=7.347$

Observed resonances are shown in Table X(15). The 7.61-, 8.0-, and 9.8-Mev states are believed to be formed by s-wave protons ($J=\frac{1}{2}, 0^+$) (Du 51). Extrapolation to low energies indicates that the major contribution to the cross section arises from the two broad resonances at $E_p=0.70$ and 2.60 Mev (Du 51). The measured cross section at 128 kev is $\gtrsim 7\times10^{-10}$ b (Wo 49a).

(Jo 52b) have observed capture γ-rays of the following energies at the 277-kev resonance: 0.75, 1.39, 2.38, 5.29, 6.21, and 6.84 Mev. These are believed to be associated with cascade transitions between the 7.61-Mev level and states in O^{15} at 5.29, 6.21, and 6.84 Mev which subsequently radiate to the ground state (the order of the cascades has, however, not been determined). No direct γ-transition has been observed between the 7.61-Mev level and the ground state.

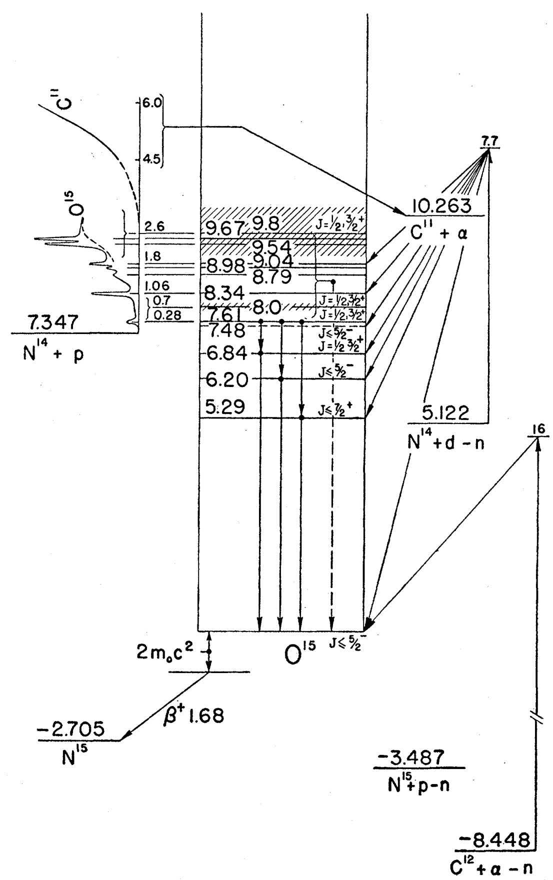

FIG. 21. Energy levels of O^{15}: for notation, see Fig. 1.

Du 51 Duncan and Perry, Phys. Rev. **82**, 809 (1951).
Wo 49a Woodbury, Hall, and Fowler, Phys. Rev. **75**, 1462 (1949).
Ta 46 Tangen, Kgl. Nord. Vid. Selsk Skr. No. 1 (1946).
Jo 52b Johnson, Robinson, and Moak, Phys. Rev. **85**, 931 (1952).
See also: Fo 51.

V. $N^{14}(p\ p)N^{14}$ $E_b = 7.347$

See (He 47).

VI. $N^{14}(d\ n)O^{15}$ $Q_m = 5.122$

$Q = 5.15 \pm 0.10$ (Gi 48: photoplate)
$Q = 5.1$ (Ro 52b: photoplate)

There is evidence, at $E_d = 1.7$ Mev, for a neutron group corresponding to a level at 4.9 Mev in O^{15} (Ro 52b). Neutron groups observed by (Ev 52) at $E_d = 7.7$ Mev are listed in Table XI(15), together with angular momentum and parity assignments obtained from the angular distributions.

Some of the γ-ray lines observed in $N^{14}+d$ may be from this reaction; see $N^{15}(N^{14}(d\ p)N^{15})$.

Gi 48 Gibson and Livesey, Proc. Phys. Soc. (London) **60A**, 523 (1948).
Ro 52b Rose, Hudspeth, and Heydenburg, Phys. Rev. **87**, 382 (1952).
Ev 52 Evans, Green, and Middleton, (to be published).

VII. $N^{15}(p\ n)O^{15}$ $Q_m = -3.487$

See (Ho 50b).

VIII. $O^{16}(\gamma\ n)O^{15}$ $Q_m = -15.597$ (not illustrated)

The threshold is $E_\gamma = 16.3 \pm 0.4$ Mev (Ba 45); see also O^{16}.

Ba 45 Baldwin and Koch, Phys. Rev. **67**, 1 (1945).

IX. $O^{16}(n\ 2n)O^{15}$ $Q_m = -15.597$ (not illustrated)

See O^{17}.

N^{16}

Mass of N^{16}

The following measurements bear on the mass of N^{16}:

1. $N^{16}(\beta^-)O^{16}$
   $E_\beta(\text{max}) \geq 9.6$ Mev (So 46).
   $E_\beta(\text{max}) = 10 \pm 1$, E_β (lower, more intense component) $+ E_\gamma = 10.5 \pm 0.5$ Mev (Bl 47).
2. $F^{19}(n\ \alpha)N^{16}$
   $Q = -0.73 \pm 0.25$ ($N^{16} - O^{16} = 9.64$) (Bl 47c)
   $Q = -1.2\ \pm 0.9$ ($N^{16} - O^{16} = 10.1$) (Je 50d)
3. $N^{15}(d\ p)N^{16}$
   $Q = 0.23 \pm 0.15$ ($N^{16} - O^{16} = 10.44$) (Wy 49c)

We adopt: $N^{16} - O^{16} = 10.3 \pm 0.5$ Mev.

I. $N^{16}(\beta^-)O^{16}$ $Q_m = 10.3$

From the character of the beta-decay, it is concluded that N^{16} has $J = 2$ odd (see O^{16}).

II. $C^{14}(d\ \alpha)B^{12}$ $Q_m = 0.355$ $E_b = 10.6$

At $E_d = 0.75$ Mev, the cross section is about 1.7 mb: the yield rises rapidly with increasing bombarding energy to $E_d = 1.3$ Mev (Hu 50e).

Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).

III. $C^{14}(d\ p)C^{15}$ $Q_m = 0.0$ $E_b = 10.6$

Production of C^{15} is quite appreciable at $E_d = 1.4$ Mev, suggesting $Q > -1.2$ Mev. There is some indication of a weak resonance at $E_d = 1.9$ Mev. At $E_d = 1.4$ Mev, formation of B^{12} is about seven times as probable as production of C^{15}; at 2.6 Mev, the ratio is 1:7 (Hu 50e).

Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).

IV. $C^{14}(d\ n)N^{15}$ $Q_m = 7.982$ $E_b = 10.6$

At $E_d = 1.26$ Mev, the yield is at least 2 or 3 times that of $C^{12}(d\ n)N^{13}$ (Hu 50e).

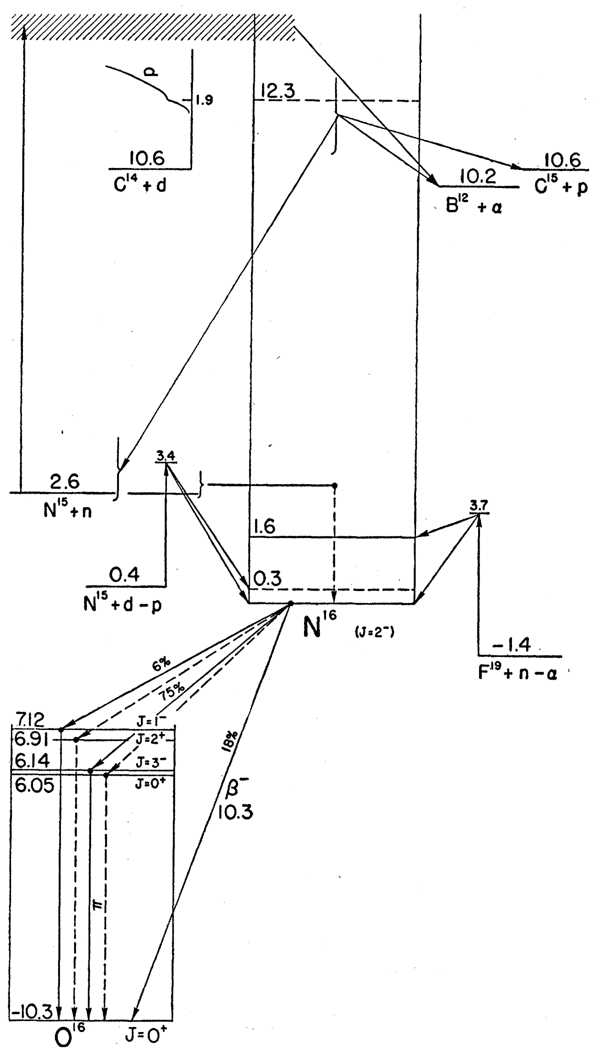

FIG. 22. Energy levels of N^{16}: for notation, see Fig. 1.

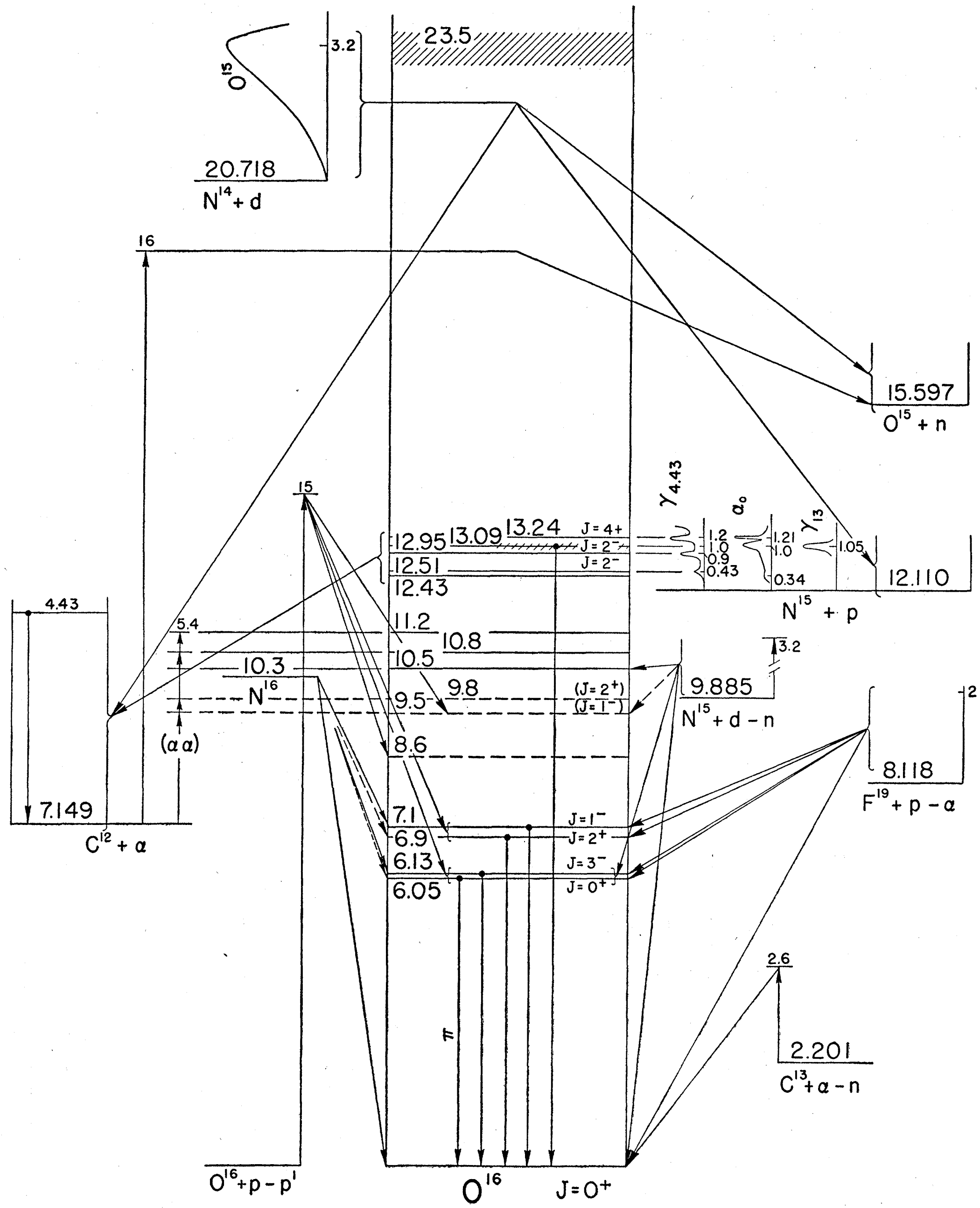

FIG. 23. Energy levels of O^{16}: for notation, see Fig. 1.

Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).

V. $N^{15}(n\ \alpha)B^{12}$ $Q_m = -7.627$ $E_b = 2.6$

See (Je 48c).

VI. $N^{15}(n\ \gamma)N^{16}$ $Q_m = 2.6$

The thermal cross section is 0.024±0.008 mb (Hu 52e).

Hu 52e Hughes *et al.*, AECU 2040 (May, 1952).
See also: Wa 50e, Fe 52.

VII. $N^{15}(d\ p)N^{16}$ $Q_m = 0.4$

Two proton groups are reported at $E_d = 3.4$ Mev, corresponding to the (presumed) ground state, $Q = 0.23 \pm 0.15$ Mev, and an excited state at 0.3 Mev (Wy 49c). At $E_d = 1.42$ Mev, only one group is reported, with $Q = -0.034 \pm 0.005$ Mev (Ma 50i).

Wy 49c Wyly, Phys. Rev. **76**, 316 (1949).
Ma 50i Malm and Buechner, Phys. Rev. **80**, 771 (1950).

VIII. $O^{16}(n\ p)N^{16}$ $Q_m = -9.5$ (not illustrated)

See (Co 51, Ho 50b, Li 52).

IX. $F^{19}(n\ \alpha)N^{16}$ $Q_m=-1.4$

Ground-state Q values are

$$Q=-0.73\pm0.25 \quad \text{(Bl 47c)}$$
$$Q=-1.2\ \pm0.9 \quad \text{(Je 50d)}$$

An excited state at 1.6 Mev is reported (Bl 47c).

Bl 47c Bleuler and Rossel, Helv. Phys. Acta **20**, 445 (1947).
Je 50d Jelley and Paul, Proc. Phys. Soc. (London) **63A**, 112 (1950).

O^{16}

I. $C^{12}(\alpha\ \alpha)C^{12}$ $E_b=7.149$

States of O^{16} at 10.5, 10.8, and 11.2 Mev are indicated by scattering anomalies (see Ho 50b). Preliminary results for $E_\alpha=0.50$ to 4.1 Mev show a broad P(?) and a D(?) resonance corresponding to levels at 9.5 and 9.8 Mev (R. W. Hill, private communication).

II. $C^{12}(\alpha\ n)O^{15}$ $Q_m=-8.448$ $E_b=7.149$

O^{15} production has been observed at $E_\alpha\sim16$ Mev (Ki 39).

Ki 39 King, Henderson, and Risser, Phys. Rev. **55**, 1118 (1939).

III. $C^{13}(\alpha\ n)O^{16}$ $Q_m=2.201$

At $E_\alpha=1.05$ Mev, $\theta=90°$, neutrons of energy 2.68 ±0.15 Mev ($Q=1.93$ Mev) are observed (Jo 51d). See also O^{17}.

Jo 51d Jones and Wilkinson, Proc. Phys. Soc. (London) **64A**, 756 (1951).

IV. $N^{14}(d\ n)O^{15}$ $Q_m=5.122$ $E_b=20.718$

The yield rises smoothly to $E_d=3.2$ Mev and drops sharply above this value (Ne 37b).

Ne 37b Newson, Phys. Rev. **51**, 620 (1937).

V. $N^{14}(d\ p)N^{15}$ $Q_m=8.609$ $E_b=20.718$

For angular distributions, see N^{15}. See also (Ho 50b).

VI. $N^{14}(d\ \alpha)C^{12}$ $Q_m=13.570$ $E_b=20.718$

For angular distributions, see C^{12}. See also (Ho 50b).

VII. $N^{14}(d\ 4\alpha)$ $Q_m=6.292$ $E_b=20.718$
(not illustrated)

See (Fo 47b).

VIII. $N^{14}(d\ t)N^{13}$ $Q_m=-4.288$ $E_b=20.718$
(not illustrated)

See (Bo 42).

IX. $N^{14}(d\ d)N^{14}$ $E_b=20.718$

The angular distribution of elastically scattered deuterons has been studied at $E_d=6.6$ Mev by (Gu 47) and at $E_d=8$ Mev by (Gi 52).

Gu 47 Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. (London) **190**, 196 (1947).
Gi 52 Gibson and Thomas, Proc. Roy. Soc. (London) **210**, 543 (1952).

X. $N^{15}(p\ \gamma)O^{16}$ $Q_m=12.110$

A resonance for capture radiation appears at $E_p=1.05$ Mev with a width of $\sim$150 kev and a peak cross section of 1 mb. The radiation, $E_\gamma\simeq13$ Mev, is probably electric dipole (Sc 52).

Sc 52 Schardt, Fowler, and Lauritsen, Phys. Rev. **86**, 527 (1952).
See also: Fo 51.

XI. $N^{15}(p\ \alpha)C^{12}$ $Q_m=4.961$ $E_b=12.110$

Resonances for ground-state (α_0) and 4.4-Mev state (α_1) α-particles are reported in Table I(16). The cross section at $E_p=100$ kev is 5×10^{-7} b: extrapolation to 30 kev gives 1.5×10^{-14} b (Sc 52).

The angular distribution of 4.4-Mev γ-rays at the 429- and 898-kev resonances exhibits terms in $\cos^2\theta$ and $\cos^4\theta$. The observed distributions are consistent with the following assumptions: (1) N^{15} has $J=\frac{1}{2}$, odd, (2) the 12.51- and 12.95-Mev states of O^{16} have $J=2^-$ and are formed by d-wave protons, (3) both states break up by emission of p-wave α-particles, leading to a $J=2^+$ state of C^{12} (at 4.4 Mev) which decays by quadrupole radiation to the ground state. The fraction of channel spin zero formation is $x=0.82\pm0.03$ for the first resonance and $x=0.58\pm0.03$ for the second (Kr 52c). In Russell-Sanders coupling, a $^3D_2$ compound state in O^{16} requires $x=0.858$, and a $^3F_2$ requires $x=0.60$. In $j-j$ coupling,

TABLE II(16). Alpha-particle groups from $F^{19}(p\ \alpha)O^{16}$.

A: Q (Mev)	B: Q (Mev)	C: Q (Mev)	D: O^{16*}
2.073	2.061±10	2.056±12	6.055
1.988	1.977±8	1.979±9	6.137
1.210	1.204±8	1.200±10	6.913
1.007	1.002±8	0.996±10	7.116

A: (Bu 50c) Errors not stated, but presumed to be $\sim$10 kev.
B: (Ch 50) Errors given in kev.
C: (Fr 50e) Errors given in kev.
D: Mean from A, B, and C.

TABLE III(16). Angular distribution of γ-rays from $F^{19}(p\ \alpha)O^{16}$.

E_p (kev)	A[a]	Assignment (Ne^{20} levels)		Ne^{20*}
340	0	s-wave,	$J=1^+$	13.19
486	0			13.33
598	0.2	p-wave,	$J=2^-$	13.44
669	0	s-wave,	$J=1^+$	13.51
874[b]	0.1	p-wave,	$J=2^-$	13.70
	0.107±0.006			
935	−0.003±0.005	s-wave,	$J=1^+$	13.76
1290	0.668±0.017	d-wave,	$J=3^+$	14.10
1355	0.233±0.016	d-wave,	$J=3^+$	14.16
1381[c]	−0.073±0.015	s, d-wave,	$J=1^+$	14.18

[a] Coefficient in $Y(\theta)=1+A\cos^2\theta$. The first five values are from (De 49d), the remainder from (Da 51b).
[b] (Sa 52) finds $A=0.01\pm0.04$ for the 6.14-Mev component and 0.33 ± 0.06 for the combined 6.9- and 7.1-Mev components, yielding 0.09 for the total.
[c] The coefficient varies linearly through the resonance, from −0.2 to +0.1 (Da 51b).

a $d_{\frac{3}{2}}$ proton corresponds to x=0.40 and a $d_{\frac{5}{2}}$ proton to x=0.60. It thus appears that the assumption of pure $L-S$ coupling gives a good account of these two resonances, while the $j-j$ scheme fits only one (Ch 52b).

The angular distribution of short-range α-particles at $E_p=898$ kev fits the calculated expression $W(\theta)=7-6\cos^2\theta$, based on the above assumptions with x=0.60. From this distribution and the γ-ray distribution, it can be shown that no other reasonable assignment is possible, i.e., O^{16*} has $J=2^-$ or $J>5$ and C^{12*} has $J=2^+$ or $J>4$ (Kr 52d). The $\alpha-\gamma$ correlations, observed in the plane perpendicular to the beam and in a plane containing the beam (α-particles at 90°), are also consistent with these assignments and with x=0.60 (French and Seed, private communication).

The angular distribution of short-range α-particles and γ-rays at $E_p=1210$ kev leads to the conclusion that the 13.24-Mev level has $J=4^+$ and, again that the C^{12*} level has $J=2^+$ or $J>4$ (Kr 52d).

Sc 52 Schardt, Fowler, and Lauritsen, Phys. Rev. **86**, 527 (1952).
Kr 52c Kraus and French, Phys. Rev. (to be published).
Ch 52b Christy, (to be published).
Kr 52d Kraus, Fowler, and Lauritsen, Phys. Rev. (to be published).
See also: Fo 51, Pa 51.

XII. $N^{15}(d\ n)O^{16}$ $Q_m=9.885$

Neutron groups corresponding to levels at 0, 6.1±0.3, 9.3, and 10.7 Mev are observed (see Ho 50b).

XIII. $N^{16}(\beta^-)O^{16}$ $Q_m=10.3$

The β-spectrum exhibits components to the ground state (~18 percent) and to the excited states at 6.1 and 7 Mev (~40 percent each). Whether transitions occur to the pair-emitting, 6.05-Mev level (~2 percent) is not established (Bl 47, So 46). Gamma-rays of energy 6.133±0.011 and 7.10±0.02 Mev, with intensities in the ratio 1:0.08±0.02, are observed: a 6.9-Mev line somewhat weaker than the 7.1-Mev line cannot be excluded (Mi 51a). [In view of the γ-ray data, it would seem that the β-decay to the 7.1-Mev state must be weaker than was formerly assumed.] The half-life is 7.35±0.05 sec (Bl 47). From the fact that the ground-state transition is first-forbidden (log ft=6.8) and the transitions to the excited states are allowed (log ft ~4.5), it is concluded that N^{16} has $J=2$, odd and that the 7.1-Mev level has odd parity (O^{16} ground state: $J=0^+$, 6.1-Mev state: $J=3^-$) (Mi 51a).

Bl 47 Bleuler, Scherrer, Walter, and Zunti, Helv. Phys. Acta **20**, 96 (1947).
So 46 Sommers and Sherr, Phys. Rev. **69**, 21 (1946).
Mi 51a Millar, Bartholomew, and Kinsey, Phys. Rev. **81**, 150 (1951).
See also: Mi 50a, Fe 51b.

XIV. $O^{16}(\gamma\ n)O^{15}$ $Q_m=-15.597$ (not illustrated)

The cross section, determined by O^{15} production, exhibits a low plateau for $E_\gamma=17$ to 20 Mev, rising to a peak of 11.4 mb at 24.2 Mev (Jo 51b). Up to $E_\gamma=60$ Mev, the cross section falls as E_γ^{-3} (Sa 51). The integrated cross section is 180 Mev-mb (Ed 52a: based on $C^{12}(\gamma\ n)C^{11}=47$ Mev-mb).¶¶

Jo 51b Johns, Horsley, Haslam, and Quinton, Phys. Rev. **84**, 856 (1951).
Sa 51 Sagane, Phys. Rev. **84**, 587 (1951).
Ed 52a Edwards and MacMillan, Phys. Rev. **87**, 377 (1952).
See also: Ho 52.

XV. $O^{16}(\gamma\ p)N^{15}$ $Q_m=-12.110$ (not illustrated)

See (Ho 50b).

XVI. (a) $O^{16}(\gamma\ \alpha)C^{12}$ $Q_m=-7.149$
(b) $O^{16}(\gamma\ 4\alpha)$ $Q_m=-14.426$
(not illustrated)

The cross section for reaction (b) exhibits at least three maxima at $E_\gamma=22.6$, 25.8, and 29.5 Mev, with some evidence of partially resolved fine structure (Go 52). The integrated cross section is ~2.5 Mev-mb (Go 52a). The cross section of reaction (a) for (Li^7+p) γ-rays is 0.18±0.05 mb (Na 52a).

As $E_\gamma=23$ Mev, some of the disintegrations lead to an excited state of C^{12} at ~9.7 Mev which further disintegrates by α-particle emission (Go 50h: see C^{12}). Direct emission of Be^8 is also reported: see (Wi 50d, Go 51c, Mi 51, Wi 51g).

Go 52 Goward and Wilkins, Proc. Phys. Soc. (London) **65A**, 671 (1952).
Go 52a Goward and Wilkins, AERE Memo G/M **127** March (1952).
Na 52a Nabholz, Stoll, and Waffler, Phys. Rev. **86**, 1043 (1952).
Go 50h Goward and Wilkins, Proc. Phys. Soc. (London) **63A**, 1171 (1950).
See also: Pr 50c, We 50a, Wi 50d, Go 51c, Mi 51, Wi 51g, Li 52b.

XVII. $O^{16}(p\ p')O^{16}$

At $E_p=7.2$ Mev, $\theta=90°$, no groups corresponding to excited states <4.6 Mev are observed (Co 52g). Work at $E_p=15$ Mev indicates levels at 5.8±0.3, 6.7±0.3, 8.6±0.4, and 9.7±1.0 Mev (Fu 48).

Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).
Fu 48 Fulbright and Bush, Phys. Rev. **74**, 1323 (1948).

XVIII. $F^{19}(p\ \alpha)O^{16}$ $Q_m=8.118$

The ground-state Q is 8.118±0.009 (St 51). In addition to the ground-state group, four α-particle groups have been identified, corresponding to levels at 6.06 (nuclear pair emitting), 6.1, 6.9, and 7.1 Mev. Table II(16) presents the pertinent Q-values. The reaction exhibits a number of pronounced resonances and the relative yield of the α-particle groups varies greatly from one resonance to another (see Ne^{20}). Generally

¶¶ *Note added in proof:* Discontinuities in the activation curve are attributed to levels of O^{16} at 15.84, 16.57, 16.73, 16.90, 18.45, 20.4, 21.06, and 21.39 Mev (Haslam, Katz, Horsley, Cameron, and Montalbetti, Phys. Rev. **87**, 196A (1952) and private communication).

speaking, resonances for α-particles to the ground state and the pair state are identical (see, however, Ne^{20} diagram) and distinct from those leading to the γ-ray emitting states. At the former resonances, the pairs are ordinarily about ten times more numerous than ground-state α-particles, for reasons which are not clear.

The existence of the pairs and absence of γ-radiation from the 6.06-Mev level clearly establishes the total angular momentum, J, of this level as zero. (O^{16} ground state $J=0^+$.) The energy spectrum, the lifetime of $7\pm1\times10^{-11}$ sec, and the angular correlation, $1+0.85\cos\theta$ (De 49b), $1+0.6\cos\theta$ (Ph 51a) are all consistent with $J=0^+$ (see Ho 50b). An upper limit of 50 percent can be placed on the probability of two-quantum decay (Ph 51a).

A resonance at $E_p=340$ kev has been shown to lead almost entirely to the 6.14-Mev level. Study of the angular correlation of α-particles and γ-rays (α_1-γ) at this resonance establish that the 6.14-Mev level has $J=3$ and that the 13.19-Mev Ne^{20} level has $J=1$, formed by s-wave protons (Ar 50, Ba 50f). The isotropy of the γ-radiation at this resonance (see Table III(16)) confirms the latter conclusion (De 49d). The polarization of the 6.14-Mev radiation indicates (Fr 52a) that it is electric octupole, establishing the parity of the O^{16} level as odd, and both the ground state of F^{19} and the 13.19-Mev state of Ne^{20} as even (Sa 52).

Correlations of (α_1-γ), observed at the 669- and 935-kev resonances establish that these levels (13.51 and 13.76 Mev in Ne^{20}) have $J=1^+$: the isotropy of the γ-rays again indicates s-wave formation. The correlation at the 874-kev resonance (13.70 Mev) indicates that J for this level is not 1^+ and favors 2^-, with p-wave formation, which is also consistent with the γ-ray angular distribution (Fr 52c).

Study of correlations of α-particles and γ-rays associated with the 6.9-Mev level of O^{16} (α_2-γ) at $E_p=874$ and 935 kev and of (α_3-γ: 7.1-Mev level) at $E_p=669$, 874, and 935 kev leads to assignments of $J=2^+$ and $J=1^-$ to the 6.9- and 7.1-Mev levels, respectively, (Fr 52c).

Further assignments of J and parity to levels of Ne^{20}, based on α and γ angular distributions are listed in Table III(16) (Ch 50a). The assignments made for the lower levels are in complete agreement with the later work.

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Bu 50c Buechner *et al.*, MIT Prog. Rept. April (1950).
Ch 50 Chao, Tollestrup, Fowler, and Lauritsen, Phys. Rev. **79**, 108 (1950).
Fr 50e Freeman, Phil. Mag. **41**, 1225 (1950).
De 49b Devons and Lindsey, Nature **164**, 539 (1949).
Ph 51a Phillips and Heydenburg, Phys. Rev. **83**, 184 (1951).
Ar 50 Arnold, Phys. Rev. **79**, 170 (1950) and **80**, 34 (1950).
Ba 50f Barnes, French, and Devons, Nature **166**, 145 (1950).
De 49d Devons and Hine, Proc. Roy. Soc. (London) **199**, 56, 73 (1949).
Fr 52a French and Newton, Phys. Rev. **85**, 1041 (1952).
Fr 52c French and Seed (to be published).
Da 51b Day, Ph.D. thesis, California Institute of Technology (1951).
Sa 52 Sanders, Phil. Mag. **43**, 630 (1952).
Ch 50a Chao, Phys. Rev. **80**, 1035 (1950).
See also: Ho 50b, Gi 51a, Sh 51f, Al 52.

F^{16}

(not illustrated)

F^{16} is almost certainly unstable with respect to proton emission. That F^{16} does not in fact exist is suggested by its failure to appear either as a positron or delayed α-particle emitter in the bombardment of O^{16} with high energy protons (Al 50g and private communication.)

Al 50g Alvarez, Phys. Rev. **80**, 519 (1950).

N^{17}

(not illustrated)

Mass of N^{17}

The mass difference $N^{17}-O^{17}$ is approximately given by the sum of the beta-ray end point, 3.7 ± 0.2 Mev, and the most probable neutron energy, 0.92 ± 0.07 Mev, plus the neutron binding energy in O^{17}, 4.143 Mev, yielding 8.8 ± 0.2 Mev. The value derived from the $O^{18}(\gamma\, p)N^{17}$ threshold is $\sim$0.25 Mev higher, but such a discrepancy is not unexpected because of the barrier effect. *We adopt:* $N^{17}-O^{17}=8.8\pm0.2$ Mev; mass defect $=13.0\pm0.2$ Mev.

I. $N^{17}(\beta^-)O^{17*}\rightarrow O^{16}+n$ $Q_m=8.8$

The decay is complex: see O^{17}.

II. $C^{14}(\alpha\, p)N^{17}$ $Q_m=-9.8$

See O^{18}.

III. $O^{17}(n\, p)N^{17}$ $Q_m=-8.0$

See O^{18}.

IV. $O^{18}(\gamma\, p)N^{17}$ $Q_m=-16.1$

The threshold is 16.35 ± 0.2 Mev. The delayed neutrons (from O^{17*}) were observed (St 51a).

St 51a Stephens, Halpern, and Sher, Phys. Rev. **82**, 511 (1951).

V. $F^{19}(\gamma\, 2p)N^{17}$ $Q_m=-24.0$

See (Ho 50b).

O^{17}

The ground state J of O^{17} is 5/2 (Al 51e, Ge 52a).

I. $C^{13}(\alpha\, n)O^{16}$ $Q_m=2.201$ $E_b=6.344$

The excitation function rises slowly to $E_\alpha=1.2$ Mev (Jo 51d: see O^{16}). At about 2 Mev, a steep rise occurs in the thick target yield, followed by a flattening off near 2.5 Mev (N. P. Heydenburg, private communication).

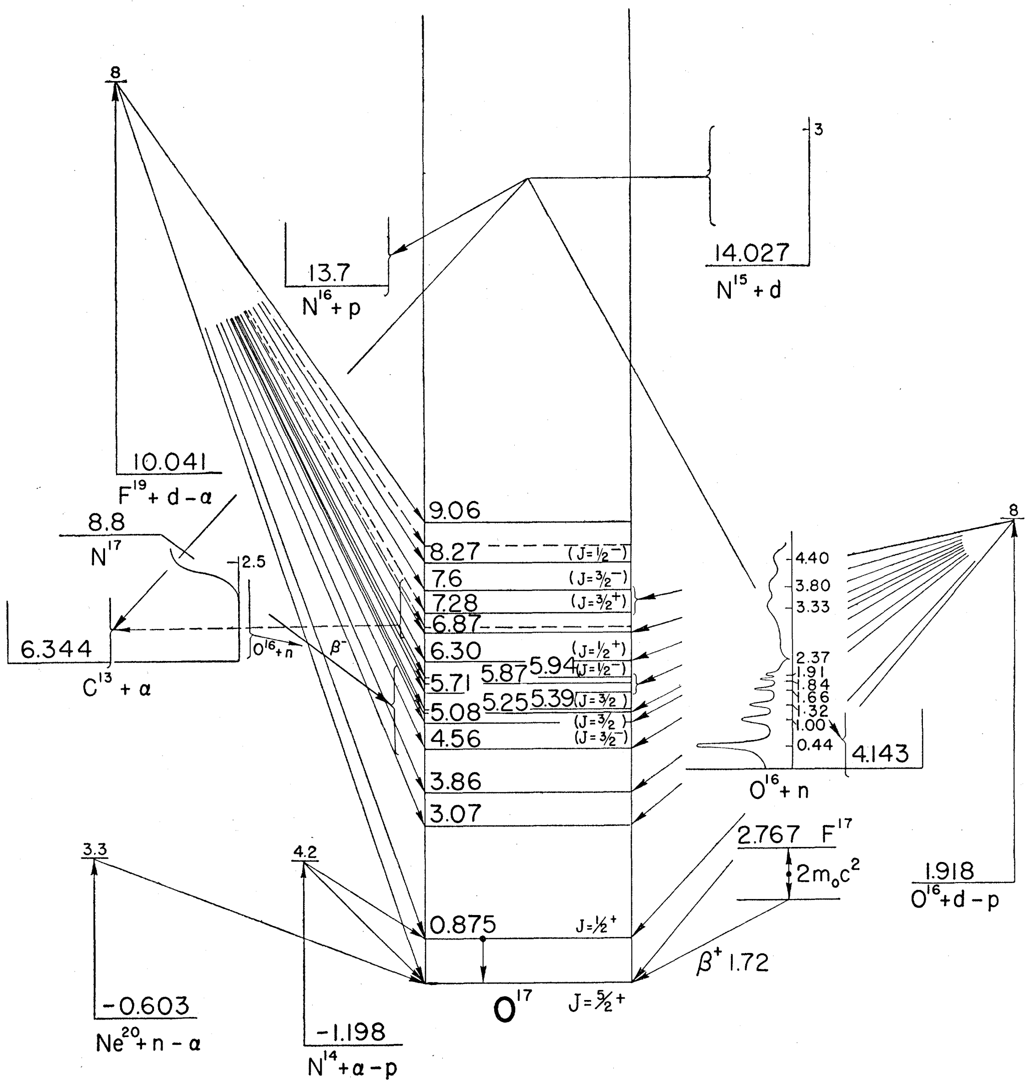

FIG. 24. Energy levels of O^{17}: for notation, see Fig. 1.

Jo 51d Jones and Wilkinson, Proc. Phys. Soc. (London) **64A**, 756 (1951).
See also: Ro 44a, An 48a.

II. $N^{14}(\alpha\ p)O^{17}$ $Q_m=-1.198$

At $E_\alpha=3.6$ and 4.2 Mev, proton groups corresponding to the ground state, $Q=-1.16$, and to the first excited state, $Q=-2.0$, of O^{17} are observed (Ro 50e, Ro 51g: photoplate). See F^{18}.

Ro 50e Roy, Bull. du Centre de Phys. Nucleaire de l'Un. Libre de Bruxelles, No. 21, September (1950).
Ro 51g Roy, Phys. Rev. **82**, 227 (1951).
See also: Ho 50b.

III. $N^{15}(d\ \alpha)C^{13}$ $Q_m=7.683$ $E_b=14.027$

At $E_d\sim 1.0$ Mev, the cross section for the ground-state group is 1 mb (Ho 40). See C^{13}.

Ho 40 Holloway and Moore, Phys. Rev. **58**, 847 (1940).

IV. $N^{15}(d\ p)N^{16}$ $Q_m=0.4$ $E_b=14.027$

See N^{16}.

V. $N^{15}(d\ n)O^{16}$ $Q_m=9.885$ $E_b=14.027$

See O^{16}.

VI. $N^{17}(\beta^-)O^{17*}\rightarrow O^{16}+n$ $Q_m=8.8$

The half-life is 4.14 ± 0.04 sec (Kn 48), 4.15 ± 0.1 sec (St 51a). $E_\beta(\max)=3.7\pm0.2$ Mev (Al 49c): log ft$=3.8$. The β-decay proceeds to an excited state of O^{17} which in turn decays to O^{16} by neutron emission. The neutron spectrum has a maximum at 0.92 ± 0.07 Mev (Al 49c, Ha 49c) and a half-width <0.5 Mev. The 5.08-Mev level in O^{17} is probably the principal level involved in the decay. Since the neutron spectrum extends to $E_n\sim 2$ Mev, other levels in O^{17} may also be involved.

TABLE I(17). Resonances in $O^{16}(n\ n)O^{16}$.

E_{res} (Mev)	Γ (kev)	σ(b)	l_n	Θ^2	φ	J	O^{17*} (Mev)
0.44[a]	40	14.0	1	0.034		3/2⁻	4.56
1.00[a]	100	7.9	1	0.033		3/2	5.08
			(2)	0.26			
1.32[a]	35	6.7	1	0.0090		3/2	5.39
			2	0.043			
1.66[a]	≤7	5.2	>0			≥3/2	5.71
1.84[a]	≤10	3.8	>0			≥3/2	5.87
1.91[b]	30	3.0	1	0.0056		1/2⁻	5.94
2.37[c]	120	0.3	0	0.013	−90°	1/2⁺	6.37
3.33[d]	220	3.0	2		−15°	3/2⁺	7.28
3.80[d]	800	3.0	1		0°	3/2⁻	7.72
4.40[d]	280	2.2	1		0°	1/2⁻	8.28

$\Theta^2=\gamma^2\ (2Ma/3\hbar^2)$, fraction of the sum-rule limit.
φ = potential scattering phase.
[a] Bo 50f, Bo 51c.
[b] Bo 51c, Ba 52b.
[c] Bo 51c, Ba 52b, Ri 51c.
[d] Fr 50b, Ba 52b.

Whether the direct β-transitions to the low states of O^{17} occur is not known.

Kn 48 Knable, Lawrence, Leith, Moyer, and Thornton, Phys. Rev. **74**, 1217A (1948).
St 51a Stephens, Halpern, and Sher, Phys. Rev. **82**, 511 (1951).
Al 49c Alvarez, Phys. Rev. **75**, 1127 (1949).
Ha 49c Hayward, Phys. Rev. **75**, 917 (1949).

VII. $O^{16}(n\ \alpha)C^{13}$ $Q_m=-2.201$ $E_b=4.143$

Resonances are observed for $E_\alpha+E_{recoil}=0.65$, 0.85, and 1.5(?) Mev, corresponding to neutron energies of 2.85, 3.05, and 3.7(?) Mev (Wi 37e).

Wi 37e Wilhelmy, Z. Physik **107**, 769 (1937).

VIII. $O^{16}(n\ p)N^{16}$ $Q_m=-9.5$ $E_b=4.143$ (not illustrated)

See (Co 51).

IX. $O^{16}(n\ 2n)O^{15}$ $Q_m=-15.597$ $E_b=4.143$ (not illustrated)

See (Ho 50b, Sh 45).

X. $O^{16}(n\ n)O^{16}$ $E_b=4.143$

The epithermal scattering cross section (free) is 3.76±0.02 b; the cross section is almost constant from thermal energies to $E_n=0.3$ Mev (Hu 52e). The magnitude both of the cross section in this region and of the apparent "nonresonant" background extending to ∼2 Mev, can be accounted for as s-wave scattering involving the 0.87-Mev level of O^{17}, with a reduced width approaching the sum-rule limit (Th 52b).

Resonances which appear from $E_n=0.4$ to 5.0 Mev are indicated in Table I(17), as are level assignments based on peak heights, peak shapes, and, for the resonances observed by (Ba 52b), angular distributions.

The total cross section for 14-Mev neutrons is 1.59 ±0.03 b (gas), 1.56±0.04 b (H_2O) (Co 52h), 1.64±0.04 b (Po 52a).

Hu 52e Hughes *et al.*, AECU 2040 (1952).
Th 52b Thomas, Phys. Rev. (to be published).
Bo 50f Bockelman, Phys. Rev. **80**, 1011 (1950).
Bo 51c Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).
Ba 52b Baldinger, Huber, and Proctor, Helv. Phys. Acta **25**, 142 (1952).
Ri 51c Ricamo and Zunti, Helv. Phys. Acta **24**, 419 (1951).
Fr 50b Freier, Fulk, Lampi, and Williams, Phys. Rev. **78**, 508 (1950).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
Po 52a Poss, Salant, Snow, and Yuan, Phys. Rev. **87**, 11 (1952).
See also: Hi 49, Ba 50g, Ad 50, Ri 50d, Br 50f, Ba 51c, Wa 51e, Sh 51b, Te 52.

XI. $O^{16}(d\ p)O^{17}$ $Q_m=1.918$

Recently reported values of the ground-state Q are:

$Q=1.917\pm0.008$ (St 51: mag. spectrometer)
$Q=1.918\pm0.008$ (Kl 52: mag. spectrometer)

TABLE II(17). States of O^{17} from $F^{19}(d\ \alpha)O^{17}$ and $O^{16}(d\ p)O^{17}$.

A		B		C	D		
O^{17*} (kev)	Rel. intens.	O^{17*} (kev)	Rel. intens.	O^{17*} (kev)	O^{17*} (kev)	Γ (kev)	Rel. intens.
0	100	0	100	0	0		100
870±50	38	870±20	56	870±20	883±11		40
3030±60	16	3070±30	16	3060±30	3069±10		36
3830±40	58	3870±40	14	3850±30	3856±11		130
4560±30	79	4590±20	54	4580±20	4567±14	22±8	23
5080±30	123	5060±20	36	5070±20			
5310±60	39	5310±20	93	5310±20	5229±13	8±6	79
					5397±14	15±8	46
5660±30	188	5790±20	77	5760±20	5723±14	28±7	87
					5875±15		16
					5947±15	8±4	31
6210±30	141	6260±30	23	6240±20			
6910±30	219	6850±40	8	6890±30			
					6869±14		39
					(6986±15)	20±11	(33)
					(7371±15)		(44)
7510±30	352	7530±50		7510±30			
8270±40	332			8270±40			
(8590±40)	100			(8590±40)			
9060±40	263			9060±40			

A: $F^{19}(d\ \alpha)O^{17}$: $E_d=7.86$ Mev, photoplate, several angles. Intensities are integrated (Bu 51f).
B: $O^{16}(d\ p)O^{17}$: $E_d=7.86$ Mev, photoplate, several angles. Intensities are integrated (Bu 51f).
C: Means of A and B (Bu 51f).
D: $F^{19}(d\ \alpha)O^{17}$: $E_d=1.8$, $\theta=90°$, magnetic spectrometer. Intensities ±30 percent (Wa 52b).

The excitation energy of the first excited state is given as 880±5 kev from magnetic analysis of proton groups (Van Patter: private communication). Proton groups observed at $E_d = 8$ Mev are listed in Table II(17) (Bu 51f). At $E_d = 8$ Mev, the angular distribution of ground-state protons, analyzed by the method of (Bu 51b), indicates capture of d-wave neutrons, leading to $J = \frac{3}{2}$ or 5/2, even; the first excited state is formed with s-wave neutrons, $J = \frac{1}{2}^+$ (Bu 50e, Bu 51f, Bu 51h). The angular distributions in the range $E_d = 0.65$ to 3.05 Mev have been studied by (He 48a).

The energy of the gamma-ray from the first excited state is 870.5±2.0 kev: the internal conversion coefficient is consistent with electric quadrupole radiation (Th 52). The $p-\gamma$ angular correlations are isotropic at $E_d = 0.5$ Mev (Th 51d) and at 1.7 and 2.0 Mev (Ph 52), consistent with $J = \frac{1}{2}$ for the excited state.

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Kl 52 Klema and Phillips, Phys. Rev. **86**, 951 (1952).
Bu 51f Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **209**, 478 (1951).
Bu 51b Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).
Bu 50e Burrows, Gibson, and Rotblat, Phys. Rev. **80**, 1095 (1950).
Bu 51h Burge, Burrows, Gibson, and Rotblat, Proc. Roy. Soc. (London) **210**, 534 (1951).
He 48a Heydenburg and Inglis, Phys. Rev. **73**, 230 (1948).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Th 51d Thirion, Compt. rend. **232**, 2418 (1951).
Ph 52 Phillips, Heydenburg, and Cowie, Phys. Rev. **85**, 742 (1952).
Wa 52b Watson, M.I.T. Prog. Rept. (LNSE), (February and June 1952) and Watson and Buechner, Phys. Rev. (to be published).
See also: Ne 49, Di 50, Ne 50a, Ne 50b, Bu 50.

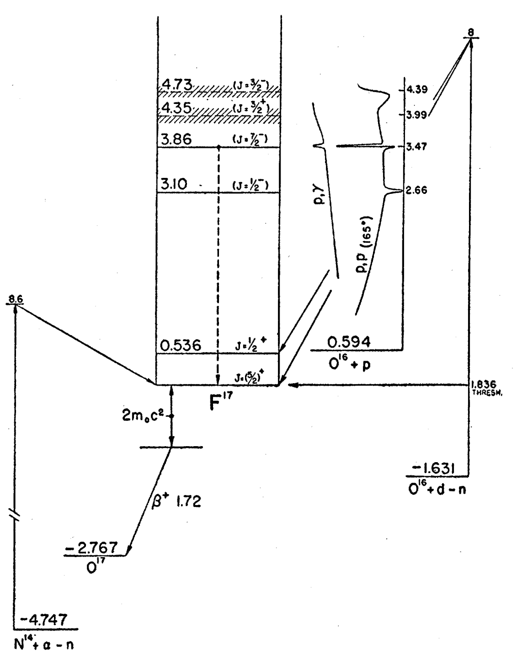

FIG. 25. Energy levels of F^{17}: for notation, **see Fig. 1.**

TABLE III(17). Resonances in $O^{16}(p\ p)O^{16}$ (La 51d, La 51e).

E_p (Mev)	Γ (kev)	F^{17*}	
2.66	19.9	3.10	$J = 1/2^{-a}$
3.47	<3.5	3.86	$J = 7/2^-$
(3.99)	≃500	(4.35)	$J = (3/2^+)$
(4.39)	240	(4.73)	$J = (3/2^-)$

[a] Reported $J = 1/2^+$ by (La 51e), but recent work by Eppling (private communication) at other angles shows that the 2.66-Mev anomaly probably corresponds to a $J = 1/2^-$ level.

XII. $F^{17}(\beta^+)O^{17}$ $Q_m = 2.767$

The beta-ray end point is 1.72±0.03 Mev (Pe 50c): no radiation is observed other than the annihilation radiation (Pe 51d). Less than 1 percent of the transitions result in γ-radiation (W. E. Meyerhof, private communication).

Pe 50c Perez-Mendez and Lindefeld, Phys. Rev. **80**, 1097 (1950).
Pe 51d Perez-Mendez and Lindenfeld, Phys. Rev. **83**, 864 (1951).
See also: Ri 51b.

XIII. $F^{19}(d\ \alpha)O^{17}$ $Q_m = 10.042$

Recently reported ground-state Q-values are:

$Q = 10.050 \pm 0.010$ (St 51: mag. spectrometer)
$Q = 10.40 \pm 0.02$ (Bu 51f: photoplate)

Table II(17) presents values for α-particle groups leading to excited states of O^{17} as reported by (Bu 51f) and (Wa 52b). Also included are values for $O^{16}(d\ p)O^{17}$ (Bu 51f).

Some of the γ-radiation observed in the bombardment of F^{19} by deuterons may be attributable to this reaction (see $F^{19}(d\ n)Ne^{20}$).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Bu 51f Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **209**, 478 (1951).
Wa 52b Watson, Phys. Rev. **87**, 215A (1952), MIT Prog. Rept. (L.N.S.E.) Feb. (1952), May (1952) and Watson and Buechner, Phys. Rev. (to be published).
See also: Ho 50b.

XIV. $Ne^{20}(n\ \alpha)O^{17}$ $Q_m = -0.603$

Reported values for the ground-state Q are:

$Q = -0.75 \pm 0.05$ (Jo 51e)
$Q = -0.6$ to -0.7 (Si 50)

There is no indication of α-groups leading to the 0.87-Mev state of O^{17} at $E_n < 3.3$ Mev (Jo 51e).

Jo 51e Johnson, Bockelman, and Barschall, Phys. Rev. **82**, 117 (1951).
Si 50 Sikkema, Nature **165**, 1016 (1950).
See also: Ho 50b.

F^{17}

I. $F^{17}(\beta^+)O^{17}$ $Q_m = 2.767$

The decay proceeds to the ground state: $E_\beta(\max) = 1.72 \pm 0.03$ Mev (Pe 50c). Recently reported values for the half-life are: 66±1 sec (Br 49), 66.3±1 sec (La 51d), 60±1 sec (Ho 52a). Log ft=3.37.

Pe 50c Perez-Mendez and Lindenfeld, Phys. Rev. **80**, 1097 (1950).
Br 49 Brown and Perez-Mendez, Phys. Rev. **75**, 1286 (1949).
La 51d Laubenstein, Laubenstein, Koester, and Mobley, Phys. Rev. **84**, 12 (1951).
Ho 52a Horsley, Haslam, and Johns, Phys. Rev. **87**, 756 (1952).

II. $N^{14}(He^3\ \alpha)N^{13}$ $Q_m=10.021$ $E_b=15.819$ (not illustrated)

See (Ho 50b).

III. $N^{14}(\alpha\ n)F^{17}$ $Q_m=-4.747$

Positrons from the F^{17} decay are observed for $E_\alpha \gtrsim 7$ Mev (Li 37). See also F^{18}.

Li 37 Livingston and Bethe, Revs. Modern Phys. **9**, 245 (1937).

IV. $O^{16}(p\ p)O^{16}$ $E_b=0.594$

Observed resonances are shown in Table III(17) (La 51d, La 51e). The cross section from $E_p \sim 0.6$ to 2 Mev appears to decrease more slowly than does the Rutherford cross section, indicating the influence of a bound $S_{\frac{1}{2}}$ level (see $O^{16}(d\ n)F^{17}$) with a reduced width of the order of the sum-rule limit (La 51e). Between $E_p=360$ and 550 kev, the cross section is Rutherford within <6 percent (We 52b).

La 51d Laubenstein, Laubenstein, Koester, and Mobley, Phys. Rev. **84**, 12 (1951).
La 51e Laubenstein and Laubenstein, Phys. Rev. **84**, 18 (1951).
We 52b Wenzel and Whaling, Phys. Rev. **87**, 499 (1952).
See also: Ko 51a, Th 52b, Te 52.

V. $O^{16}(p\ \gamma)F^{17}$ $Q_m=0.594$

The relative F^{17} activity has been measured from $E_p=1.1$ to 4.1 Mev. The cross section increases almost linearly with proton energy from 1.1 to 3.75 Mev except for a sharp resonance at 3.47 Mev. Above 3.75 Mev, the rate of increase of the cross section is more rapid. This increase may be associated with the broad resonance at $E_p=3.99$ Mev (see $O^{16}(p\ p)O^{16}$). The large capture cross section which extends over the entire energy range is probably attributable to the broad $J=\frac{1}{2}^+$ level at 0.536-Mev excitation in F^{17} (see $O^{16}(d\ n)F^{17}$). The excitation function is consistent with the assumption of $J=5/2^+$ for the ground state (La 51d, La 51e).

La 51d Laubenstein, Laubenstein, Koester, and Mobley, Phys. Rev. **84**, 12 (1951).
La 51e Laubenstein and Laubenstein, Phys. Rev. **84**, 18 (1951).

VI. $O^{16}(d\ n)F^{17}$ $Q_m=-1.631$

The threshold is 1.836±0.003 Mev; $Q=-1.631$ ±0.003 (Bo 51b).

A neutron group corresponding to an excited state in F^{17} at 0.536±0.010 Mev (Aj 51b), 0.53±0.06 Mev (El 51a) has been observed. Angular distributions of neutron groups from the ground state and the 0.536-Mev state of F^{17}, analyzed by the method of (Bu 51b), indicate $J=\frac{3}{2}$ or $5/2^+$ for the ground state and $J=\frac{1}{2}^+$ for the first excited state. (Aj 51b, Aj 52a, El 51a: photoplate; $E_d=3.1$ and 8 Mev, respectively.)

Bo 51b Bonner and Butler, Phys. Rev. **83**, 1091 (1951).
Aj 51b Ajzenberg, Phys. Rev. **83**, 693 (1951).
El 51a El Bedewi, Middleton, and Tai, Proc. Phys. Soc. (London) **64A**, 757 (1951).
Aj 52a Ajzenberg, Ph.D. thesis, University of Wisconsin (1952).
See also: Hu 51g.

VII. $F^{19}(\gamma\ 2n)F^{17}$ $Q_m=-19.567$ (not illustrated)

See F^{19}.

O^{18}

The ground state J of O^{18} is zero (Mi 51b).

I. $C^{14}(\alpha\ p)N^{17}$ $Q_m=-9.8$ $E_b=6.238$ (not illustrated)

The excitation function rises smoothly from $E_\alpha=16$ Mev to a peak of 60 mb at $E_\alpha=27$ Mev (Su 51b).

Su 51b Sun, Jennings, Shoupp, and Allen, Phys. Rev. **82**, 267 (1951).

II. $O^{17}(n\ \alpha)C^{14}$ $Q_m=1.825$ $E_b=8.063$

The thermal cross section is 0.46±0.11 b (Ma 47).

Ma 47 May and Hincks, Can. J. Research **25**, 77 (1947).

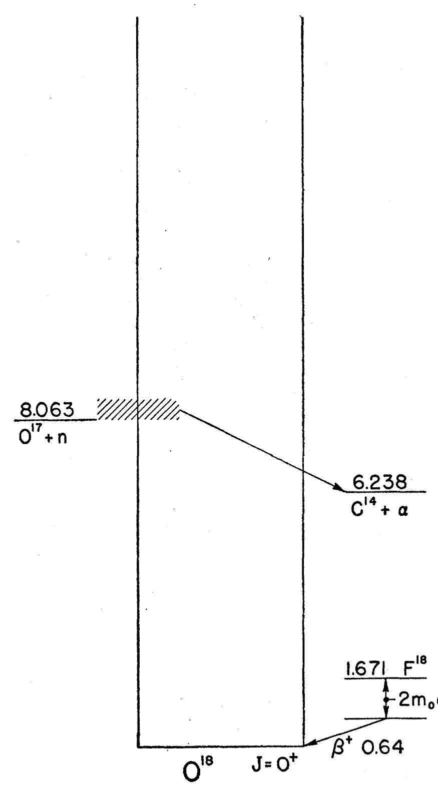

FIG. 26. Energy levels of O^{18}: for notation, see Fig. 1.

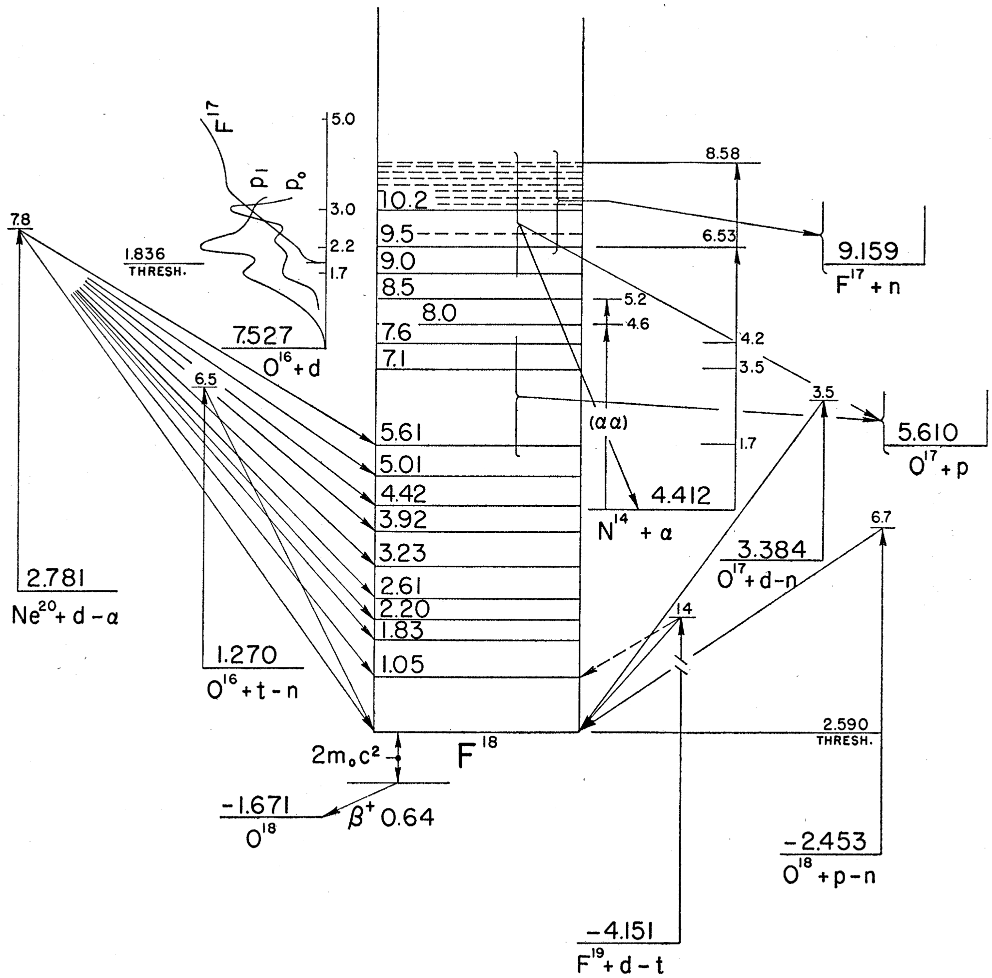

FIG. 27. Energy levels of F^{18}: for notation, see Fig. 1.

III. $O^{17}(n\ p)N^{17}$ $Q_m=-8.0$ $E_b=8.063$

(not illustrated)

The average cross section is 10 mb from $E_n=8$ to 29 Mev (Ch 49d).

Ch 49d Charpie, Sun, Jennings, and Nechaj, Phys. Rev. **76**, 1255 (1949).

TABLE I(18). Alpha-particle groups from $Ne^{20}(d\ \alpha)F^{18}$ (Mi 51d).

Q	F^{18*}
2.78±0.02	0
1.73±0.02	1.05
0.95±0.02	1.83
0.58±0.05	2.20
0.17±0.04	2.61
−0.45±0.07	3.23
−1.14±0.03	3.92
−1.64±0.10	4.42
−2.23±0.08	5.01
−2.83±0.10	5.61

IV. $O^{18}(\gamma\ p)N^{17}$ $Q_m=-16.1$ (not illustrated)

The peak cross section is 37 mb at 24±2 Mev. The integrated cross section is 0.15±0.1 Mev-b (St 51a).

St 51a Stephens, Halpern, and Sher, Phys. Rev. **82**, 511 (1951).

V. $F^{18}(\beta^+)O^{18}$ $Q_m=1.671$

See F^{18}.

F^{18}

I. $F^{18}(\beta^+)O^{18}$ $Q_m=1.671$

The positron end point is $E_\beta(\max)=635\pm15$ kev (Bl 49a), 649±9 kev (Ru 51). The spectrum is simple. The half-life is 112±1 min (Bl 49a): Log ft=3.62.

Bl 49a Blaser, Boehm, and Marmier, Phys. Rev. **75**, 1953 (1949).
Ru 51 Ruby and Richardson, Phys. Rev. **83**, 698 (1951).
See also: Ho 50b.

II. $N^{14}(\alpha\ \alpha)N^{14}$ $E_b=4.412$

Two narrow resonances are reported at $E_\alpha=4.6$ and 5.2 Mev ($\theta=90°$). The 5.2-Mev resonance may involve

d-wave α-particles (De 39a). The scattering at $\theta=53°$ to 104° has been studied for $E_\alpha=4$ to 7 Mev, and the resonance at 5.2 Mev verified by (Br 39).

De 39a Devons, Proc. Roy. Soc. (London) **172**, 127 (1939).
Br 39 Brubaker, Phys. Rev. **56**, 1181 (1939).

III. $N^{14}(\alpha\ p)O^{17}$ $Q_m=-1.198$ $E_b=4.412$

Resonances are reported for $E_\alpha \sim 1.7$, 3.5, and 4.2 Mev (see Ho 50b and Ro 51g). The angular distribution of the protons is isotropic for $E_\alpha \lesssim 3.0$ Mev. The distribution of the ground-state protons has the form $Y(\theta)=1-\cos^2\theta$ at $E_\alpha=3.6$ and 4.2 Mev. The distribution of the proton groups corresponding to the 0.87-Mev level of O^{17} remains isotropic at these energies. The yields at 3.6 Mev are 0.31 and 0.038×10^{-6} p/α, and at 4.2 Mev, 0.364 and 0.045×10^{-6} p/α for the ground and excited state transitions, respectively (Ro 51g).

TABLE I(19). Proton groups from $O^{16}(\alpha\ p)F^{19}$ (Bu 51c).

Q	F^{19*}
-8.08 ± 0.1	0
-9.44 ± 0.1	1.36 ± 0.05
-10.75 ± 0.1	2.67 ± 0.05
-12.00 ± 0.1	3.92 ± 0.05

The cross section is 60 mb at $E_\alpha=6$ Mev; a sharp decrease occurs above the $(\alpha\ n)$ threshold (Ha 35).

Ro 51g Roy, Phys. Rev. **82**, 227 (1951).
Ha 35 Haxel, Z. Physik **93**, 400 (1935).
See also: Ho 50b, Ch 52b.

IV. $N^{14}(\alpha\ n)F^{17}$ $Q_m=-4.747$ $E_b=4.412$

Eleven resonances, from $E_\alpha=6.53$ to $E_\alpha=8.58$ Mev, are reported by (Fu 38).

Fu 38 Fünfer, Ann. Physik **32**, 313 (1938).

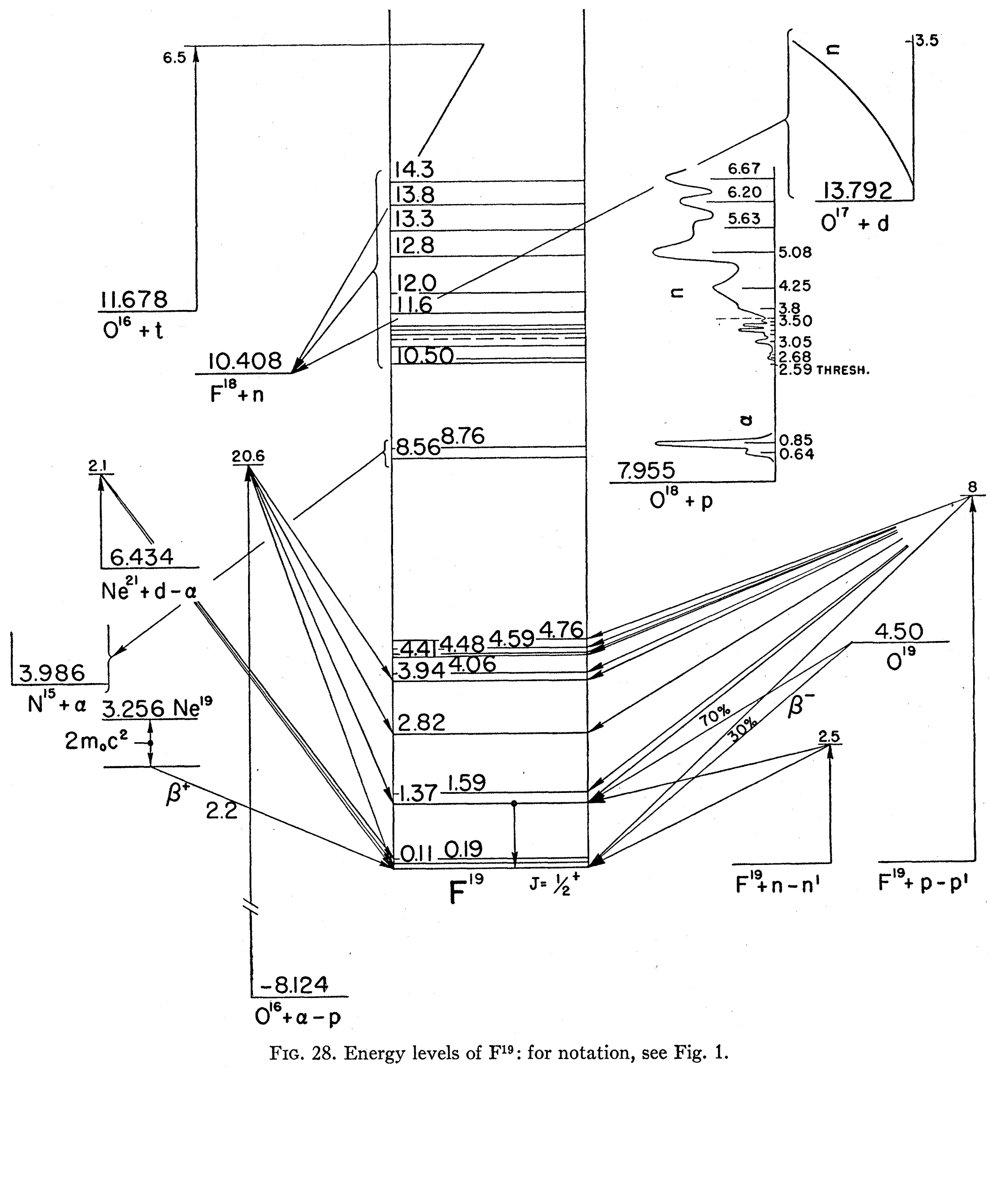

FIG. 28. Energy levels of F^{19}: for notation, see Fig. 1.

TABLE II(19). Resonances in $O^{18}(p\ n)F^{18}$.

E_{res} (Mev)[a]	σ (mb)	F^{19*}
2.68		10.49
2.78		10.59
3.05		10.84
(3.2)		(10.99)
3.29		11.07
3.40		11.18
3.50		11.27
3.3	50	
3.8	150	11.6
4.25	250	12.0
5.08	500	12.8
5.63	330	13.3
6.20	360	13.8
6.67	450	14.3

[a] The first seven values refer to thin target, forward neutron yields, reported by (Br 50b, Ri 50e): the remainder are obtained by the stacked-foil method (Bl 51a). Cross sections are estimated from the published curve of (Bl 51a).

V. $O^{16}(d\ \alpha)N^{14}$ $Q_m=3.116$ $E_b=7.527$

The differential cross section for the ground-state transition is 9 mb/sterad at $E_d=3.42$ Mev, $\theta=135°$ (Cr 52b).

See N^{14} and (Ho 50b).

Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).

VI. $O^{16}(d\ p)O^{17}$ $Q_m=1.918$ $E_b=7.527$

Resonances for both the ground- and the first excited state proton groups are observed at $E_d=1.7$, 2.2, and 3.0 Mev (He 48a).

For angular distributions: see O^{17}.

He 48a Heydenburg and Inglis, Phys. Rev. **73**, 230 (1948).
See also: Ho 50b.

VII. $O^{16}(d\ n)F^{17}$ $Q_m=-1.631$ $E_b=7.527$

The thin target excitation function for slow neutrons and for F^{17} production has been studied from $E_d=1.8$ to 2.08 Mev. The resonances observed in the proton yield (see $O^{16}(d\ p)O^{17}$) also influence the neutron yield in this region (Bo 51b). The excitation function for F^{17} production has been studied by (Ne 37b) for $E_d=2$ to 5 Mev. A change in slope is observed at $E_d=8$ Mev, $\sigma\simeq0.2$ b (Br 49).

For angular distributions: see F^{17}.

Bo 51b Bonner and Butler, Phys. Rev. **83**, 1091 (1951).
Ne 37b Newson, Phys. Rev. **51**, 620 (1937).
Br 49 Brown and Perez-Mendez, Phys. Rev. **75**, 1286 (1949).
See also: Ho 50b.

VIII. $O^{16}(t\ n)F^{18}$ $Q_m=1.270$

This reaction has been observed with 6.5-Mev tritons (Po 51).

Po 51 Pool, Kundu, Weiler, and Donaven, Phys. Rev. **82**, 305 (1951).
See also: Kn 45.

IX. $O^{16}(\alpha\ pn)F^{18}$ $Q_m=-18.53$ (not illustrated)

See (Te 47).

X. $O^{17}(d\ n)F^{18}$ $Q_m=3.384$

See F^{19}.

XI. $O^{18}(p\ n)F^{18}$ $Q_m=-2.453$

The threshold is 2.590 ± 0.004 Mev; $Q=-2.453\pm0.004$ (Ri 50e).

Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).

XII. $F^{19}(\gamma\ n)F^{18}$ $Q_m=-10.408$ (not illustrated)

See F^{19}.

XIII. $F^{19}(n\ 2n)F^{18}$ $Q_m=-10.408$ (not illustrated)

See F^{20}.

XIV. $F^{19}(d\ t)F^{18}$ $Q_m=-4.151$

See (Bo 50d, Sh 51a, Ho 50b).

XV. $Ne^{20}(d\ \alpha)F^{18}$ $Q_m=2.781$

Alpha-particle groups observed at $E_d=7.8$ Mev are listed in Table I(18) (Mi 51d).

Mi 51d Middleton and Tai, Proc. Phys. Soc. (London) **64A**, 801 (1951).

O^{19}

(not illustrated)

Mass of O^{19}

The observed beta end point, 4.5 ± 0.3 Mev (Bl 47a), yields a mass defect of 8.65 ± 0.3 Mev.

I. $O^{19}(\beta^-)F^{19}$ $Q_m=4.50$

The decay is complex: see F^{19}.

II. $O^{18}(n\ \gamma)O^{19}$ $Q_m=4.24$

The thermal cross section is 0.21 ± 0.04 mb (Hu 52e).

Hu 52e Hughes *et al.*, AECU 2040 (1952).
See also: Wa 50e.

TABLE III(19). Proton groups from $F^{19}(p\ p')F^{19*}$.

A		B
Q	σ(b)	Q
−1.49	0.11	−1.37
		−1.59
		−2.82
−3.90	0.025	−3.94
		−4.06
		−4.41
		−4.48
		−4.59
		−4.76

A: (Co 52g): $E_p=7.17$ Mev, $\theta=90°$, cross section for elastically scattered group is 0.36 b.
B: (Bender *et al.*, private communication): $E_p=8$ Mev.

III. $F^{19}(n\ p)O^{19}$ $Q_m=-3.72$

$Q=-3.9\pm0.75$ (Je 50d)

Je 50d Jelley and Paul, Proc. Phys. Soc. (London) **63A**, 112 (1950).

F^{19}

I. $O^{16}(t\ n)F^{18}$ $Q_m=1.270$ $E_b=11.678$

See (Ho 50b).

II. $O^{16}(\alpha\ p)F^{19}$ $Q_m=-8.124$

Proton groups observed at $E_\alpha=20.6$ Mev, $\theta=36°$ and 90°, are listed in Table I(19) (Bu 51c).

Bu 51c Bullock and Sampson, Phys. Rev. **84**, 967 (1951).

III. $O^{17}(d\ n)F^{18}$ $Q_m=3.385$ $E_b=13.792$

The excitation function exhibits only a smooth increase: the cross section at $E_d=3.45$ Mev is 77 mb (see Ho 50b).

IV. $O^{18}(p\ \alpha)N^{15}$ $Q_m=3.969$ $E_b=7.955$

The excitation function indicates a small resonance at $E_p=640$ kev (Se 51b) (680 kev, Mi 50e) and a ~30 kev broad one at 850 kev (Se 51b), superposed on what may be a third, broad resonance (levels of F^{19} at 8.56 and 8.76 Mev).

Se 51b Seed, Phil. Mag. **42**, 566 (1951).
Mi 50e Mileikowsky and Pauli, Nature **166**, 602 (1950).

V. $O^{18}(p\ n)F^{18}$ $Q_m=-2.453$ $E_b=7.955$

The threshold is 2.590 ± 0.004 Mev; $Q=-2.453$ (Ri 50e). Observed resonances are listed in Table II(19).

Br 50b Browne, Smith, and Richards, Phys. Rev. **77**, 754 (1950).
Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
Bl 51a Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).

VI. $O^{19}(\beta^-)F^{19}$ $Q_m=4.50$

The decay proceeds to the ground state, 30 ± 10 percent, $E_\beta(\max)=4.5\pm0.3$ Mev, and 70 percent to the 1.6-Mev excited state, $E_\beta(\max)=2.9\pm0.3$ Mev (Bl 47a). The half-life is 29 sec: log ft=5.55 (ground state) and 4.33 (1.6-Mev state) (Fe 51b).

Bl 47a Bleuler and Zunti, Helv. Phys. Acta **20**, 195 (1947).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
See also: Ho 50b.

VII. $F^{19}(\gamma\ n)F^{18}$ $Q_m=-10.408$

The cross section rises steeply from threshold to a value of ~2 mb at $E_\gamma=12$ Mev, remains almost constant for 3 Mev and then rises to a peak of 3.48 mb at $E_\gamma=20$ Mev. The half-width of the peak is 12.9 Mev (Ho 52a). The integrated cross section, to $E_\gamma=26$ Mev, is 39 Mev-mb (Ho 52a), to $E_\gamma=70$ Mev, is 110 Mev-mb (Ed 52a).

TABLE I(20). Resonances in F^{19} total neutron cross section.

E_{res} (kev)	Γ (kev)	σ_{max}(b)	F^{20*}
30[a]	~15	5.2	6.63
50	~10	9.5	6.65
105	15	17.2	6.70
275	30	10.0	6.86
340	~200	8.0	6.92
420	25	8.8	7.00
510	35	5.7	7.08
600	30	6.0	7.17
950		3.3	7.50
1240		3.0	7.78
1660		3.4	8.18
2040		3.2	8.54

[a] The first eight values are from (Bo 50f); the remainder are from (Wi 51, Hu 52e). Cross sections and widths estimated from published curves.

Ho 52a Horsley, Haslam, and Johns, Phys. Rev. **87**, 756 (1952).
Ed 52a Edwards and MacMillan, Phys. Rev. **87**, 377 (1952).

VIII. $F^{19}(\gamma\ 2n)F^{17}$ $Q_m=-19.567$ (not illustrated)

The cross section rises smoothly from threshold to a peak of 0.66 mb at $E_\gamma=26$ Mev. The integrated cross-section to 26 Mev is 2.4 Mev-mb (Ho 52a).

Ho 52a Horsley, Haslam, and Johns, Phys. Rev. **87**, 756 (1952).

IX. $F^{19}(n\ n')F^{19*}$

A gamma-ray of energy 1.3 ± 0.1 Mev is observed in the inelastic scattering of 2.5-Mev neutrons. The cross section is 0.52 ± 0.18 b (Gr 51a).

Gr 51a Grace, Beghian, Preston, and Halban, Phys. Rev. **82**, 969 (1951).
See also: Be 50a.

X. $F^{19}(p\ p')F^{19*}$

Inelastically scattered proton groups are listed in Table III(19).

Co 50g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).

XII. $Ne^{19}(\beta^+)F^{19}$ $Q_m=3.256$

See Ne^{19}.

XIII. $Ne^{21}(d\ \alpha)F^{19}$ $Q_m=6.434$

$Q=6.432\pm0.010$ (Mi 52, separated Ne^{21} target, magnetic spectrometer). Two other α-particle groups correspond to excited states at 113 ± 8 and 192 ± 12 kev (Mi 52).

Mi 52 Mileikowsky and Whaling (to be published).

Ne^{19}

(not illustrated)

I. $Ne^{19}(\beta^+)F^{19}$ $Q_m=3.256$

The positron end point is 2.18 ± 0.03 Mev: no γ-rays of energy greater than 0.51 Mev are observed. The

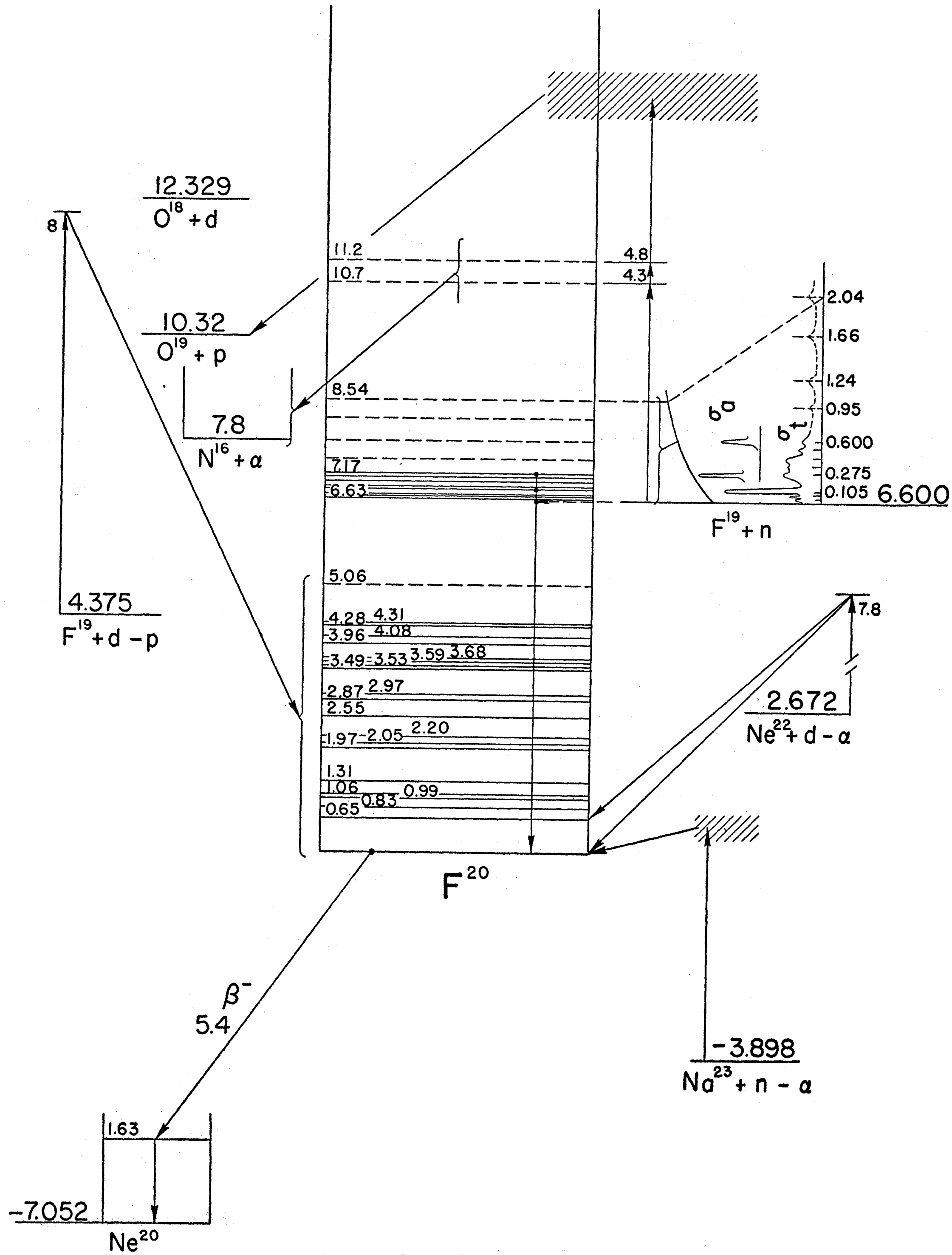

FIG. 29. Energy levels of F^{20}: for notation, see Fig. 1.

half-life is 18.5±0.5 sec (Sc 52a), 20.3±0.5 sec (Wh 39). Log ft=3.30.

Sc 52a Schrank and Richardson, Phys. Rev. **86**, 248 (1952).
Wh 39 White, Delsasso, Fox, and Creutz, Phys. Rev. **56**, 512 (1939).

See also: Bl 46.

II. $O^{16}(\alpha\ n)Ne^{19}$ $Q_m=-12.172$

See (Te 47).

III. $F^{19}(p\ n)Ne^{19}$ $Q_m=-4.038$

The threshold is 4.253±0.005 Mev; $Q=-4.039$ (Wi 52a).

Wi 52a Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).

F^{20}

I. $F^{20}(\beta^-)Ne^{20}$ $Q_m=7.052$

See Ne^{20}.

II. $F^{19}(n\ n)F^{19}$ $E_b=6.600$

The coherent scattering cross section is 3.8±0.3 b: the total cross section (epithermal, bound) is 4.0±0.1 b (Hu 52e).

Resonances in the total cross section are listed in Table I(20). The 105-kev resonance is assumed to arise from s-wave neutrons, forming a state of $J=1$, with a reduced width $\gamma^2=0.09\times10^{-13}$ Mev-cm (Bo 50f), or 0.006 of the sum-rule limit (Te 52).

The cross section at $E_n=14$ Mev is 1.70±0.05 b (Co 52h).

Hu 52e Hughes *et al.*, AECU 2040 (1952).
Bo 50f Bockelman, Phys. Rev. **80**, 1011 (1950).
Wi 51 Willard, Preston, and Goodman, Phys. Rev. **81**, 329A (1951).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
Co 52h Coon, Graves, and Barschall, Phys. Rev. (to be published).
See also: Ad 50, Wa 50e, Wa 51e, Sh 51b.

III. $F^{19}(n\ 2n)F^{18}$ $Q_m=-10.408$ $E_b=6.600$

(not illustrated)

See: (Wa 50f, Co 51, Ho 50b).

IV. $F^{19}(n\ \gamma)F^{20}$ $Q_m=6.600$

The thermal cross section is 9.4±2 mb (Se 47). A gamma-ray of energy 6.63±0.03 Mev is observed, with an intensity of 0.35±0.10 photon per capture: lower energy γ-rays could not be detected because of a relatively large background (Ki 51a: pair spectrometer). It is pointed out that the high intensity of the ground-state transition is somewhat anomalous in view of the large number of low-lying excited levels in F^{20} (Ki 51a).

Two resonances are observed, at $E_n=280$ and 590 kev, with widths ~20 kev and peak cross sections of 1.2 and 1.0 mb, respectively. Comparison with the total cross section (see $F^{19}(n\ n)F^{19}$) at the same resonances yields a radiation width of ~15 ev. No capture resonances are found corresponding to the maxima at $E_n=340$ and 510 kev observed in the total cross section (He 50b).

Se 47 Seren, Friedlander, and Turkel, Phys. Rev. **72**, 888 (1947).
Ki 51a Kinsey, Bartholomew, and Walker, Phys. Rev. **83**, 519 (1951).
He 50b Henkel and Barschall, Phys. Rev. **80**, 145 (1950).

TABLE II(20). Proton groups from $F^{19}(d\ p)F^{20}$.

A F^{20*}	B F^{20*}	C F^{20*}	D F^{20*}	Rel. intens.
0.63	0.64±0.03	0.69	0.652±0.008	2.3
0.83			0.828±0.008	0.18
1.00	0.97±0.05	0.98	0.988±0.008	0.44
			1.059±0.008	1.2
1.37	1.31±0.05		1.309±0.008	0.38
	1.91±0.04		1.970±0.008	0.25
			2.048±0.008	2.0
		2.20	2.195±0.008	0.85
2.55	2.52±0.04			
2.91	2.83±0.04	2.70	2.870±0.008	0.53
		3.12	2.966±0.008	1.2
3.49	3.45±0.03		3.491±0.008	4.6
			3.528±0.008	1.3
			3.586±0.008	0.37
		3.74	3.681±0.008	0.18
			3.961±0.009	0.61
4.06	4.01±0.15		4.079±0.009	3.0
			4.275±0.009	0.50
4.31		4.41	4.310±0.009	3.2
4.73			(5.062±0.011)	

A: Bu 51f: Range in photoplate. Probable errors, 0.05 Mev. $E_d=8$ Mev.
B: Al 51d: Range in Al: $E_d=3.76$ Mev, $\theta=90°$.
C: Sh 51a: preliminaty results, magnetic analysis: $E_d=10.3$, $\theta=90°$.
D: Wa 52b: magnetic spectrometer: $E_d=1.8$ Mev, $\theta=90°$. Rel. intens. of ground-state group =1.0.

TABLE III(20). Resonances in $F^{19}(p\ n)Ne^{19}$ (Wi 52a).

E_{res} (Mev)	Γ(kev)	Ne^{20*}
4.29	45	16.95
4.46	80	17.11
4.49	20	17.14
4.57	20	17.21
4.62	60	17.26
4.71	25	17.35
4.78	45	17.41
4.99	20	17.61
5.07	30	17.69
5.20	70	17.81

V. $F^{19}(n\ \alpha)N^{16}$ $Q_m=-1.2$ $E_b=6.600$

Levels at $E_n=4.3$ and 4.8 Mev are reported (Wi 37e). See also (Ho 50b).

Wi 37e Wilhelmy, Z. Physik **107**, 769 (1937).
See also: Ho 50b, Wi 51.

VI. $F^{19}(n\ p)O^{19}$ $Q_m=-3.72$ $E_b=6.600$

See (Ho 50b).

VII. $F^{19}(d\ p)F^{20}$ $Q_m=4.375$

$Q=4.373\pm0.007$ (St 51: mag. spectrometer)

Energy levels of F^{20} derived from the proton groups are reported in Table II(20).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Bu 51f Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **209**, 478 (1951).
Al 51d Allen and Rall, Phys. Rev. **81**, 60 (1951).
Sh 51a Shull, Phys. Rev. **83**, 875A (1951).
Wa 52b Watson, Phys. Rev. **87**, 215A (1952) and MIT Progress Rept. (LNSE) February and May, 1952; and Watson and Buechner, Phys. Rev. (to be published).
See also: Ne 50a, Ne 50b, Je 50e.

VIII. $Ne^{22}(d\ \alpha)F^{20}$ $Q_m = 2.672$

Alpha-particle groups with $Q = 2.62 \pm 0.10$ and 2.05 ± 0.07, corresponding to the ground state and a level at 0.57 ± 0.13 Mev, are observed (Mi 51d).

Mi 51d Middleton and Tai, Proc. Phys. Soc. (London) **64A**, 801 (1951).

IX. $Na^{23}(n\ \alpha)F^{20}$ $Q_m = -3.898$

See (Je 50d).

Ne^{20}

I. $O^{16}(\alpha\ \alpha)O^{16}$ $E_b = 4.746$

Scattering anomalies indicate levels at 9.0 and 10.1 Mev (Fe 40). Recent work, with $E_\alpha = 1.0$ to 4.0 Mev, indicates *s*-waves resonances corresponding to levels at 6.75 and 7.23 Mev, an *f*-wave resonance leading to a level at 7.19 Mev, and *d*-wave resonances corresponding to levels at 7.46 and 7.87 Mev (J. R. Cameron, private communication).

Fe 40 Ferguson and Walker, Phys. Rev. **58**, 666 (1940).

II. $O^{16}(\alpha\ p)F^{19}$ $Q_m = -8.124$ $E_b = 4.746$

See F^{19}.

III. $O^{16}(\alpha\ pn)F^{18}$ $Q_m = -18.53$ (not illustrated)

See (Te 47).

IV. $F^{19}(p\ \gamma)Ne^{20}$ $Q_m = 12.870$

A resonance for capture radiation occurs at $E_p = 669$ kev with a yield of 2 percent of the 6- to 7-Mev radiation (De 48c). The observed γ-ray energy is 12.0 ± 0.2 Mev (Ra 50b), 12.09 ± 0.21 Mev (Ca 51a), indicating transition to a state of Ne^{20} at $\sim$1.5 Mev. No other

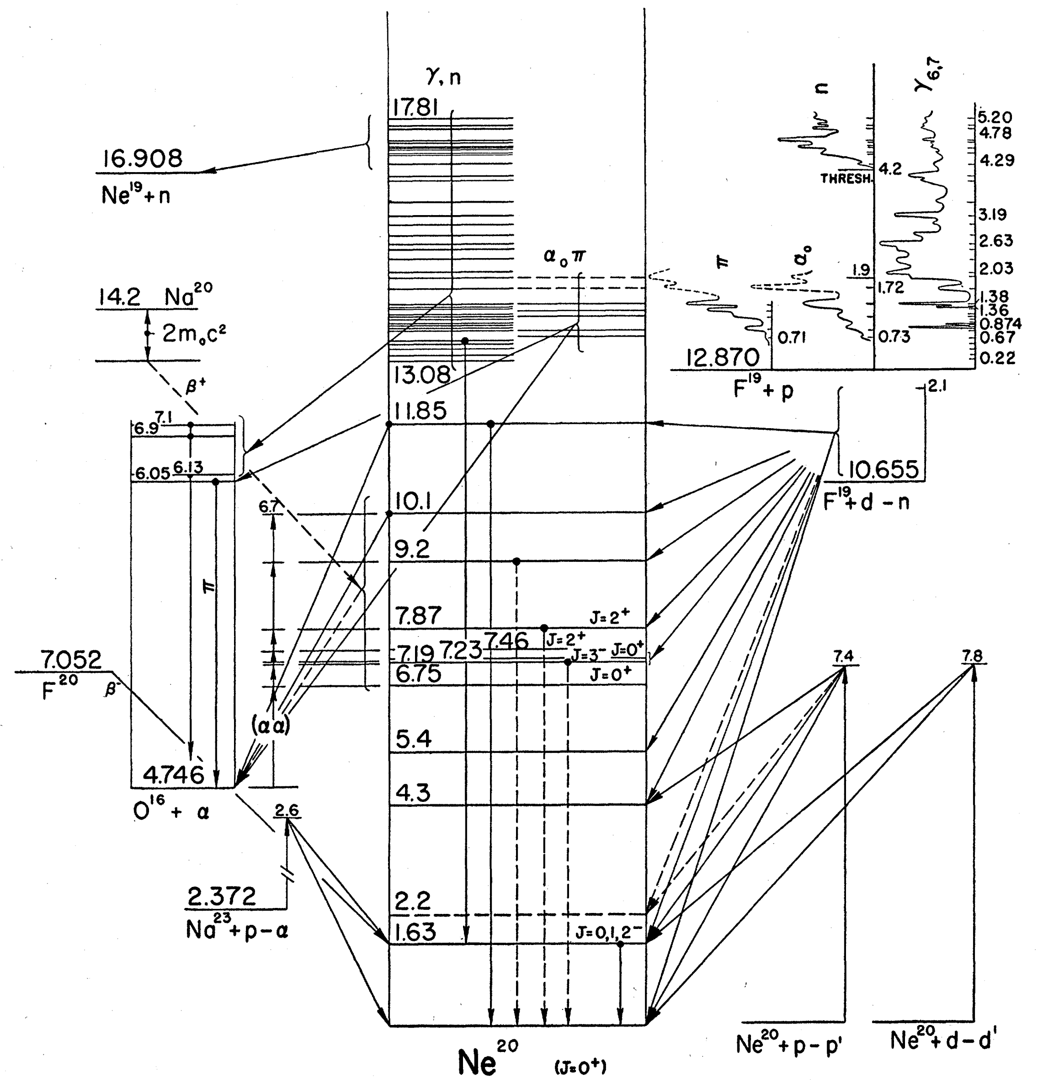

FIG. 30. Energy levels of Ne^{20}: for notation, see Fig. 1.

TABLE IV(20). Gamma-ray resonances.[a]

E_p (Mev)	Yield[b]	Γ (kev)	Ne^{20*}
0.2244[c]	0.0002	<1	13.083
0.3404[d]	0.174	2.3	13.193
0.4831[c]	0.054	2.2	13.329
0.598	0.27	37	13.438
0.669	0.48	7.5	13.505
0.831	0.2	8.3	13.659
0.8735[e]	3.7	5.2	13.700
0.900	0.15	4.8	13.725
0.9353	2.0	8.0	13.759
1.092	0.024	<1.2	13.907
1.137	0.1	3.7	13.950
1.176	3.9	~130	13.987
1.290	0.92	19.2	14.096
1.355	1.37	8.6	14.157
1.381	8.2	15.0	14.182
1.69[f]		30	14.48
1.94		15	14.71
2.03		60	14.80
2.32		85	15.07
2.51		30	15.25
2.63		90	15.37
2.80		60	15.53
3.02		30	15.74
3.19		80	15.90
3.49		40	16.19
3.92		30	16.59
4.00		110	16.67
4.29		50	16.95
4.49		30	17.14
4.57		30	17.21
4.71		30	17.35
4.78		35	17.41
4.99		20	17.61
5.07		35	17.69
5.20		70	17.81

[a] From (Ch 50, Wi 52a, Hu 52f, Hu 52g).
[b] Number of quanta per 10^7 protons; the measured α-particle yields at $\theta=138°$ average 0.92 of these values; see (Ch 50).
[c] (Hu 52f, Hu 52g): absolute electrostatic analyzer, ±0.5 kev.
[d] (Mo 49a, Hu52f).
[e] (He 49): absolute electrostatic analyzer, ±0.8 kev.
[f] Above $E_p=1.69$ Mev, all values are from (Wi 52a). Those above 4.2 Mev appear also in $F^{19}(p\ n)Ne^{19}$ (Wi 52a).

resonances appear for $E_p<1$ Mev (De 48c) and most of the radiation observed for $E_p=2$ to 5.3 Mev is from $F^{19}(p\ \alpha)O^{16}$ (Wi 52a). It is not clear wherein the 669-Mev level differs from other $J=1^+$ levels at $E_p=340$ and 935 kev (Fr 52c: see $F^{19}(p\ \alpha)O^{16}$).

De 48c Devons and Hereward, Nature **162**, 331 (1948).
Ra 50b Rae, Rutherglen, and Smith, Proc. Phys. Soc. (London) **63A**, 775 (1950).
Ca 51a Carver and Wilkinson, Proc. Phys. Soc. (London) **64A**, 199 (1951).
Wi 52a Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).
Fr 52c French and Seed (to be published).

V. $F^{19}(p\ n)Ne^{19}$ $Q_m=-4.038$ $E_b=12.870$

Resonances observed by (Wi 52a) are listed in Table III(20). All these resonances except the two at $E_p=4.46$ and 4.62 Mev occur also in the γ-ray yield from $F^{19}(p\ \alpha)O^{16}$. Broad resonances, observed by the stacked-foil method, are reported at $E_p=4.84$, 5.41, 5.78, 6.09, and 6.47 Mev (Bl 51a).

Wi 52a Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).
Bl 51a Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).

VI. $F^{19}(p\ \alpha)O^{16}$ $Q_m=8.118$ $E_b=12.870$

Five α-particle groups result from this reaction: all show resonance effects, with relative intensities varying greatly with bombarding energy. The long-range group leaves O^{16} in the ground state; the next longest results in the formation of a pair-emitting state at 6.05 Mev (see O^{16}) while the three remaining groups result in γ-radiation of 6.13, 6.9, and 7.1-Mev, respectively. Resonances for γ-rays are listed in Table IV(20). Spin and parity assignments have been established for several of the levels indicated by γ-ray resonances: see O^{16}.

Reported resonances for nuclear pairs and long-range α-particles are given in Tables V(20) and VI(20). Earlier reported pair resonances near $E_p=730$ and 1630 kev are not confirmed by (Ph 51a). There appear to be some differences between the pair and long-range α-particle excitation functions, particularly in the relative heights of the 1.7- and 1.9-Mev resonances: further work on the angular distributions may shed some light on this question (E. B. Paul and R. L. Clarke, private communication).

For angular distributions and correlations, see O^{16}.

Ch 50 Chao, Tollestrup, Fowler, and Lauritsen, Phys. Rev. **79**, 108 (1950).
Wi 52a Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).
Hu 52f Hunt (to be published).
Hu 52g Hunt and Jones (to be published).
Mo 49a Morrish, Phys. Rev. **76**, 1651 (1949).
He 49 Herb, Snowden, and Sala, Phys. Rev. **75**, 246 (1949).
Ph 51a Phillips and Heydenburg, Phys. Rev. **83**, 184 (1951).
See also: Ra 50, Ch 50a, Fr 50e, Ho 50b, St 51g.

TABLE V(20). Nuclear pair resonances in $F^{19}(p\ \alpha)O^{16}$.[a]

E_p (Mev)	Yield[b]	Γ (kev)[c]	Ne^{20*}
0.710		35	13.545
0.842	0.048	24	13.670
1.130	0.089	43	13.944
1.236	0.31	58	14.044
1.367	0.39	26	14.169
(1.40)	0.85	~1000[d]	14.20
1.63[e]			14.42
1.73			14.51
1.87			14.65
2.20			14.96

[a] From (Ch 50), (Perry and Day, private communication), (Ph 51a).
[b] Thick Ca F_2 target yield per 10^7 protons: (Ch 50).
[c] From (Ph 51a).
[d] Ch 50.
[e] Not confirmed by (Ph 51a).

TABLE VI(20). Long-range α-particle resonances in $F^{19}(p\ \alpha)O^{16}$ (Ch 50).

E_p (Mev)	Yield[a]	Γ (kev)	Ne^{20*}
0.730	0.008	~30	13.564
0.850	0.006	~30	13.678
~1.10	0.06	~60	13.92
1.38	0.14	~25	14.18
(1.40)	0.5	~1000	14.20
1.40[b]		~50	
1.72[b]		~50	
1.92[b]		~75	

[a] Thick CaF_2 target yield per 10^7 protons.
[b] Paul and Clarke (private communication).

VII. $F^{19}(d\ n)Ne^{20}$ $Q_m = 10.655$

Neutron groups corresponding to levels at 1.5, 2.2, 4.2, 5.4, 7.1, 7.8, 9.0, and 10.1 Mev are reported (Bo 40b, Po 42). A level at 9.7 Mev, possibly to be identified with the 10.1-Mev level, is observed to decay by α-particle emission (Fr 50d) as is also a level at 11.85 Mev (Wa 52b). Observed gamma-rays are listed in Table VII(20) (Te 51a).

The angular distribution of ground-state neutrons, observed at $E_d = 4$ Mev, is consistent with s-wave proton capture, indicating that F^{19} and Ne^{20} have the same parity (Br 52b).

Bo 40b Bonner, Phys. Rev. **174**, 339 (1940).
Po 42 Powell, Proc. Roy. Soc. (London) **181**, 344 (1942).
Fr 50d French, Meyer, and Treacy, Proc. Phys. Soc. (London) **63A**, 666 (1950).
Wa 52b Watson and Buechner (to be published).
Te 51a Terrell and Phillips, Phys. Rev. **83**, 703 (1951).
Br 52b Bromley, Univ. of Rochester Rept., NYO 3211 (1952).
Be 41c Bennett, Bonner, and Watt, Phys. Rev. **59**, 793 (1941).

VIII. $F^{20}(\beta^-)Ne^{20}$ $Q_m = 7.052$

The decay appears to go mainly, if not entirely, to an excited state of Ne^{20}. Recently reported values of the transition energies are (in Mev):

$E_\beta(\max) = 5.33 \pm 0.05$, $E_\gamma = 1.63 \pm 0.02$, $Q = 6.96 \pm 0.06$ (Li 50).

$E_\beta(\max) = 5.406 \pm 0.017$, $E_\gamma = 1.631 \pm 0.006$, $Q = 7.038 \pm 0.018$ (Al 52a).

The relative intensity of the ground-state transition is given as 3.5 percent by (Li 50); (Al 52a), however, places an upper limit of 1 percent on any such transition. The Fermi plot is straight down to $E_\beta \sim 1$ Mev (Wong and Mackin, private communication). The half-life is 10.7 ± 0.2 sec (Sn 50), 12.1 ± 0.1 sec (Je 50e); log ft = 4.99.

TABLE VII(20). Gamma-rays from $F^{19} + d$ (Te 51a).

E_γ (Mev)	Yield[a]
6.7 ± 0.3[b]	
8.1 ± 0.4	0.5
9.3 ± 0.3	1.1
11.5 ± 0.4	0.2

[a] Yield in 10^6 quanta per microcoulomb at $E_d = 1.56$ Mev.
[b] (Be 41c).

TABLE I(21). $Ne^{20}(n\ \alpha)O^{17}$ resonances.

A		B		
E_n (Mev)	σ (mb)	E_n (Mev)	σ (mb)	Ne^{21*}
		2.12	5	8.77
2.47	20	2.45	42	9.09
		2.62	20	9.25
		2.72	25	9.35
2.96	17	2.87	120	9.49
3.4	>40	3.26	160	9.86

A: $D(d\ n)$ neutrons (Si 50).
B: $H^3(p\ n)$ neutrons (Jo 51e).

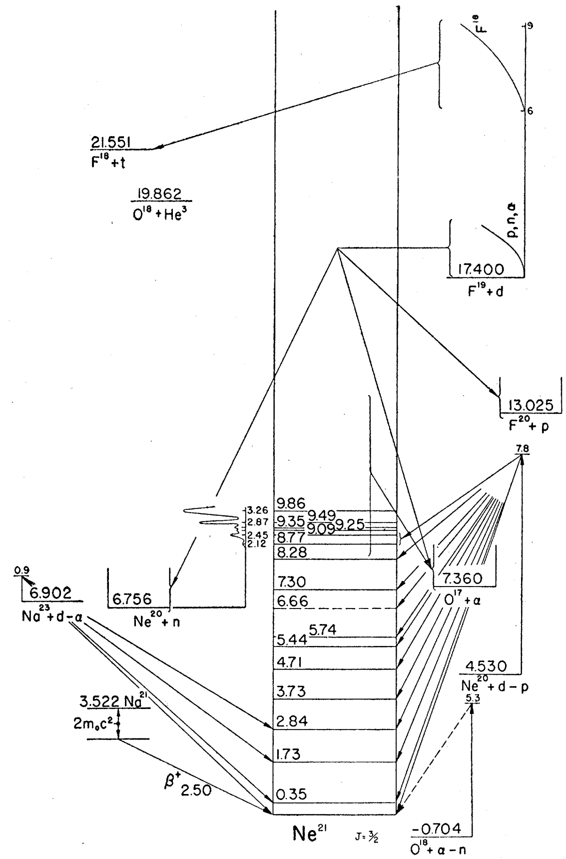

FIG. 31. Energy levels of Ne^{21}: for notation, see Fig. 1.

Li 50 Littauer, Phil. Mag. **41**, 1214 (1950).
Al 52a Alburger, Phys. Rev. (to be published).
Sn 50 Snell, Barker, and Sternberg, Phys. Rev. **80**, 637 (1950).
Je 50e Jelley, Phil. Mag. **41**, 1199 (1950).

IX. $Ne^{20}(p\ p')Ne^{20*}$

At $E_p = 7.37$ Mev, $\theta = 90°$, proton groups are observed corresponding to states at 0, 1.44, and 4.36 Mev, with cross sections of 0.48, 0.30, and 0.019 b, respectively (Co 52g). A group with $Q = -2$ Mev reported by (He 47) may also be associated with Ne^{20} (see Ne^{22}).

Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).
He 47 Heitler, May, and Powell, Proc. Roy. Soc. (London) **190**, 180 (1947).

X. $Ne^{20}(d\ d')Ne^{20*}$

An inelastically scattered deuteron group, observed at $E_d = 7.8$ Mev, yields a level energy of 1.66 ± 0.02 Mev (Mi 51d). The angular distribution, analyzed by a procedure analogous to that used in the stripping process, indicates $J = 0$, 1, or 2 and odd parity for the excited state (Hu 51b).***

*** *Note added in proof:* Spin zero is excluded by the observation of a gamma-ray transition to the ground state in the decay of F^{20} and in $F^{19}(p\ \gamma)Ne^{20}$: see Middleton and Tai, Proc. Phys. Soc. (London) **65A**, 752 (1952) and Jones and Wilkinson, Proc. Phys. Soc. (to be published).

Mi 51d Middleton and Tai, Proc. Phys. Soc. (London) **64A**, 801 (1951).
Hu 51b Huby and Newns, Phil. Mag. **42**, 1442 (1951).

XI. $Na^{20}(\beta^+)Ne^{20}$ $Q_m=15.3$

The threshold for $Ne^{20}(p\ n)Na^{20}$ is 16.9 Mev (Al 50g): the mass defect of Na^{20} is then 14.2 ($\pm$0.5) Mev which implies that Na^{20} is $\sim$0.8 Mev stable with respect to $Ne^{19}+p$.

The decay proceeds to excited states of Ne^{20} between 6.8 and 10.8 Mev which decay by α-particle emission (Al 50g). The half-life is 0.23$\pm$0.08 sec (Sh 51c), 0.385$\pm$0.01 sec (A. C. Birge, private communication).

Al 50g Alvarez, Phys. Rev. **80**, 519 (1950).
Sh 51c Sheline, Phys. Rev. **82**, 954 (1951).

XII. $Na^{23}(p\ \alpha)Ne^{20}$ $Q_m=2.372$

The ground-state Q is 2.372$\pm$0.008 (Va 52: mag. spectrometer), 2.3795$\pm$0.003 (Do 52a).

A gamma-ray of energy 1.63$\pm$0.02 Mev attributed to this reaction has been observed (St 52d), as have alphas corresponding to a first excited state of Ne^{20} at 1.634$\pm$0.004 Mev. (Do 52a).

Va 52 Van Patter, Sperduto, Endt, Buechner, and Enge,
Do 52a Donahue, Ph.D. thesis, University of Wisconsin (1952).
St 52d Stelson, Preston, and Goodman, Phys. Rev. **86**, 629 (1952).

Ne^{21}

I. $O^{18}(\alpha\ n)Ne^{21}$ $Q_m=-0.704$

See (Ho 50b).

II. $F^{19}(d\ \alpha)O^{17}$ $Q_m=10.040$ $E_b=17.400$

The excitation function shows a smooth rise to $E_d=0.9$ Mev (Bu 38).

Bu 38 Burcham and Smith, Proc. Roy. Soc. (London) **168**, 176 (1938).

III. $F^{19}(d\ p)F^{20}$ $Q_m=4.375$ $E_b=17.400$

The excitation function rises smoothly from $E_d=0.7$ to 1.8 Mev: the cross section is $\sim$10 mb at 1 Mev and $\sim$48 mb at 2 Mev (Sn 50a).

Sn 50a Snowdon, Phys. Rev. **78**, 299 (1950).

IV. $F^{19}(d\ n)Ne^{20}$ $Q_m=10.645$ $E_b=17.400$

The cross section for forward neutrons rises smoothly from $E_d=0.5$ to 2.0 Mev. No slow neutron thresholds are observed (Bu 52c).

Bu 52c Butler, Phys. Rev. **85**, 743 (1952).
See also: Tu 51.

V. $F^{19}(d\ t)F^{18}$ $Q_m=-4.151$ $E_b=17.400$

The cross section rises smoothly from $E_d\sim6$ Mev to 9 Mev: $\sigma=3.9\pm0.4$ mb at $E_d=8.8$ Mev (Kr 41).

Kr 41 Krishnan, Nature **148**, 407 (1941).
See also: Bo 50d.

VI. $Ne^{20}(n\ n)Ne^{20}$ $E_b=6.756$

The total cross section for thermal neutrons is 2.79 $\pm$0.14 b (Ca 41): the scattering cross section is 2.4$\pm$0.2 b (Ha 50f).

Ca 41 Carroll, Phys. Rev. **60**, 702 (1941).
Ha 50f Harris, Phys. Rev. **80**, 20 (1950).
See also: Hu 52e.

VII. $Ne^{20}(n\ \alpha)O^{17}$ $Q_m=-0.603$ $E_b=6.756$

Resonances observed with monochromatic neutrons are indicated in Table I(21). For $E_n<3.3$ Mev, only the ground state of O^{17} is involved (Jo 51e). Several resonances for α-particle production, observed with a continuous neutron spectrum, have been reported up to $E_n=6.8$ Mev (see Ho 50b).

Jo 51e Johnson, Bockelman, and Barschall, Phys. Rev. **82**, 117 (1951).
Si 50 Sikkema, Nature **165**, 1016 (1950).
See also: Ho 50b.

VIII. $Ne^{20}(d\ p)Ne^{21}$ $Q_m=4.530$

Recently reported values for the ground-state Q are:

$Q=4.529\pm0.007$ (Va 52: mag. spectrometer)
$Q=4.54\ \pm0.04$ (Mi 51d: photoplate)

Levels derived from proton group observations are listed in Table II(21).†††

Va 52 Van Patter, Sperduto, Endt, Buechner, and Enge, Phys. Rev. **85**, 142 (1952).
Mi 51d Middleton and Tai, Proc. Phys. Soc. (London) **64A**, 801 (1951).
Sp 51 Sperduto, Buechner, and Van Patter, M.I.T. Progress Report (May, 1951).
Zu 50a Zucker and Watson, Phys. Rev. **78**, 14 (1950).
See also: Ho 50b.

IX. $Na^{21}(\beta^+)Ne^{21}$ $Q_m=3.522$

The positron end point is E_β(max)$=2.50\pm0.03$ Mev; no γ-radiation above $E_\gamma=0.51$ Mev is observed (Sc 52a). The half-life is 22.8$\pm$0.5 sec (Sc 52a);

TABLE II(21). Proton groups from $Ne^{20}(d\ p)Ne^{21}$.

A: Ne^{21*} (Mev)	B: Ne^{21*} (Mev)	C: Ne^{21*} (Mev)
0.352$\pm$0.012	0.34$\pm$0.07	0.33$\pm$0.05
	1.80$\pm$0.06	1.68$\pm$0.07
	2.85$\pm$0.07	2.79$\pm$0.05
		3.73$\pm$0.06
		4.71$\pm$0.05
		5.44$\pm$0.05
		5.74$\pm$0.05
		(6.66$\pm$0.09)
		7.30$\pm$0.06
		8.28$\pm$0.06
		8.91$\pm$0.06

A: (Sp 51 and Van Patter, private communication); $E_d=1.8$ Mev, $\theta=90°$.
B: (Zu 50a): $E_d=2.9$ Mev, $\theta=90°$. Since the ground-state group does not appear to be clearly resolved, we have used Q_m in computing the level energies.
C: (Mi 51d): $E_d=7.8$ Mev, $\theta=30°$ to 150°.

††† *Note added in proof:* Assignments of spin and parity have been made for eight levels; see Middleton and Tai, Proc. Phys. Soc. (London) **64A**, 752 (1952).

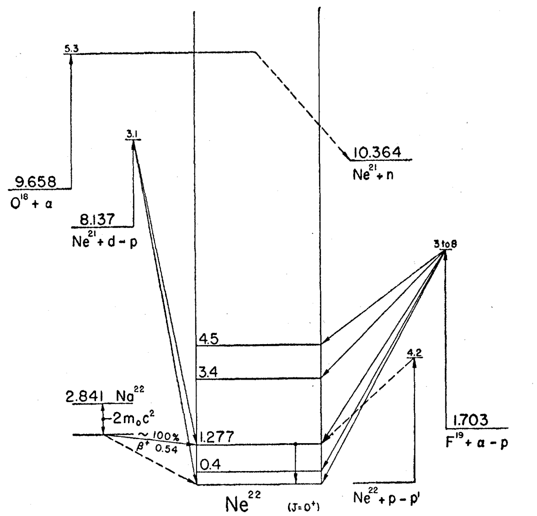

FIG. 32. Energy levels of Ne^{22}: for notation, see Fig. 1.

log ft = 3.56. There appears to be a discrepancy of ~0.4 Mev between the mass of Na^{21} indicated by this measurement and that given by the Q of $Ne^{20}(d\,n)Na^{21}$ (Sw 52).

Sc 52a Schrank and Richardson, Phys. Rev. **86**, 248 (1952).
Sw 52 Swann and Mandeville, Phys. Rev. **87**, 215A (1952).
See also: Po 40b.

X. $Na^{23}(d\,\alpha)Ne^{21}$ $Q_m = 6.902$

$Q = 6.902 \pm 0.010$ (St 51)

Alpha-particle groups observed by (Fr 51d) and (Sp 51a) are given in Table III(21).

St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
Fr 51d French and Thomson, Proc. Phys. Soc. (London) **64A**, 203 (1951).
Sp 51a Sperduto, M.I.T. Progress Report (LNSE) (May, 1951).
See also: Ho 50b.

Ne^{22}

I. $O^{18}(\alpha\,n)Ne^{21}$ $Q_m = -0.704$ $E_b = 9.658$

See (Ho 50b).

II. $F^{19}(\alpha\,p)Ne^{22}$ $Q_m = 1.703$

Levels at 0, 0.4±0.1, and 1.41±0.1 Mev are reported by (Jo 51f). Earlier work (see Ho 50b) indicated levels at 0.60, 1.1, 3.4, and 4.5 Mev.

TABLE III(21). Alpha-particle groups from $Na^{23}(d\,\alpha)Ne^{21}$.

A: Q (Mev)	B: Q (Mev)	Ne^{21*}
6.84±0.05	6.902±0.010	0
6.46±0.04	6.559±0.010	0.343±0.010
5.09±0.04	5.164±0.015	1.735±0.016
4.08±0.06	4.047±0.020	2.852±0.021

A: (Fr 51d): E_d = 0.83 to 0.93 Mev: range measurements.
B: (Sp 51a and Van Patter, private communication): E_d = 2.0 Mev: magnetic spectrometer.

Jo 51f Jolley and Champion, Proc. Phys. Soc. (London) **64A**, 88 (1951).
See also: Ho 50b.

III. $Ne^{21}(d\,p)Ne^{22}$ $Q_m = 8.137$

$Q = 8.137 \pm 0.011$ (Mi 52: separated target, mag. spectrometer).

A proton group of $Q = 6.97 \pm 0.1$ Mev, corresponding to a level at 1.17 Mev, is observed by (Zu 50a). (Am 50) find a level energy of 1.39 Mev.

Mi 52 Mileikowsky and Whaling, Phys. Rev. (to be published).
Zu 50a Zucker and Watson, Phys. Rev. **78**, 14 (1950).
Am 50 Ambrosen and Bisgaard, Nature **165**, 888 (1950).

IV. $Ne^{22}(p\,p')Ne^{22*}$

Inelastically scattered protons from neon may be associated with levels of Ne^{22} at ~0.9 and ~2.0 Mev (He 47). [It is also possible that the second value refers to Ne^{20}.]

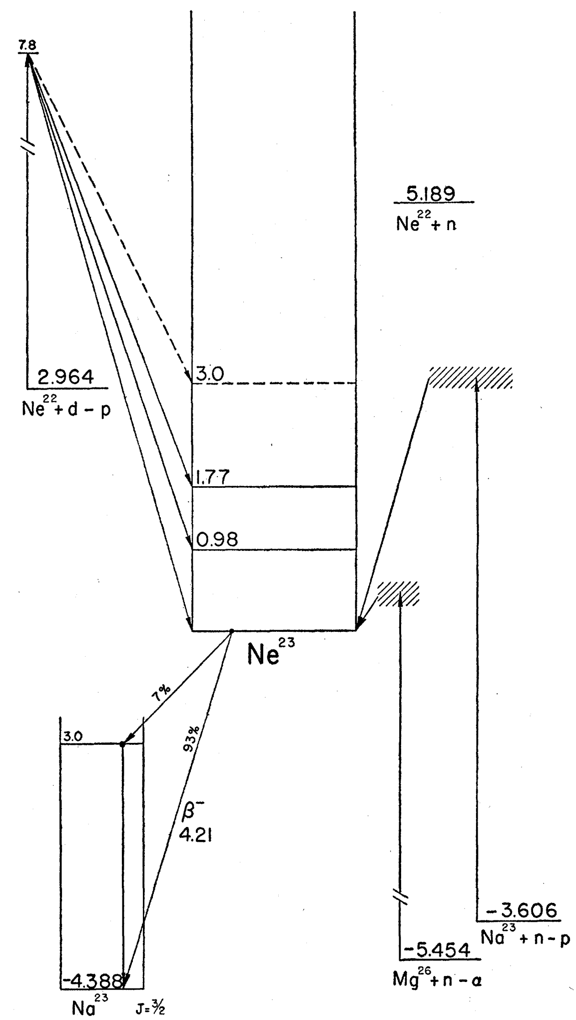

FIG. 33. Energy levels of Ne^{23}: for notation, see Fig. 1.

Table of atomic mass defects.[a]

Nuclide	$M-A$ (Mev)
n^1	8.3638±0.0029
H^1	7.5815±0.0027
H^2	13.7203±0.006
H^3	15.8271±0.010
He^3	15.8086±0.010
He^4	3.6066±0.014
He^5	12.97 ±0.1[b]
He^6	19.40 ±0.036[b]
Li^5	12.99 ±0.3[b]
Li^6	15.850 ±0.021
Li^7	16.969 ±0.024
Li^8	23.296 ±0.028
Li^9	28.1 ±1[b]
Be^7	17.832 ±0.024
Be^8	7.309 ±0.027
Be^9	14.007 ±0.028
Be^{10}	15.560 ±0.026
B^8	25.1 ±0.3[b]
B^9	15.076 ±0.029
B^{10}	15.004 ±0.026
B^{11}	11.909 ±0.022
B^{12}	16.912 ±0.020
C^{10}	18.94 ±0.1[b]
C^{11}	13.889 ±0.022
C^{12}	3.542 ±0.015
C^{13}	6.958 ±0.013
C^{14}	7.153 ±0.010
C^{15}	13.3 ±0.5[b]
N^{12}	21.2 ±0.1[b]
N^{13}	9.179 ±0.013
N^{14}	6.998 ±0.010
N^{15}	4.528 ±0.011
N^{16}	10.3 ±0.5[b]
N^{17}	13.0 ±0.2[b]
O^{14}	12.13 ±0.1[b]
O^{15}	7.233 ±0.012
O^{16}	0 (Standard)
O^{17}	4.221 ±0.006
O^{18}	4.522 ±0.022[c]
O^{19}	8.65 ±0.3[b]
F^{17}	6.988 ±0.005[c]
F^{18}	6.193 ±0.021[c]
F^{19}	4.149 ±0.014
F^{20}	5.913 ±0.016[c]
Ne^{19}	7.405 ±0.014[c]
Ne^{20}	−1.139 ±0.019[c]
Ne^{21}	0.469 ±0.021[c]
Ne^{22}	−1.529 ±0.023[c]
Ne^{23}	1.646 ±0.023[c]
Na^{20}	14.2 ±0.5[b]
Na^{21}	3.991 ±0.037[c]
Na^{22}	1.312 ±0.023[c]
Na^{23}	−2.742 ±0.023[c]
Na^{24}	−1.333 ±0.024[c]
Mg^{26}	−8.565 ±0.027[c]

[a] All values except those marked b and c are from Li, Whaling, Fowler, and Lauritsen, Phys. Rev. 83, 512 (1951).
[b] These values are derived from experimental data reviewed in the present article.
[c] These values are from C. W. Li, Phys. Rev. (to be published).

He 47 Heitler, May, and Powell, Proc. Roy. Soc. (London) 190, 180 (1947).

V. $Na^{22}(\beta^+)Ne^{22}$ $Q_m=2.841$

The decay proceeds almost entirely by positron emission of maximum energy 542±5 kev (Ma 50a), followed by a 1277±4 kev γ-ray (Al 49d). The positron spectrum has the allowed shape down to 25 kev: the $\beta-\gamma$ angular correlation is isotropic. K-capture occurs in <5 percent of the transitions. The direct ground-state transition is also reported to occur, to the extent of 1/26000 or more. The half-life is 2.6 years: log ft =7.40 (excited state), log ft∼13.8 (ground-state) (Fe 51b). The spin of Na^{22} is $J=3$. See (Ho 50b, Mi 50g, Wa 50e).

Ma 50a Macklin, Lidofsky, and Wu, Phys. Rev. **78**, 318 (1950).
Al 49d Alburger, Phys. Rev. **76**, 435 (1949).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).

Ne^{23}

I. $Ne^{23}(\beta^-)Na^{23}$ $Q_m=4.388$

The decay is complex: the ground-state transition with $E_\beta(\max)=4.21\pm0.05$ Mev comprises 93 percent, while a 7 percent branch with $E_\beta(\max)=1.18\pm0.04$ Mev proceeds to an excited state of Na^{23}. The half-life is 40.2±0.04 sec; log ft=4.94 and 3.78 for the ground-state and excited state transitions, respectively, (Br 50c). [Using Q_m for the ground-state transition energy, one obtains log ft=5.17.]

Br 50c Brown and Perez-Mendez, Phys. Rev. **78**, 812 (1950).
See also: Ho 50b, Wa 50e, Pe 50d.

II. $Ne^{22}(n\ \gamma)Ne^{23}$ $Q_m=5.189$

The thermal cross section is 36±15 mb (Hu 52e).

Hu 52e Hughes *et al.*, AECU 2040 (1952).

III. $Ne^{22}(d\ p)Ne^{23}$ $Q_m=2.964$

$Q=2.964\pm0.007$ (Va 52: mag. spectrometer)

Proton groups corresponding to levels at 0.98 and 1.75 Mev are reported by (Zu 50a). (Mi 51d) give Q-values of 1.17±0.05 and −0.04±0.08 (uncertain), leading to level energies of 1.79 and 3.0(?) Mev.

Va 52 Van Patter, Sperduto, Endt, Buechner, and Enge, Phys. Rev. **85**, 142 (1952).
Zu 50a Zucker and Watson, Phys. Rev. **78**, 14 (1950).
Mi 51d Middleton and Tai, Proc. Phys. Soc. (London) **64A**, 801 (1951).
See also: Ho 50b.

IV. $Na^{23}(n\ p)Ne^{23}$ $Q_m=-3.606$

See (Ho 50b).

V. $Mg^{26}(n\ \alpha)Ne^{23}$ $Q_m=-5.454$

See (Ho 50b).

REFERENCES

(Closed September 1, 1952)

(References are arranged and designated by first two letters of first-mentioned author's name, and year. Otherwise duplicate designations are distinguished by postscript letter.)

Ad 49 Adair, Barschall, Bockelman, and Sala, Phys. Rev. **75**, 1124 (1949).
Ad 50 Adair, Revs. Modern Phys. **22**, 249 (1950).
Ad 50a Adair, Phys. Rev. **79**, 1018 (1950).
Ad 50b Adamson, Buechner, Preston, Goodman, and Van Patter, Phys. Rev. **80**, 985 (1950).
Ad 51b Adair, Phys. Rev. **82**, 750 (1951).
Ad 52 Adair, Phys. Rev. **86**, 155 (1952).
Ad 52a Adair, Phys. Rev. **87**, 1041 (1952).
Ag 51 Agnew, Leland, Argo, Crews, Hemmendinger, Scott, and Taschek, Phys. Rev. **84**, 862 (1951).
Aj 51 Ajzenberg, Phys. Rev. **82**, 43 (1951).
Aj 51b Ajzenberg, Phys. Rev. **83**, 693 (1951).
Aj 52 Ajzenberg, Phys. Rev. **87**, 205A (1952).
Aj 52a Ajzenberg, Ph.D. thesis, University of Wisconsin (1952).
Aj 52b Ajzenberg, Phys. Rev. **88**, 298 (1952).
Al 47b Allen, Burcham, and Wilkinson, Proc. Roy. Soc. (London) **A192**, 114 (1947).
Al 49a Alvarez, Phys. Rev. **75**, 1815 (1949).
Al 49c Alvarez, Phys. Rev. **75**, 1127 (1949).
Al 49d Alburger, Phys. Rev. **76**, 435 (1949).
Al 50g Alvarez, Phys. Rev. **80**, 519 (1950).
Al 50i Almqvist, Can. J. Res. **28A**, 433 (1950).
Al 51 Allen, Almqvist, Dewan, Pepper, and Sanders, Phys. Rev. **82**, 262 (1951).
Al 51a Almqvist, Allen, Dewan, and Pepper, Phys. Rev. **83**, 202 (1951).
Al 51b Allen, Nechaj, Sun, and Jennings, Phys. Rev. **81**, 536 (1951).
Al 51c Allen and Poole, Proc. Roy. Soc. (London) **204**, 488 and 500 (1951).
Al 51d Allen and Rall, Phys. Rev. **81**, 60 (1951).
Al 51e Alder and Yu, Phys. Rev. **81**, 1067 (1951).
Al 51i Alburger, Phys. Rev. **83**, 184 (1951).
Al 51k Allred, Phys. Rev. **84**, 695 (1951).
Al 51l Allred, Froman, Hudson, and Rosen, Phys. Rev. **82**, 786 (1951).
Al 51n C. de Alemany and Perez, Nuclear Sci. Abst. **6**, 316 (1952).
Al 52 Alburger, Phys. Rev. (to be published).
Al 52a Alburger, Phys. Rev. (to be published).
Am 46 Amaldi, Bocciarelli, Cacciapuoti, and Trabacchi, Nuovo cimento **3**, 203 (1946).
Am 50 Ambrosen and Bisgaard, Nature **165**, 888 (1950).
An 48a Anderson, N. R. C. Nuclear Science Series, No. 3 (December, 1948).
An 51 Anderson and Libby, Phys. Rev. **81**, 64 (1951).
Ar 50 Arnold, Phys. Rev. **79**, 170 (1950); Phys. Rev. **80**, 34 (1950).
Ar 51b Arakatsu *et al.*, J. Phys. Soc. Japan **6**, 66, Jan.–Feb. (1951).
Ar 51c Arfken, Biedenharn, and Rose, Phys. Rev. **84**, 89 (1951).
Ar 51d Artemov and Vlasov, Dokl. Akad. Nauk, SSSR, 77 (No. 2) 225 (1951); Phys. Abstr. 6450 (1951).
Ar 52 Argo, Adair, Agnew, Hemmendinger, Leland, and Taschek, Phys. Rev. **87**, 205A (1952).
Ar 52a Armstrong, Allred, Hudson, Potter, Robinson, Rosen, and Stovall, Phys. Rev. **87**, 238A (1952).
Ar 52b Arthur, Allen, Bender, Hausman, McDole, Diana, Rhodes, and Barjon, Phys. Rev. **87**, 237A (1952).
Ar 52d Argo, Taschek, Agnew, Hemmendinger, and Leland, Phys. Rev. **87**, 612 (1952).
As 51 Ashmore and Raffle, Proc. Phys. Soc. (London) **64A**, 754 (1951).
As 52 Ashmore and Raffle, Proc. Phys. Soc. (London) **65A**, 296 (1952).
Av 50 Avery and Blanchard, Phys. Rev. **78**, 704 (1950).
Ba 39a Barkas, Phys. Rev. **56**, 287 (1939).
Ba 45 Baldwin and Koch, Phys. Rev. **67**, 1 (1945).
Ba 48 Bailey, Freier, and Williams, Phys. Rev. **73**, 274 (1948).
Ba 49b Baldwin, Phys. Rev. **76**, 182 (1949).
Ba 50e Baxter, Burcham, and Paul, Phil. Mag. **41**, 937 (1950).
Ba 50f Barnes, French, and Devons, Nature **166**, 145 (1950).
Ba 50g Baldinger, Huber, Ricamo, and Zünti, Helv. Phys. Acta **23**, 503 (1950).
Ba 50i Bateson, Phys. Rev. **80**, 982 (1950).
Ba 51a Bashkin, Mooring, and Petree, Phys. Rev. **82**, 378 (1951).
Ba 51b Baggett and Bame, Phys. Rev. **84**, 154 (1951).
Ba 51c Baldinger, Huber, and Proctor, Phys. Rev. **84**, 1058 (1951).
Ba 51e Bashkin and Richards, Phys. Rev. **84**, 1124 (1951).
Ba 51f Bame and Baggett, Phys. Rev. **84**, 891 (1951).
Ba 52 Baggett and Bame, Phys. Rev. **85**, 434 (1952).
Ba 52a Bair, Willard, Snyder, Hahn, Kington, and Green, Phys. Rev. **85**, 946 (1952).
Ba 52b Baldinger, Huber, and Proctor, Helv. Phys. Acta **25**, 142 (1952).
Ba 52c Baker, Dodd, and Simmons, Phys. Rev. **85**, 1051 (1952).
Ba 52e Battat and Ribe, Phys. Rev. **88**, 159A (1952).
Ba 52f Bartholomew and Kinsey, Can. J. Phys. (to be published).
Be 41c Bennett, Bonner, and Watt, Phys. Rev. **59**, 793 (1941).
Be 50a Beghian, Grace, Preston, and Halban, Phys. Rev. **77**, 286 (1950).
Be 50d Bethe, Revs. Modern Phys. **22**, 213 (1950).
Be 50f Bell and Jordan, Phys. Rev. **79**, 392 (1950).
Be 50h Beghian, Grace, and Halban, Proc. Phys. Soc. (London) **63A**, 913 (1950).
Be 50i Berlman, Phys. Rev. **80**, 775 (1950).
Be 51 Bennett, Roys, and Toppel, Phys. Rev. **82**, 20 (1951).
Be 51a Benveniste and Cork, Phys. Rev. **83**, 894 (1951).
Be 51e Bergmann, Acta Phys. Austr. **4**, 338 (1951).
Be 52a Benveniste, thesis, UCRL 1689 (1952).
Be 52b Benenson, Phys. Rev. **87**, 207A (1952).
Bh 52 Bhatia, Huang, Huby, and Newns, Phil. Mag. **43**, 485 (1952).
Bi 51 Bichsel, Hälg, Huber, and Stebler, Phys. Rev. **81**, 456 (1951).
Bi 51d Biedenharn, Arfken, and Rose, Phys. Rev. **83**, 586 (1951).
Bi 52 Bichsel, Hälg, Huber, and Stebler, Helv. Phys. Acta **25**, 119 (1952).
Bj 38 Bjerge, Proc. Roy. Soc. (London) **164A**, 243 (1938).
Bl 47 Bleuler, Scherrer, Walter, and Zünti, Helv. Phys. Acta **20**, 96 (1947).
Bl 47a Bleuler and Zünti, Helv. Phys. Acta **20**, 195A (1947).
Bl 47c Bleuler and Rossel, Helv. Phys. Acta **20**, 445 (1947).
Bl 49 Blair, Freier, Lampi, and Sleator, Phys. Rev. **75**, 1678 (1949).
Bl 49a Blaser, Boehm, and Marmier, Phys. Rev. **75**, 1953 (1949).
Bl 51 Blundell and Rotblat, Phys. Rev. **81**, 144 (1951).
Bl 51a Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).
Bl 52 Black, Phys. Rev. **87**, 205A (1952).
Bo 40b Bonner, Proc. Roy. Soc. (London) **174A**, 339 (1940).
Bo 42 Borst, Phys. Rev. **61**, 106A (1942).
Bo 48c Bonner and Evans, Phys. Rev. **73**, 666 (1948).
Bo 49a Bonner, Evans, Harris, and Phillips, Phys. Rev. **75**, 1401 (1949).
Bo 49c Bonner, Evans, and Hill, Phys. Rev. **75**, 1398 (1949).
Bo 50 Boyer, Phys. Rev. **78**, 345A (1950).
Bo 50c Bouchez, Compt. rend. **230**, 440 (1950).
Bo 50d Boyer, MIT Prog. Rept. (LNSE), July (1950).
Bo 50e Bouchez and Nataf, J. phys. et radium **11**, 266 (1950).
Bo 50f Bockelman, Phys. Rev. **80**, 1011 (1950).
Bo 51b Bonner and Butler, Phys. Rev. **83**, 1091 (1951).
Bo 51c Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).

Bo 51d Bollmann and Zünti, Helv. Phys. Acta **24**, 517 (1951).
Bo 52 Bondi and Salpeter, Nature **169**, 304 (1952).
Bo 52a Bonner, Conner, and Lillie, Phys. Rev. **88**, 473 (1952).
Br 39 Brubaker, Phys. Rev. **56**, 1181 (1939).
Br 48a Breit and Bloch, Phys. Rev. **74**, 397 (1948).
Br 49 Brown and Perez-Mendez, Phys. Rev. **75**, 1286 (1949).
Br 49a Bretscher and French, Phys. Rev. **75**, 1154 (1949).
Br 50 Bradford and Bennett, Phys. Rev. **78**, 302 (1950).
Br 50b Browne, Smith, and Richards, Phys. Rev. **77**, 754 (1950).
Br 50c Brown and Perez-Mendez, Phys. Rev. **78**, 812 (1950).
Br 50d Brown and Perez-Mendez, Phys. Rev. **78**, 649 (1950).
Br 50f Bretscher and Martin, Helv. Phys. Acta **23**, 15 (1950).
Br 51 Britten, Phys. Rev. **82**, 295 (1951).
Br 51a Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951).
Br 51b Brolley, Fowler, and Stovall, Phys. Rev. **82**, 502 (1951).
Br 51d Bromley, Can. J. Phys. **29**, 129 (1951).
Br 51e Britten, Princeton University Rept. NYO 971, June, (1951).
Br 51f Browne, Williamson, Craig, and Donahue, Phys. Rev. **83**, 179 (1951).
Br 51g Brinkworth and Titterton, Phil. Mag. **42**, 952 (1951).
Br 51h Braden, Phys. Rev. **84**, 762 (1951).
Br 51i Braden, Carter, and Ford, Phys. Rev. **84**, 837 (1951).
Br 51j Brinkworth and Titterton, Phil. Mag. **42**, 1191 (1951).
Br 52 Bromley and Goldman, Phys. Rev. **86**, 790 (1952).
Br 52a Brinkworth, Goward, and Wilkins, AERE Memo G/M 130 (1952).
Br 52b Bromley, Phys. Rev. **88**, 565 (1952).
Bu 38 Burcham and Smith, Proc. Roy. Soc. (London) **168A**, 176 (1938).
Bu 48c Buechner, Strait, Stergiopoulos, and Sperduto, Phys. Rev. **74**, 1569 (1948).
Bu 49e Buechner and Strait, Phys. Rev. **76**, 1547 (1949).
Bu 50 Butler, Phys. Rev. **80**, 1095 (1950).
Bu 50c Buechner *et al.*, MIT Prog. Rept. (LNSE), April (1950).
Bu 50d Buechner, Van Patter, Strait, and Sperduto, Phys. Rev. **79**, 262 (1950).
Bu 50e Burrows, Gibson, and Rotblat, Phys. Rev. **80**, 1095 (1950).
Bu 50g Burcham and Freeman, Phil. Mag. **41**, 337 (1950).
Bu 50h Burcham and Freeman, Phil. Mag. **41**, 921 (1950).
Bu 51 Bullock, McMinn, Rasmussen, and Sampson, Phys. Rev. **83**, 212A (1951).
Bu 51a Burke and Risser, Phys. Rev. **83**, 211 (1951).
Bu 51b Butler, Proc. Roy. Soc. (London) **208A**, 559 (1951).
Bu 51c Bullock and Sampson, Phys. Rev. **84**, 967 (1951).
Bu 51f Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **209A**, 478 (1951).
Bu 51h Burge, Burrows, Gibson, and Rotblat, Proc. Roy. Soc. (London) **210A**, 534 (1951).
Bu 51i Butler and Symonds, Phys. Rev. **83**, 858 (1951).
Bu 52a Buechner *et al.*, MIT Prog. Rept. (LSNE), February (1952).
Bu 52b Buechner, Browne, Elkind, Sperduto, Enge, and Bockelman, Phys. Rev. **87**, 237A (1952).
Bu 52c Butler, Phys. Rev. **85**, 743 (1952).
Bu 52d Buechner, University of Pittsburgh, Medium-Energy Nuclear Physics Conf. (June, 1952).
Bu 52e Burke and Risser, Phys. Rev. **87**, 294 (1952).
Ca 41 Carroll, Phys. Rev. **60**, 702 (1941).
Ca 51 Carlson, Phys. Rev. **84**, 749 (1951).
Ca 51a Carver and Wilkinson, Proc. Phys. Soc. (London) **64A**, 199 (1951).
Ca 51d Calcraft and Titterton, Phil. Mag. **42**, 666 (1951).
Ca 52 Canavan, Phys. Rev. **87**, 136 (1952).
Ch 47c Chupp and McMillan, Phys. Rev. **72**, 873 (1947).
Ch 49c Chao, Lauritsen, and Rasmussen, Phys. Rev. **76**, 582 (1949).
Ch 49d Charpie, Sun, Jennings, and Nechaj, Phys. Rev. **76**, 1255 (1949).
Ch 50 Chao, Tollestrup, Fowler, and Lauritsen, Phys. Rev. **79**, 108 (1950).
Ch 50a Chao, Phys. Rev. **80**, 1035 (1950).
Ch 50b Chastel, J. phys. et radium **11**, 291 (1950).
Ch 51b Chastel, Compt. rend. **233**, 1440 (1951).
Ch 52 Chastel, Compt. rend. **234**, 522 (1952).
Ch 52a Chastel, Compt. rend. **234**, 318 (1952).
Ch 52b Christy (to be published).
Cl 51 Class and Hanna, Nature **168**, 429 (1951).
Cl 52 Class and Hanna, Phys. Rev. **87**, 247 (1952).
Co 41a Cornog and Libby, Phys. Rev. **59**, 1046A (1941).
Co 49 Cohen, Phys. Rev. **75**, 1463A (1949); Ph.D. thesis, California Institute of Technology (1949).
Co 50d Colmer and Littler, Proc. Phys. Soc. (London) **63A**, 1175 (1950).
Co 51 Cohen, Phys. Rev. **81**, 184 (1951).
Co 51b Courant, Phys. Rev. **82**, 703 (1951).
Co 51c Cohen, Phys. Rev. **81**, 632 (1951).
Co 51d Collins, McKenzie, and Ramm, Nature **167**, 682 (1951).
Co 51g Cohen and Falk, Phys. Rev. **84**, 173 (1951).
Co 52a Cork, Phys. Rev. **83**, 893A (1951); U. of Calif. Rad. Lab. Rept. No. 1673 (February, 1952).
Co 52b Cowie, Heydenburg, Temmer, and Little, Phys. Rev. **86**, 593A (1952).
Co 52c Conner, Bonner, and Smith, Phys. Rev. **88**, 158A (1952).
Co 52d Cohen, Shafroth, Class, and Hanna, Phys. Rev. **87**, 206A (1952).
Co 52e Cochran, Ryan, Givin, Kern, and Hahn, Phys. Rev. **87**, 672 (1952).
Co 52f Conner, Bonner, and Smith, Phys. Rev. **88**, 468 (1952).
Co 52g Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).
Co 52h Coon, Graves, and Barschall, Phys. Rev. **88**, 562 (1952).
Co 52i Coon, Bondelid, and Phillips (to be published).
Cr 49a Critchfield and Dodder, Phys. Rev. **76**, 602 (1949).
Cr 49c Creagan, Phys. Rev. **76**, 1769 (1949).
Cr 50 Crussard, Compt. rend. **231**, 141 (1950).
Cr 50a Crussard, Nature **166**, 825 (1950).
Cr 51b Crews, Phys. Rev. **82**, 100 (1951).
Cr 52 Craig, Ph.D. thesis, University of Wisconsin (1952).
Cr 52b Craig, Donahue, and Jones, Phys. Rev. **87**, 206A (1952).
Cr 52c Craig, Donahue, and Jones, Phys. Rev. (to be published).
Cu 39 Curran and Strothers, Proc. Roy. Soc. (London) **172A**, 72 (1939).
Cu 39a Curran, Dee, and Petrzilka, Proc. Roy. Soc. (London) **169A**, 269 (1939).
Cu 50 Curling and Newton, Nature **165**, 609 (1950).
Cu 50a Curling and Newton, Nature **166**, 339 (1950).
Cu 51 Cüer and Lonchamp, Compt. rend. **232**, 1824 (1951).
Cu 52 Cüer and Jung, Compt. rend. **234**, 204 (1952).
Cu 52a Cüer and Magnac-Vallette, Compt. rend. **234**, 1049 (1952).
Da 51 Day and Perry, Phys. Rev. **81**, 662 (1951).
Da 51a Davis, Phys. Rev. **82**, 295 (1951).
Da 51b Day, Ph.D. thesis, California Institute of Technology (1951).
Da 52 Day and Walker, Phys. Rev. **85**, 582 (1952).
Da 52a Day and Huus, Phys. Rev. **85**, 761A (1952).
Da 52b Davis, Phys. Rev. **86**, 976 (1952).
De 39a Devons, Proc. Roy. Soc. (London) **172A**, 127 (1939).
De 48c Devons and Hereward, Nature **162**, 331 (1948).
De 49b Devons and Lindsey, Nature **164**, 539 (1949).
De 49d Devons and Hine, Proc. Roy. Soc. (London) **199A**, 56, 73 (1949).
De 50a Devons and Lindsey, Proc. Phys. Soc. (London) **63A**, 1202 (1950).
De 52 Dewan, Pepper, Allen, and Almqvist, Phys. Rev. **86**, 416 (1952).
De 52a De Jong and Endt, Physica **18**, 407 (1952).
Di 50 Diesendruck, Phys. Rev. **77**, 753 (1950).
Di 52 Dissanaike and Newton, Proc. Phys. Soc. (London) **65A**, 675 (1952).
Do 52 Donaven, Kundu, Long, and Pool, Phys. Rev. **88**, 158A (1952).
Do 52a Donahue, Ph.D. thesis, University of Wisconsin (1952).
Do 52b Dodder and Gammel, Phys. Rev. **88**, 520 (1952).
Du 51 Duncan and Perry, Phys. Rev. **82**, 809 (1951).
Du 51a Dunbar and Hirst, Phys. Rev. **83**, 164 (1951).
Du 51b Dunbar and Hirst, Australian J. Sci. Research **4**, 3, 268 (1951).
Ec 37 Eckardt, Ann. Physik **29**, 497 (1937).

Ed 52 Eder and Telegdi, Helv. Phys. Acta **25**, 55 (1952).
Ed 52a Edwards and MacMillan, Phys. Rev. **87**, 377 (1952).
Eg 48 Eggler, Hughes, and Huddleston, Phys. Rev. **74**, 1238 (1948).
Eh 51 Ehrman, Phys. Rev. **81**, 412 (1951).
El 51 El-Bedewi, Proc. Phys. Soc. (London) **64A**, 947 (1951).
El 51a El-Bedewi, Middleton, and Tai, Proc. Phys. Soc. (London) **64A**, 757 (1951).
El 51c El-Bedewi, Middleton, and Tai, Proc. Phys. Soc. (London) **64A**, 1055 (1951).
El 52 El-Bedewi, Proc. Phys. Soc. (London) **65A**, 64 (1952).
En 52 Endt, Paris, Jongerius, and Valckx, Physica **18**, 423 (1952).
Ev 49 Evans, Malich, and Risser, Phys. Rev. **75**, 1161 (1949).
Ev 52 Evans, Green, and Middleton (to be published).
Fa 51 Facchini, Gatti, and Germagnoli, Phys. Rev. **81**, 475 (1951); **82**, 555 (1951).
Fa 51a Facchini, Gatti, and Germagnoli, Nuovo cimento **8**, 145 (1951).
Fa 51c Falk, Phys. Rev. **83**, 499 (1951).
Fa 52 Famularo, Thompson, and Bonner, Phys. Rev. **85**, 742 (1952).
Fe 40 Ferguson and Walker, Phys. Rev. **58**, 666 (1940).
Fe 50a Feenberg and Trigg, Revs. Modern Phys. **22**, 399 (1950).
Fe 51 Feenberg, Phys. Rev. **81**, 644 (1951).
Fe 51a Feld, Phys. Rev. **82**, 308A (1951).
Fe 51b Feingold, Revs. Modern Phys. **23**, 10 (1951).
Fe 52 Ferguson and Montague, Phys. Rev. **87**, 215A (1952).
Fl 51 Flowers, Proc. Roy. Soc. (London) **204A**, 503 (1951).
Fo 47b Fowler, Burrows, and Curry, Nature **159**, 569 (1947).
Fo 49b Fowler and Lauritsen, Phys. Rev. **76**, 314 (1949).
Fo 51 Fowler, Phys. Rev. **81**, 655 (1951).
Fr 49c Freier, Lampi, Sleator, and Williams, Phys. Rev. **75**, 1345 (1949).
Fr 50 Franzen, Halpern, and Stevens, Phys. Rev. **77**, 641 (1950).
Fr 50a Freier, Stratton, and Rosen, Phys. Rev. **79**, 721 (1950).
Fr 50b Freier, Fulk, Lampi, and Williams, Phys. Rev. **78**, 508 (1950).
Fr 50c Freeman, Proc. Phys. Soc. (London) **63A**, 668 (1950).
Fr 50d French, Meyer, and Treacy, Proc. Phys. Soc. (London) **63A**, 666 (1950).
Fr 50e Freeman, Phil. Mag. **41**, 1225 (1950).
Fr 50f Fränz and Westmeyer, Z. Physik **128**, 617 (1950).
Fr 51 Freeman and Burcham, Phil. Mag. **42**, 434 (1951).
Fr 51b French and Treacy, Proc. Phys. Soc. (London) **64A**, 452 (1951).
Fr 51c Frye and Wiedenbeck, Phys. Rev. **82**, 960 (1951).
Fr 51d French and Thomson, Proc. Phys. Soc. (London) **64A**, 203 (1951).
Fr 52 Franzen and Likely, Phys. Rev. **87**, 667 (1952).
Fr 52a French and Newton, Phys. Rev. **85**, 1041 (1952).
Fr 52c French and Seed (to be published).
Fu 38 Fünfer, Ann. Physik **32**, 313 (1938).
Fu 48 Fulbright and Bush, Phys. Rev. **74**, 1323 (1948).
Fu 51a Futterman, Phys. Rev. **83**, 893A (1951).
Fu 52 Fulbright, Bruner, Bromley, and Goldman, Phys. Rev. (to be published).
Ga 50b Gaerttner and Yeater, Phys. Rev. **79**, 401 (1950).
Ga 51a Gardner, Phys. Rev. **82**, 283 (1951).
Ga 51c Gardner, Knable, and Moyer, Phys. Rev. **83**, 1054 (1951).
Ge 51 Gerjuoy, Phys. Rev. **81**, 62 (1951).
Ge 51a Gelinas and Hanna, Phys. Rev. **82**, 298 (1951).
Ge 51b Gelinas, Class, and Hanna, Phys. Rev. **83**, 1260 (1951).
Ge 52 Gelinas and Hanna, Phys. Rev. **86**, 253 (1952).
Ge 52a Geschwind, Gunther-Mohr, and Silvey, Phys. Rev. **85**, 474 (1952).
Gi 48 Gibson and Livesey, Proc. Phys. Soc. (London) **60A**, 523 (1948).
Gi 49 Gibson, Proc. Phys. Soc. (London) **62A**, 586 (1949).
Gi 50b Gibson and C. de Alemany, An. Real Soc. Esp. Fis. y Quim, **64A**, 307 (1950); Phys. Abs. 4716 (1951).
Gi 51 Giegerl and Broda, Nature **167**, 399 (1951).
Gi 51a Gibson, Grotdal, Orlin, and Trumpy, Phil. Mag. **42**, 555 (1951).
Gi 52 Gibson and Thomas, Proc. Roy. Soc. (London) **210A**, 543 (1952).
Gl 52 Glättli, Seippel, and Stoll, Helv. Phys. Acta **25**, 491 (1952).
Go 47a Goldsmith, Ibser, and Feld, Revs. Modern Phys. **19**, 259 (1947).
Go 50e Goward, Titterton, and Wilkins, Proc. Phys. Soc. (London) **63A**, 172 (1950).
Go 50h Goward and Wilkins, Proc. Phys. Soc. (London) **63A**, 1171 (1950).
Go 51 Goldhaber and Williamson, Phys. Rev. **82**, 495 (1951).
Go 51a Gove and Harvey, Phys. Rev. **82**, 658 (1951).
Go 51c Goward and Wilkins, Proc. Phys. Soc. (London) **64A**, 93, 94 (1951).
Go 51d Gove and Harvey, MIT Prog. Rept. (L.N.S.E.) (January, 1951).
Go 51e Goward and Wilkins, Proc. Phys. Soc. (London) **64A**, 312 (1951).
Go 51g Good, Kunz, and Moak, Phys. Rev. **83**, 845 (1951).
Go 51h Gove, Phys. Rev. **84**, 1059 (1951).
Go 51i Gove, Phys. Rev. **81**, 364 (1951).
Go 52 Goward and Wilkins, Proc. Phys. Soc. (London) **65A**, 671 (1952).
Go 52a Goward and Wilkins, AERE Memo G/M 127 (March, 1952).
Go 52b Gove and Stoddart, Phys. Rev. **86**, 572 (1952).
Gr 40 Graves, Phys. Rev. **57**, 855 (1940).
Gr 49a Grosskreutz, Phys. Rev. **76**, 482 (1949).
Gr 50 Grosskreutz and Mather, Phys. Rev. **77**, 580 (1950).
Gr 51 Graves, Phys. Rev. **84**, 1250 (1951).
Gr 51a Grace, Beghian, Preston, and Halban, Phys. Rev. **82**, 969 (1951).
Gu 47 Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. (London) **190A**, 196 (1947).
Gu 50 Guier and Roberts, Phys. Rev. **79**, 719 (1950).
Gu 51 Gugelot, Phys. Rev. **81**, 51 (1951).
Gu 51b Gutowsky, McClure, and Hoffman, Phys. Rev. **81**, 635 (1951).
Gu 52 Guier, Bertini, and Roberts, Phys. Rev. **85**, 426 (1952).
Ha 35 Haxel, Z. Physik **93**, 400 (1935).
Ha 39 Haxby, Allen, and Williams, Phys. Rev. **55**, 140 (1939).
Ha 39a Haxel and Stuhlinger, Z. Physik **114**, 178 (1939).
Ha 49c Hayward, Phys. Rev. **75**, 917 (1949).
Ha 50b Hamermesh and Hummel, Phys. Rev. **78**, 73 (1950).
Ha 50e Hanna, Phys. Rev. **80**, 530 (1950).
Ha 50f Harris, Phys. Rev. **80**, 20 (1950).
Ha 51a Harvey, Phys. Rev. **82**, 298 (1951); MIT Prog. Rept. (LNSE) (January, 1951).
Ha 51b Haslam, Johns, and Horsley, Phys. Rev. **82**, 270 (1951).
Ha 51c Harris, Phys. Rev. **84**, 1249 (1951).
Ha 51e Haefner, Revs. Modern Phys. **23**, 228 (1951).
Ha 51f Halpern and Mann, Phys. Rev. **83**, 370 (1951).
Ha 51i Hatton, Rollin, and Seymour, Phys. Rev. **83**, 672 (1951).
Ha 52a Harvey, Goldberg, and Hughes, Phys. Rev. **86**, 604A (1952).
Ha 52c Hanna and Gelinas, The Johns Hopkins University Rept. NYO 3290 (1952).
Ha 52e Hahn, Snyder, Willard, Bair, Klema, Kington, and Green, Phys. Rev. **85**, 934 (1952).
Ha 52f Harries and Davies, Proc. Phys. Soc. (London) **65A**, 564 (1952).
Ha 52g Halpern, Mann, and Rothman, Phys. Rev. **87**, 164 (1952).
He 47 Heitler, May, and Powell, Proc. Roy. Soc. (London) **190A**, 180 (1947).
He 48a Heydenburg and Inglis, Phys. Rev. **73**, 230 (1948).
He 48e Heydenburg, Hudson, Inglis, and Whitehead, Phys. Rev. **74**, 405 (1948).
He 49 Herb, Snowden, and Sala, Phys. Rev. **75**, 246 (1949).
He 49b Hemmendinger, Phys. Rev. **75**, 1267 (1949).
He 50b Henkel and Barschall, Phys. Rev. **80**, 145 (1950).
He 51 Heckrotte and Schecter, Phys. Rev. **83**, 203A (1951).
He 51a Heckrotte and Schecter, Phys. Rev. **83**, 894A (1951).
He 52a Heusinkveld and Freier, Phys. Rev. **85**, 80 (1952).
Hi 46 Hincks, Phys. Rev. **70**, 770 (1946).
Hi 49 Hibdon and Muehlhause, Phys. Rev. **76**, 100 (1949).
Hi 50 Hine and Senftle, Phys. Rev. **80**, 904 (1950).
Hi 51 Hibdon and Muehlhause, A.N.L. 4680 (September, 1951).
Hi 51a Hirst and Uebergang, Aust. J. Res. **4**, 284 (1951).

Hi 52 Hinchey, Stelson, and Preston, Phys. Rev. **86**, 483 (1952).
Ho 40 Holloway and Moore, Phys. Rev. **58**, 847 (1940).
Ho 49a Hornyak, Lauritsen, and Rasmussen, Phys. Rev. **76**, 731 (1949).
Ho 50 Hornyak and Lauritsen, Phys. Rev. **77**, 160 (1950).
Ho 50b Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 291 (1950).
Ho 50 Houtermans and Teucher, Z. Physik **129**, 365 (1951).
Ho 51c Hodgson, Phil. Mag. 42, 207 (1951).
Ho 52 Horsley, Haslam, and Johns, Can. J. Phys. **30**, 159 (1952).
Ho 52a Horsley, Haslam, and Johns, Phys. Rev. **87**, 756 (1952).
Ho 52b Holt, Thorn, and Waniek, Phys. Rev. **87**, 378 (1952).
Ho 52c Holtzman and Sugarman, Phys. Rev. **87**, 633 (1952).
Ho 52d Hodgson, Phil. Mag. **43**, 190 (1952).
Hu 47 Hughes, Eggler, and Huddleston, Phys. Rev. **71**, 269 (1947).
Hu 47a Hughes, Hall, Eggler, and Goldfarb, Phys. Rev. **72**, 646 (1947).
Hu 49a Hughes, Eggler, and Huddleston, Phys. Rev. **75**, 515 (1949).
Hu 49j Hudspeth and Swann, Phys. Rev. **76**, 1150 (1949).
Hu 50a Hudspeth, Swann, and Heydenburg, Phys. Rev. **77**, 736 (1950).
Hu 50e Hudspeth, Swann, and Heydenburg, Phys. Rev. **80**, 643 (1950).
Hu 51a Hummel and Inglis, Phys. Rev. **81**, 910 (1951); **83**, 1078 (1951).
Hu 51b Huby and Newns, Phil. Mag. **42**, 1442 (1951).
Hu 51f Huber, Baldinger, and Proctor, Helv. Phys. Acta **24**, 302 (1951).
Hu 51g Hughes, Proc. Phys. Soc. (London) **64A**, 797 (1951).
Hu 52 Hudspeth, Rose, and Heydenburg, Phys. Rev. **85**, 742A (1952).
Hu 52a Huus and Day, Phys. Rev. **85**, 761A (1952).
Hu 52b Hubbard, Nelson, and Jacobs, Phys. Rev. **87**, 378 (1952).
Hu 52c Huber and Baldinger, Helv. Phys. Acta **25**, 435 (1952).
Hu 52d Huber, Baldinger, and Buddle, Helv. Phys. Acta **25**, 444 (1952).
Hu 52e Hughes *et al.*, AECU 2040 (May 1952).
Hu 52f Hunt (to be published).
Hu 52g Hunt and Jones (to be published).
Hu 52h Hunt, Phys. Rev. **87**, 902 (1952).
In 50 Inglis, Phys. Rev. **77**, 724 (1950).
In 50a Inglis, Phys. Rev. **78**, 616 (1950).
In 50b Inglis, Phys. Rev. **78**, 104 (1950).
In 51 Inglis, Phys. Rev. **82**, 181 (1951).
In 51a Inglis, Phys. Rev. **81**, 914 (1951).
In 52 Inglis, Phys. Rev. **85**, 492 (1952).
In 52a Inall and Salmon (to be published).
Is 50 Ishiwari and Yuasa, Memoirs of the College of Science, University of Kyoto, Series A, Vol. 26, Nos. 1 & 2 (1950).
Ja 51b Jackson and Galonsky, Phys. Rev. **84**, 401 (1951).
Ja 52a Jackson, Galonsky, Eppling, Hill, Goldberg, and Cameron, Phys. Rev. (to be published).
Ja 52b Jackson and Galonsky, Phys. Rev. (to be published).
Je 48c Jelley and Paul, Proc. Cambridge Phil. Soc. **44**, 133 (1948).
Je 49e Jensen, Arkiv. Fysik **1**, 25 (1949).
Je 50 Jesse, Forstat, and Sadauskis, Phys. Rev. **77**, 782 (1950).
Je 50a Jelley, Proc. Phys. Soc. (London) **63A**, 538 (1950).
Je 50b Jensen, Arkiv. Fysik **1**, 515 (1950).
Je 50c Jennings, Leiter, and Sun, Phys. Rev. **80**, 109 (1950).
Je 50d Jelley and Paul, Proc. Phys. Soc. (London) **63A**, 112 (1950).
Je 50e Jelley, Phil. Mag. **41**, 1199 (1950).
Je 50g Jesse and Sadauskis, Phys. Rev. **78**, 1 (1950).
Je 52 Jenks and Sweeton, Phys. Rev. **86**, 803 (1952).
Jo 50 Johnson, Laubenstein, and Richards, Phys. Rev. **77**, 413 (1950).
Jo 50a Johnson, Ajzenberg, and Laubenstein, Phys. Rev. **79**, 187 (1950).
Jo 50b Johnson and Barschall, Phys. Rev. **80**, 818 (1950).
Jo 51a Johnson, Petree, and Adair, Phys. Rev. **84**, 775 (1951).
Jo 51b Johns, Horsley, Haslam, and Quinton, Phys. Rev. **84**, 856 (1951).
Jo 51d Jones and Wilkinson, Proc. Phys. Soc. (London) **64A**, 756 (1951).
Jo 51e Johnson, Bockelman, and Barschall, Phys. Rev. **82**, 117 (1951).
Jo 51f Jolley and Champion, Proc. Phys. Soc. (London) **64A**, 88 (1951).
Jo 52a Johnson, Phys. Rev. **86**, 302 (1952).
Jo 52b Johnson, Robinson, and Moak, Phys. Rev. **85**, 931 (1952).
Jo 52c Jones and Wilkinson, Phil. Mag. **43**, 958 (1952).
Ke 50 Keepin and Roberts, Rev. Sci. Instr. **21**, 167 (1950).
Ke 50a Keepin, Phys. Rev. **80**, 768 (1950).
Ke 50b Keepin and Roberts, Phys. Rev. **77**, 758 (1950).
Ke 51a Kern, Moak, Good, and Robinson, Phys. Rev. **83**, 211 (1951).
Ke 51b Keller, Niedner, Wang, and Shull, Phys. Rev. **81**, 481 (1951).
Ki 39 King, Henderson, and Risser, Phys. Rev. **55**, 1118 (1939).
Ki 51 Kinsey, Bartholomew, and Walker, Can. J. Phys. **29**, 1 (1951).
Ki 51a Kinsey, Bartholomew, and Walker, Phys. Rev. **83**, 519 (1951).
Kl 52 Klema and Phillips, Phys. Rev. **86**, 951 (1952).
Kn 45 Knight, Novey, Cannon, and Turkevich, Plut. Prog. Rept. CC 2605 (February, 1945).
Kn 48 Knable, Lawrence, Leith, Moyer, and Thornton, Phys. Rev. **74**, 1217A (1948).
Kn 48a Knox, Phys. Rev. **74**, 1192 (1948).
Ko 51 Koch, McElhinney, and Cunningham, Phys. Rev. **81**, 318A (1951).
Ko 51a Koester, Jackson, and Adair, Phys. Rev. **83**, 1250 (1951).
Ko 52 Koehler and Wollan, Phys. Rev. **85**, 491 (1952).
Ko 52b Kofoed-Hansen and Winther, Phys. Rev. **86**, 428 (1952).
Ko 52c Koudijs, Endt, van der Hart, and Palmer, Physica **18**, 415 (1952).
Kr 41 Krishnan, Nature **148**, 407 (1941).
Kr 50 Krone, Hanna, and Inglis, Phys. Rev. **80**, 603 (1950).
Kr 52a Kreger, Kerman, and Jentschke, Phys. Rev. **86**, 593A (1952).
Kr 52c Kraus and French, Phys. Rev. (to be published).
Kr 52d Kraus, Fowler, and Lauritsen, Phys. Rev. (to be published).
La 47b Lattes, Fowler, and Cuer, Proc. Phys. Soc. (London) **59A**, 883 (1947).
La 48b Lawson and Perlman, Phys. Rev. **74**, 1190 (1948).
La 50a Lampi, Freier, and Williams, Phys. Rev. **80**, 853 (1950).
La 51b Lasday, Phys. Rev. **81**, 139 (1951).
La 51c Landon, Phys. Rev. **83**, 1081 (1951).
La 51d Laubenstein, Laubenstein, Koester, and Mobley, Phys. Rev. **84**, 12 (1951).
La 51e Laubenstein and Laubenstein, Phys. Rev. **84**, 18 (1951).
La 52 Lataste, J. phys. et radium **13**, 39 (1952).
Le 50a Levinger and Bethe, Phys. Rev. **78**, 115 (1950).
Le 51 Leininger, Segrè, and Wiegand, Phys. Rev. **81**, 280 (1951).
Le 51a Leland and Agnew, Phys. Rev. **82**, 559 (1951).
Le 52 Lewis, Phil. Mag. **43**, 690 (1952).
Li 37 Livingston and Bethe, Revs. Modern Phys. **9**, 245 (1937).
Li 50 Littauer, Phil. Mag. **41**, 1214 (1950).
Li 50a Livingston, Boyer, Gove, Harvey, and Deutsch, Phys. Rev. **78**, 344 (1950).
Li 50b Littauer, Proc. Phys. Soc. (London) **63A**, 294 (1950).
Li 51 Li and Whaling, Phys. Rev. **81**, 661 (1951).
Li 51a Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
Li 51b Li and Whaling, Phys. Rev. **82**, 122 (1951).
Li 52 Lillie, Phys. Rev. **87**, 716 (1952).
Li 52a Livesey and Smith, Proc. Phys. Soc. (London) **65A**, 298 (1952).
Li 52b Livesey and Smith, Proc. Phys. Soc. (London) **65A**, 758 (1952).
Lo 50 Los Alamos Scientific Laboratory, Phys. Rev. **79**, 238A (1950).

Ma 47 May and Hincks, Can. J. Research **25**, 77 (1947).
Ma 50a Macklin, Lidofsky, and Wu, Phys. Rev. **78**, 318 (1950).
Ma 50d Mandeville and Swann, Phys. Rev. **79**, 787 (1950).
Ma 50h Mann and Halpern, Phys. Rev. **80**, 470 (1950).
Ma 50i Malm and Buechner, Phys. Rev. **80**, 771 (1950).
Ma 51 Malm and Buechner, Phys. Rev. **81**, 519 (1951).
Ma 51a Mather, Phys. Rev. **82**, 126 (1951).
Ma 51d Marshall, Phys. Rev. **83**, 345 (1951).
Ma 51e Manov and Curtiss, J. Research Natl. Bur. Standards **46**, 328 (1951); Phys. Abs. 5692 (1951).
Mc 40a McLean, Young, Whitson, Plain, and Ellett, Phys. Rev. **57**, 1083A (1940).
Mc 48 McMillan and Miller, Phys. Rev. **73**, 80 (1948).
Mc 49 McElhinney, Hanson, Becker, Duffield, and Diven, Phys. Rev. **75**, 542 (1949).
Mc 51a McNeill and Rall, Phys. Rev. **83**, 1244 (1951).
Mc 51b McMinn, Sampson, and Rasmussen, Phys. Rev. **84**, 963 (1951).
Mc 51d McReynolds, Phys. Rev. **84**, 969 (1951).
Mc 52a McManaway, Kiger, and Waltner, Phys. Rev. **87**, 176A (1952).
Me 49b Melkonian, Phys. Rev. **76**, 1750 (1949).
Me 50a Meyer, Z. Physik **128**, 451 (1950); Phys. Abs. 1309 (1951).
Me 51a Meyerhof, Roderick, and Mann, Phys. Rev. **83**, 203A (1951).
Mi 50a Millar, Cameron, and Glicksman, Phys. Rev. **77**, 742 (1950) and Can. J. Research **28A**, 475 (1950).
Mi 50b Millar and Cameron, Phys. Rev. **78**, 78 (1950).
Mi 50c Miller, Phys. Rev. **78**, 806 (1950).
Mi 50d Millar and Cameron, Phys. Rev. **79**, 182 (1950).
Mi 50e Mileikowsky and Pauli, Nature **166**, 602 (1950).
Mi 51 Millar and Cameron, Phys. Rev. **81**, 316 (1951).
Mi 51a Millar, Bartholomew, and Kinsey, Phys. Rev. **81**, 150 (1951).
Mi 51b Miller, Javan, and Townes, Phys. Rev. **82**, 454 (1951).
Mi 51c Miller, Petree, and Johnson, Phys. Rev. **83**, 211A (1951).
Mi 51d Middleton and Tai, Proc. Phys. Soc. (London) **64A**, 801 (1951).
Mi 52 Mileikowsky and Whaling (to be published).
Mo 37 Mohr and Pringle, Proc. Roy. Soc. (London) **160**, 190 (1937).
Mo 49a Morrish, Phys. Rev. **76**, 1651 (1949).
Mo 50 Mobley and Laubenstein, Phys. Rev. **80**, 309 (1950).
Mo 51 Mottelson, Phys. Rev. **82**, 287 (1951).
Mo 52 Moak, Good, and Kunz, Phys. Rev. **85**, 928 (1952).
Mu 49 Mullin and Guth, Phys. Rev. **76**, 682 (1949).
Na 50 Nabholz, Stoll, and Wäffler, Helv. Phys. Acta **23**, 858 (1950).
Na 51 Nabholz, Stoll, and Wäffler, Phys. Rev. **82**, 963 (1951).
Na 52 Nabholz, Stoll, and Wäffler, Helv. Phys. Acta **25**, 153 (1952).
Na 52a Nabholz, Stoll, and Wäffler, Phys. Rev. **86**, 1043 (1952).
Ne 37a Neuert, Physik. Z. **38**, 618 (1937).
Ne 37b Newson, Phys. Rev. **51**, 620 (1937).
Ne 49 Nemilov and Funshtein, Dokl. Akad. Nauk SSSR, **66**, 609 (1949): Phys. Abs. 3383 (1950).
Ne 50a Nemilov, Izv. Akad. Nauk, SSSR, Ser. Fiz. 14, (3), 319 (1950); Phys. Abs. 3766 (1951).
Ne 50b Nemilov and Gedeonov, Dokl. Akad. Nauk SSSR, **70**, 219 (1950); Phys. Abs. 5261 (1950).
Ne 51 Neuendorffer, Inglis, and Hanna, Phys. Rev. **82**, 75 (1951).
Ne 51a Newton, Proc. Phys. Soc. (London) **64A**, 938 (1951).
Ne 52 Nereson, Phys. Rev. **87**, 221 (1952).
No 51 Nordheim, Revs. Modern Phys. **23**, 322 (1951).
No 52 Noyes, Van Hoomissen, Miller, and Waldman, Phys. Rev. **85**, 727A (1952).
Pa 50a Paul, Phil. Mag. **41**, 942 (1950).
Pa 51 Pauli and Mileikowsky, Nature **167**, 155 (1951).
Pa 52 Palevsky and Smith, Phys. Rev. **86**, 604A (1952).
Pa 52a Panofsky and Reagan, Phys. Rev. **87**, 543 (1952).
Pe 50 Perez-Mendez and Brown, Phys. Rev. **77**, 404 (1950).
Pe 50a Perkin, Phys. Rev. **79**, 175 (1950).
Pe 50c Perez-Mendez and Lindenfeld, Phys. Rev. **80**, 1097 (1950).
Pe 50d Perez-Mendez and Brown, Phys. Rev. **78**, 812 (1950).
Pe 51 Pepper, Allen, Almqvist, and Dewan, Phys. Rev. **81**, 315A (1951).
Pe 51a Peshkin and Siegert, Phys. Rev. **83**, 202 (1951).
Pe 51b Perkin, Phys. Rev. **81**, 892 (1951).
Pe 51c Petree, Johnson, and Miller, Phys. Rev. **83**, 1148 (1951).
Pe 51d Perez-Mendez and Lindenfeld, Phys. Rev. **83**, 864 (1951).
Pe 52 Pepper, Allen, Almqvist, and Dewan, Phys. Rev. **85**, 155 (1952).
Pe 52a Pepper, Almqvist, and Lorrain, Phys. Rev. **86**, 630 (1952).
Pe 52b Peterson and Levy, Phys. Rev. **87**, 462 (1951).
Pe 52c Peshkin and Siegert, Phys. Rev. **87**, 735 (1952).
Ph 50 Phillips, Phys. Rev. **79**, 240 (1950).
Ph 50b Phillips, Phys. Rev. **80**, 164 (1950).
Ph 51a Phillips and Heydenburg, Phys. Rev. **83**, 184 (1951).
Ph 51b Phillips, Cowie, and Heydenburg, Phys. Rev. **83**, 1049 (1951).
Ph 52 Phillips, Heydenburg, and Cowie, Phys. Rev. **85**, 742 (1952).
Po 35b Pollard and Margenau, Phys. Rev. **47**, 833 (1935).
Po 40b Pollard and Watson, Phys. Rev. **58**, 12 (1940).
Po 42 Powell, Proc. Roy. Soc. (London) **181A**, 344 (1942).
Po 51 Pool, Kundu, Weiler, and Donaven, Phys. Rev. **82**, 305 (1951).
Po 52a Poss, Salant, Snow, and Yuan, Phys. Rev. **87**, 11 (1952).
Pr 50a Price and Kerst, Phys. Rev. **77**, 806 (1950).
Pr 50b Pringle, Roulston, and Standil, Phys. Rev. **78**, 627 (1950).
Pr 50c Preston, Phys. Rev. **80**, 307 (1950).
Pr 52a Pruitt, Hanna, and Swartz, Phys. Rev. **87**, 534 (1952).
Pu 52 Putnam, Phys. Rev. **85**, 774A (1952); (thesis) Uni- (August, 1951); Phys. Rev. **87**, 932 (1952).
Ra 49a Rasmussen, Lauritsen, and Lauritsen, Phys. Rev. **75**, 199 (1949).
Ra 49b Rasmussen, Hornyak, and Lauritsen, Phys. Rev. **76**, 581 (1949).
Ra 50 Rasmussen, Hornyak, Lauritsen, and Lauritsen, Phys. Rev. **77**, 617 (1950).
Ra 50a Rasmussen, Ph.D. thesis, California Institute of Technology (1950).
Ra 50b Rae, Rutherglen, and Smith, Proc. Phys. Soc. (London) **63A**, 775 (1950).
Ra 51 Rall and McNeill, Phys. Rev. **83**, 1244 (1951).
Ra 52 Radicatti, Phys. Rev. **87**, 521 (1952).
Re 49b Resnick and Inglis, Phys. Rev. **76**, 1318 (1949).
Re 50 Redman, Phys. Rev. **79**, 6 (1950).
Re 51 Resnick, Phys. Rev. **82**, 447 (1951).
Re 51a Resnick and Hanna, Phys. Rev. **82**, 463 (1951).
Rh 50 Rhoderick, Proc. Roy. Soc. (London) **201A**, 348 (1950).
Rh 52 Rhodes, Franzen, and Stephens, Phys. Rev. **87**, 141 (1952).
Ri 50c Richardson, Phys. Rev. **80**, 850 (1950).
Ri 50d Ricamo, Zünti, Baldinger, and Huber, Helv. Phys. Acta **23**, 508, (1950).
Ri 50e Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
Ri 51 Richards, Laubenstein, Johnson, Ajzenberg, and Browne, Phys. Rev. **81**, 316 (1951).
Ri 51b Richards, Phys. Rev. **83**, 694 (1951).
Ri 51c Ricamo and Zünti, Helv. Phys. Acta **24**, 419 (1951).
Ri 51d Ricamo and Zünti, Helv. Phys. Acta **24**, 302 (1951).
Ri 51e Ricamo, Nuovo cimento **8**, 893 (1951).
Ri 52 Risser and Burke, Phys. Rev. **85**, 742 (1952).
Ri 52a Ribe, Phys. Rev. **87**, 205A (1952).
Ri 52b Richards, University of Pittsburgh, Medium-Energy Nuclear Physics Conf. (June, 1952).
Ro 44a Roberts, M.D.D.C. 731 (1944).
Ro 49d Ross and Story, Repts. on Prog. in Phys. **12**, 291 (Phys. Soc. London) (1949).
Ro 50 Rose and Wilson, Phys. Rev. **78**, 68 (1950).
Ro 50d Rotblat, Proc. Harwell Conf., AERE G/M 68 (1950).
Ro 50e Rosenfeld, Helv. Phys. Acta **23**, Supplement III (1950).
Ro 51 Roberts, Darlington, and Haugsnes, Phys. Rev. **82**, 299 (1951).
Ro 51f Roberts and Mann, Phys. Rev. **83**, 202 (1951).
Ro 51g Roy, Phys. Rev. **82**, 227 (1951).
Ro 51h Roseborough, McCue, Preston, and Goodman, Phys. Rev. **83**, 1133 (1951).

Ro 51j Rotblat, Nature **167**, 1027 (1951).
Ro 51k Rotblat, Phys. Rev. **83**, 1271 (1951).
Ro 52a Rogers, Odencrantz, and Plain, Phys. Rev. **85**, 756A (1952).
Ro 52b Rose, Hudspeth, and Heydenburg, Phys. Rev. **87**, 382 (1952).
Ro 52c Rochat and Stoll, Helv. Phys. Acta **25**, 451 (1952).
Ru 51 Ruby and Richardson, Phys. Rev. **83**, 698 (1951).
Ru 51a Rutherglen, Rae, and Smith, Proc. Phys. Soc. (London) **64A**, 906 (1951).
Sa 51 Sagane, Phys. Rev. **84**, 587 (1951).
Sa 51a Salmon, Proc. Phys. Soc. (London) **64A**, 848 (1951).
Sa 52 Sanders, Phil. Mag. **43**, 630 (1952).
Sa 52a Salmon (to be published).
Sc 51a Schuster and Pake, Phys. Rev. **81**, 886 (1951).
Sc 51c Schecter, Phys. Rev. **83**, 695 (1951).
Sc 52 Schardt, Fowler, and Lauritsen, Phys. Rev. **86**, 527 (1952).
Sc 52a Schrank and Richardson, Phys. Rev. **86**, 248 (1952).
Se 47 Seren, Friedlander, and Turkel, Phys. Rev. **72**, 888 (1947).
Se 49 Segrè and Wiegand, Phys. Rev. **75**, 39 (1949).
Se 49a Sexl, Acta Phys. Aust. **2**, 377 (1949).
Se 51a Segrè and Wiegand, Phys. Rev. **81**, 284 (1951).
Se 51b Seed, Phil. Mag. **42**, 566 (1951).
Se 51c Seagrave, Ph.D. thesis, California Institute of Technology (1951).
Se 51e Seagrave, Phys. Rev. **84**, 1219 (1951).
Se 52 Seagrave, Phys. Rev. **85**, 197 (1952).
Sh 45 Sherr, Phys. Rev. **68**, 240 (1945).
Sh 49 Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949).
Sh 49a Shoupp, Jennings, and Sun, Phys. Rev. **75**, 1 (1949).
Sh 49d Shoupp, Jennings, and Jones, Phys. Rev. **76**, 502 (1949).
Sh 51 Sher, Halpern, and Stephens, Phys. Rev. **81**, 154 (1951).
Sh 51a Shull, Phys. Rev. **83**, 875 (1951).
Sh 51b Shull and Wollan, Phys. Rev. **81**, 527 (1951).
Sh 51c Sheline, Phys. Rev. **82**, 954 (1951).
Sh 51d Sher, Halpern, and Mann, Phys. Rev. **84**, 387 (1951).
Sh 51e Sharpe and Stafford, Proc. Phys. Soc. (London) **64A**, 211 (1951).
Sh 51f Shapiro, Dokl. Akad. Nauk SSSR, **76**, No. 1, 45 (1951); Phys. Abs. 2975 (1951).
Sh 52 Sheline, Phys. Rev. **87**, 557 (1952).
Sh 52a Sherr and Gerhart, Phys. Rev. **86**, 619A (1952).
Si 50 Sikkema, Nature **165**, 1016 (1950).
Sl 48b Slätis, Nature **161**, 899 (1948).
Sl 48c Slätis, Arkiv. f. Ast. Math. Fys. **35A**, No. 31 (1948).
Sl 51 Slätis, Hjalmar, and Carlsson, Phys. Rev. **81**, 641; **82**, 753 (1951).
Sm 39 Smith and Murrell, Proc. Cambridge Phil. Soc. **35**, 298 (1939).
Sm 51 Smith and Allen, Phys. Rev. **81**, 381 (1951).
Sm 51a Smith and Kruger, Phys. Rev. **83**, 1137 (1951).
Sn 50 Snell, Barker, and Sternberg, Phys. Rev. **80**, 637 (1950).
Sn 50a Snowdon, Phys. Rev. **78**, 299 (1950).
So 46 Sommers and Sherr, Phys. Rev. **69**, 21 (1946).
Sp 50 Sperduto, Holland, Van Patter, and Buechner, Phys. Rev. **80**, 769 (1950).
Sp 51 Sperduto, Buechner, and Van Patter, M.I.T. Prog. Rept. (L.N.S.E.) (May, 1951).
Sp 51a Sperduto, M.I.T. Prog. Rept. (L.N.S.E.) (May, 1951).
St 39 Stuhlinger, Z. Physik **114**, 185 (1939)
St 48a Stebler and Huber, Helv. Phys. Acta **21**, 59 (1948).
St 50d Stebler, Bichsel, and Huber, Helv. Phys. Acta **23**, 511 (1950).
St 51 Strait, Van Patter, Sperduto, and Buechner, Phys. Rev. **81**, 747 (1951).
St 51a Stephens, Halpern, and Sher, Phys. Rev. **82**, 511 (1951).
St 51b Stetter and Bothe, Z. Naturforsch. **6a**, 61 (1951).
St 51c Stearns and McDaniel, Phys. Rev. **82**, 450 (1951).
St 51d Stafford, Proc. Phys. Soc. (London) **64A**, 388 (1951).
St 51e Stelson and Preston, Phys. Rev. **83**, 469 (1951).
St 51f Stelson and Preston, Phys. Rev. **84**, 162 (1951).
St 51g Sturm and Johnson, Phys. Rev. **83**, 542 (1951).
St 52 Stratton, Freier, Keepin, Rankin, and Stratton, Phys. Rev. **86**, 593 (1952).
St 52a Stovall, Arnold, Phillips, Sawyer, and Tuck, Phys. Rev. **88**, 159A (1952).
St 52b Stoddart and Gove, Phys. Rev. **87**, 262 (1952).
St 52c Stratton and Freier, Phys. Rev. **88**, 261 (1952).
St 52d Stelson, Preston, and Goodman, Phys. Rev. **86**, 629 (1952).
St 52e Stratton, Freier, Keepin, Rankin, and Stratton, Phys. Rev. **88**, 257 (1952).
Su 51a Sun, Harris, Pecjak, Jennings, Allen, and Nechaj, Phys. Rev. **82**, 266 (1951).
Su 51b Sun, Jennings, Shoupp, and Allen, Phys. Rev. **82**, 267 (1951).
Sw 52 Swann and Mandeville, Phys. Rev. **87**, 215A (1952).
Sz 39 Szalay, Z. Physik **112**, 29 (1939).
Ta 46 Tangen, Kgl. Nord. Vid. Selsk Skr. No. 1 (1946).
Ta 48 Taschek and Hemmendinger, Phys. Rev. **74**, 373 (1948).
Ta 51a Talbott, Busala, and Weiffenbach, Phys. Rev. **82**, 1 (1951).
Ta 51d Talbott, Busala, and Weiffenbach, Catholic University of America Prog. Rept. No. 2 (July, 1951).
Te 47 Templeton, Howland, and Perlman, Phys. Rev. **72**, 758 (1947).
Te 50 Terrell, Phys. Rev. **80**, 1076 (1950).
Te 50c Telegdi and Zünti, Helv. Phys. Acta **23**, 745 (1950).
Te 51a Terrell and Phillips, Phys. Rev. **83**, 703 (1951).
Te 51b Telegdi, Phys. Rev. **84**, 600 (1951).
Te 52 Teichmann and Wigner, Phys. Rev. **87**, 123 (1952).
Te 52a Telegdi, Phys. Rev. **87**, 196A (1952).
Th 49 Thomas, Rubin, Fowler, and Lauritsen, Phys. Rev. **75**, 1612 (1949).
Th 49d Thirion, Compt. rend. **229**, 1007 (1949).
Th 51a Thomas, Phys. Rev. **81**, 661 (1951).
Th 51d Thirion, Compt. rend. **232**, 2418 (1951).
Th 51e Thirion and Muller, Compt. rend. **232**, 1093 (1951).
Th 51f Thirion, Compt. rend. **233**, 37 (1951).
Th 51g Thomas, Phys. Rev. **84**, 1061 (1951).
Th 52 Thomas and Lauritsen, Phys. Rev. (to be published).
Th 52b Thomas (to be published).
Th 52c Thomson, Cohen, French, and Hutchinson, Proc. Phys. Phys. Soc. (London) **65A**, 745 (1952).
Ti 49 Titterton, Nature **163**, 990 (1949).
Ti 50 Titterton, Nature **165**, 721 (1950).
Ti 50a Titterton, Proc. Phys. Soc. (London) **63A**, 915 (1950).
Ti 50b Titterton, Proc. Phys. Soc. (London) **63A**, 1297 (1950).
Ti 51 Titterton, and Brinkley, Proc. Phys. Soc. (London) **64A**, 212 (1951).
Ti 51a Titterton, Phil. Mag. **43**, 113 (1951).
To 49b Tollestrup, Fowler, and Lauritsen, Phys. Rev. **76**, 428 (1949).
To 52 Tollestrup, Day, and Woodbury, Phys. Rev. **85**, 760 (1952).
Tr 52 True and Diesendruck, Phys. Rev. **87**, 381 (1952).
Tu 51 Tucker, Phys. Rev. **82**, 299A (1951).
Tu 51a Tucker, Phys. Rev. **83**, 473 (1951).
Tu 52 Tuck, Arnold, Phillips, Sawyer, and Stovall, Phys. Rev. **88**, 159A (1952).
Tu 52a Tucker and Gregg, Phys. Rev. **87**, 907 (1952).
Ub 42 Ubisch, Kgl. Nord. Vid. Selk. Forh. **15**, 71 (1942).
Va 49 Van Patter, Phys. Rev. **76**, 1264 (1949).
Va 50 Van Patter, Sperduto, Strait, and Buechner, Phys. Rev. **79**, 900 (1950).
Va 51 Van Patter, Sperduto, Huang, Strait, and Buechner, Phys. Rev. **81**, 233 (1951).
Va 51a Van Patter, Buechner, and Sperduto, Phys. Rev. **82**, 248 (1951).
Va 52 Van Patter, Sperduto, Endt, Buechner, and Enge, Phys. Rev. **85**, 142 (1952).
Va 52b Van de Graaff, Sperduto, Buechner, and Enge, Phys. Rev. **86**, 966 (1952).
Ve 51a Vendryes, Compt. rend. **232**, 1549 (1951).
Ve 51b Vendryes, Compt. rend. **233**, 391 (1951).
Wa 48 Walker and McDaniel, Phys. Rev. **74**, 315 (1948).
Wa 50a Walker, Phys. Rev. **79**, 172 (1950).
Wa 50e Way, Fano, Scott, and Thew, Nat'l. Bur. Stds. Circ. 499 (September, 1950), and supplements (April, 1951), (November, 1951), (June, 1952).
Wa 50f Wäffler, Helv. Phys. Acta **23**, 239 (1950).
Wa 51e Wakatsuki and Sugimoto, J. of Phys. Soc. (Japan) **6**, 3, 157, May–June (1951).
Wa 52a Warters and Milne, Phys. Rev. **85**, 761A (1952).

Wa 52b Watson, M.I.T. Prog. Rept. (LNSE) (February and May, 1952); Watson and Buechner, Phys. Rev. (to be published).
We 50a Welton, Phys. Rev. **79**, 399 (1950).
We 52b Wenzel and Whaling, Phys. Rev. **87**, 499 (1952).
Wh 39 White, Delsasso, Fox, and Creutz, Phys. Rev. **56**, 512 (1939).
Wh 41a Wheeler, Phys. Rev. **59**, 16 (1941).
Wh 50c Whitehead, Phys. Rev. **79**, 393 (1950).
Wh 50d Whaling and Bonner, Phys. Rev. **79**, 258 (1950).
Wh 50f Whitehead, Phys. Rev. **79**, 1022 (1950).
Wh 51 Whaling and Li, Phys. Rev. **81**, 150 (1951).
Wh 51b Whitehead, Phys. Rev. **82**, 553 (1951).
Wi 37c Williams, Shepherd, and Haxby, Phys. Rev. **52**, 390 (1937).
Wi 37d Williams, Haxby, and Shepherd, Phys. Rev. **52**, 1031 (1937).
Wi 37e Wilhelmy, Z. Physik **107**, 769 (1937).
Wi 50 Wilkins and Goward, Proc. Phys. Soc. (London) **63A**, 663 (1950).
Wi 50a Wilson, Phys. Rev. **80**, 90 (1950).
Wi 50b Willard, Preston, and Goodman, M.I.T. Tech. Rept. 45 (1950).
Wi 50d Wilkins and Goward, Proc. Phys. Soc. (London) **63A**, 1173 (1950).
Wi 51 Willard, Preston, and Goodman, Phys. Rev. **81**, 329A (1951).
Wi 51a Willard and Preston, Phys. Rev. **81**, 480 (1951).
Wi 51c Wilkins and Goward, Proc. Phys. Soc. (London) **64A**, 201 (1951).
Wi 51d Williamson, Browne, Craig, and Donahue, Phys. Rev. **84**, 731 (1951).
Wi 51f Wilkins and Goward, Proc. Phys. Soc. (London) **64A**, 1056 (1951).
Wi 51g Wilkins and Goward, Proc. Phys. Soc. (London) **64A**, 849 (1951).
Wi 52 Willard, Bair and Kington, Phys. Rev. **87**, 206A (1952).
Wi 52a Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).
Wi 52b Willard and Bair, Phys. Rev. **86**, 629 (1952).
Wo 49a Woodbury, Hall, and Fowler, Phys. Rev. **75**, 1462A (1949).
Wo 50a Wolfenstein, Phys. Rev. **78**, 322A (1950).
Wo 52 Wolfgang and Libby, Phys. Rev. **85**, 437 (1952).
Wo 52a Woodbury and Fowler, Phys. Rev. **85**, 51 (1952).
Wo 52b Woodbury, Day, and Tollestrup, Phys. Rev. **85**, 760A (1952).
Wr 50 Wright, Phys. Rev. **79**, 838 (1950).
Wu 50 Wu, Revs. Modern Phys. **22**, 386 (1950).
Wu 52 Wu, Rustad, Perez-Mendez, and Lidofsky, Phys. Rev. **87**, 1140 (1952).
Wy 49b Wyly, Sailor, and Ott, Phys. Rev. **76**, 1532 (1949).
Wy 49c Wyly, Phys. Rev. **76**, 316 (1949).
Ya 51 Yaffe and Stevens, Can. J. Phys. **29**, 186 (1951); Phys. Rev. **79**, 893 (1950).
Ya 52 Yarnell, Lovberg, Stratton, and Stratton, Phys. Rev. **88**, 158A (1952).
Ya 52a Yarnell, Lovberg, Stratton, and Stratton (unpublished).
Zu 50a Zucker and Watson, Phys. Rev. **78**, 14 (1950).