

Energy Levels of Light Nuclei $A = 16$

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Abstract: An evaluation of $A = 16$ – 17 was published in *Nuclear Physics A564* (1993), p. 1. This version of $A = 16$ differs from the published version in that we have corrected some errors discovered after the article went to press. The introduction and introductory tables have been omitted from this manuscript. [Reference](#) key numbers have been changed to the NNDC/TUNL format.

(References closed December 31, 1992)

This work is supported by the US Department of Energy, Office of High Energy and Nuclear Physics, under: Contract No. DEFG05-88-ER40441 (North Carolina State University); Contract No. DEFG05-91-ER40619 (Duke University).

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$A = 16$ theoretical

Because of the very large body of theoretical work that has been carried out for the $A = 16$, and the importance of the spherical shell model in this work, a general discussion of the shell model description of $A = 16$ nuclei is provided here.¹

The spherical shell-model provides a complete basis for the description of nuclear states. It is convenient to use harmonic oscillator single-particle wave functions since the coordinate transformations necessary to separate spurious center of mass states, to relate shell-model to cluster-model wave functions and so on can be made exactly. Configurations are classified by the number of oscillator quanta that they carry beyond the minimum allowed by the Pauli Principle as $0\hbar\omega$, $1\hbar\omega$, $2\hbar\omega$. . . excitations. Non-spurious states of $A = 16$ in general involve admixtures of $npnh$ configurations but the lowest excitations of each isospin can, with the exception of the $K^\pi = 0^-$ band with the ^{16}O 9.58 MeV 1^- state as bandhead, be thought of as dominantly $p^{-n}(sd)^n$ excitations. In fact, the lowest eigenstates of an $n\hbar\omega$ calculation can usually be written economically in terms of product states of low-lying p^{-n} and $(sd)^n$ eigenstates. In the simplest version of this weak-coupling model, one identifies the p^{-n} and $(sd)^n$ eigenstates with the physical states of the relevant nuclei and takes the diagonal expectation value of $H_p + H_{sd}$ from the known masses. The contribution from the cross-shell, or particle-hole, interaction can often be quite reliably estimated by using ph matrix elements extracted from the nominal $1p1h$ states of ^{16}O or ^{16}N .

The $2p2h$ states with $T = 0$ and $T = 1$ cannot, in general, be described in terms of the simple weak-coupling model, although there are examples to which such a description can be applied. Shell-model calculations which use empirical interactions fitted to data on $1\hbar\omega$ excitations in the mass region do, however, produce $2p2h$ $T = 1$ states in one-to-one correspondence with the lowest positive-parity states of ^{16}N (see Table 16.5). They also produce $T = 0$ $2p2h$ states starting at around 12 MeV in ^{16}O . In this case, the $2p2h$ states are interleaved with $4p4h$ states which begin at lower energies. The lowest $2p2h$ $T = 0$ states can be related in energy to the 14.82 MeV 6^+ state which is strongly populated by the addition of a stretched $d_{5/2}^2$ pair in the $^{14}\text{N}(\alpha, d)^{16}\text{O}$ reaction. The lowest six $2p2h$ $T = 2$ states can be very well described in this way.

Weak-coupling ideas can be extended to the lowest $3p3h$ and $4p4h$ states. Since the 3 and 4 particle (or hole) configurations are strongly configuration mixed in the jj -coupling scheme, the ph interaction is usually represented in the simple monopole form $E_{ph} = a + bt_p \cdot t_h$ plus a small attractive Coulomb contribution. The ph interaction then gives a repulsive contribution of $9a$ and $16a$ to $3p3h$ and $4p4h$ configurations and separates the $T = 0$ and $T = 1$ $3p3h$ states by b MeV. The empirical values of a and b are $a \approx 0.4$ MeV and $b \approx 5$ MeV, which put the $4p4h$ 0^+ state and the $3p3h$ 1^- states close to experimental candidates at 6.05, 12.44 and 17.28 MeV respectively, each of which is the lowest member of a band.

The weak-coupling states can be used as a basis for shell-model calculations, but the elimination of spurious center-of-mass motion is approximate even within an oscillator framework; orbits outside the $p(sd)$ space are needed and can be important components of states of physical interest. If complete $n\hbar\omega$ spaces are used, the choice of basis can be one of computational convenience. A more physical LS-coupled basis is obtained by classifying the states according to the Wigner

¹ We are very grateful to Dr. John Millener for providing these comments on the shell model for the $A = 16$ system.

supermultiplet scheme ($SU4 \supset SU2 \times SU2$ symmetry $[\tilde{f}]$ in spin-isospin space) and the $SU3$ symmetry $(\lambda \mu)$ of the harmonic oscillator. States with the highest spatial symmetry $[f]$ maximize the number of spatially symmetric interacting pairs to take advantage of the fact that the NN interaction is most strongly attractive in the relative $0s$ state and weak or repulsive in relative p states. These symmetries are broken mainly by the one-body spin-orbit interaction. In np and nh calculations the lowest states are dominated by the $[f](\lambda \mu)$ configurations $[n](2n 0)$ and $[4^2 4 - n](0 n)$ respectively (these symmetries are very good if the one-body spin-orbit interaction is turned off). In nph calculations, the lowest states are dominated by the highest spatial symmetry allowed for given isospin T and $(2n n)$ $SU3$ symmetry. These states are identical to harmonic oscillator cluster-model states with $2n$ quanta on the relative motion coordinate between the nh core and the np cluster. States with a large parentage to the ground state of the core should be seen strongly in the appropriate transfer reaction.

In the above, a basic $n\hbar\omega$ (mainly nph) shell-model structure has been matched, through characteristic level properties and band structures, with experimental candidates. The mixing between shell-model configurations of different $n\hbar\omega$ is of several distinct types.

First, there is direct mixing between low-lying states with different nph structure; the $p^2 \rightarrow (sd)^2$ mixing matrix elements ($SU3$ tensor character mainly $(4 2)$) are not large (up to a few MeV) although the mixing can be large in cases of near degeneracy.

A second type of mixing is more easily understood by reference to cluster models in which an oscillator basis is used to expand the relative motion wave function. To get a realistic representation of the relative motion wave function for a loosely-bound state or an unbound resonance requires many oscillators up to high $n\hbar\omega$ excitation. A related problem, which also involves the radial structure of the nucleus, occurs for the expansion of deformed states (of which cluster states are an example) in a spherical oscillator (shell-model) basis; e.g., deformed Hartree-Fock orbits may require an expansion in terms of many oscillator shells. It is difficult to accommodate this type of radial mixing in conventional shell-model calculations, but symplectic $Sp(6, R)$ shell-models, in which the $SU3$ algebra is extended to include $1p1h$ $2\hbar\omega$ monopole and quadrupole excitations, do include such mixing up to high $n\hbar\omega$.

A third type of mixing involves the coupling of nph excitations to high-lying $(n + 2)\hbar\omega$ configurations via the strong $(\lambda \mu) = (2 0)$ component of the $p^2 \rightarrow (sd)^2$ interaction. In the full $(0 + 2 + 4)\hbar\omega$ calculations, the large (30-45%) $2p2h$ admixtures in the ground state are mainly of the $(2 0)$ type, which are intimately related to the ground-state correlations of RPA theory, and lead to the enhancement (quenching) of $\Delta T = 0$, $\Delta S = 0$ (otherwise) excitations at low momentum transfer.

For most detailed structure questions, a shell-model calculation is required to include the relevant degrees of freedom. For example, (1990HA35) address two important problems with complete $(0 + 2 + 4)\hbar\omega$ and $(1 + 3)\hbar\omega$ model spaces. One is the rank-zero $^{16}\text{N}(0^-) \rightarrow ^{16}\text{O}(gs) \beta$ decay and the inverse μ capture which receive large two-body meson-exchange current contributions. The other is the distribution of M1 and Gamow-Teller strength based on the ^{16}O ground state; this is a complicated problem which involves $2p2h \dots$ admixtures in the ground state which break $SU4$ symmetry.

Many interesting structure problems remain. A detailed understanding of the shapes and magnitudes of inelastic form factors is lacking, particularly the shapes at momentum transfers beyond 2 fm^{-1} . Even in the relatively simple case of M4 excitations, much studied via (e, e') , (p, p') and (π, π') reactions, a rather low value of the oscillator parameter b is required to describe the form factor. Also, the configuration mixing which splits the $4^-; T = 0$ strength into two major components and causes isospin mixing has not been satisfactorily described by a shell-model calculation. Similar interesting problems occur for isospin-mixed negative-parity states near 13 MeV excitation energy. It is worth noting that, to avoid some serious consistency problems, the large shell-model calculations have omitted orbits outside the $p(sd)$ space except in as much to cleanly separate spurious center-of-mass states. A consistent treatment of $1p1h$ and $2p2h$ correlations in multi- $\hbar\omega$ shell-model spaces remains a challenging question.

^{16}He
(not illustrated)

This nucleus has not been observed. See ([1982AV1A](#), [1983ANZQ](#), [1986AJ04](#)).

^{16}Li
(not illustrated)

This nucleus has not been observed. Shell model studies ([1988POZS](#)) are used to predict J^π and the magnetic dipole moment.

^{16}Be
(not illustrated)

This nucleus has not been observed. Its atomic mass is calculated to be 59.22 MeV. It is then unstable with respect to breakup into $^{14}\text{Be} + 2n$ by 2.98 MeV. See ([1974TH01](#), [1986AJ04](#), [1987SA15](#)). The first three excited states with $J^\pi = 2^+, 4^+, 4^+$ are calculated to be at 1.90, 5.08, and 6.51 MeV using a $(0 + 1)\hbar\omega$ space shell model ([1985PO10](#)).

^{16}B
(not illustrated)

This nucleus has not been observed in the 4.8 GeV proton bombardment of a uranium target. It is particle unstable. Its mass excess is predicted to be 37.97 MeV; it would then be unstable with respect to decay into $^{15}\text{B} + n$ by 0.93 MeV. See ([1985WA02](#), [1986AJ04](#)). The ground state is predicted to have $J^\pi = 0^-$ and the first three excited states are predicted to lie at 0.95, 1.10, and 1.55 MeV [$J^\pi = 2^-, 3^-, 4^-$] in a $(0 + 1)\hbar\omega$ space shell model calculation. See ([1983ANZQ](#), [1985PO10](#), [1986AJ04](#)). Predicted masses and excitation energies for higher isospin multiplets for $9 \leq A \leq 60$ are included in the compilation ([1986AN07](#)). An experiment ([1985LA03](#)) involving in-flight identification of fragments from 44 MeV/u ^{40}Ar found no trace of ^{18}B or ^{16}B and provides strong evidence that ^{16}B is particle-unstable.

^{16}C
(Figs. 1 and 5)

GENERAL: See Table 16.1.

1. $^{16}\text{C}(\beta^-)^{16}\text{N}$ $Q_m = 8.012$

The half life of ^{16}C is 0.747 ± 0.008 sec. It decays to $^{16}\text{N}^*(0.12, 3.35, 4.32)$ [$J^\pi = 0^-, 1^+, 1^+$]: see Table 16.3 and (1993CH06). See also (1986AJ04) and see (1986KI05, 1988WA1E, 1992WA1L) for theoretical discussions of extended shell-model calculations of $0^+ \rightarrow 0^-$ transitions and determination of the mesonic enhancements ε_{mec} of the time-like component of the axial current. See also (1992TO04) and see ^{16}N , reaction 1.

2. $^{14}\text{C}(t, p)^{16}\text{C}$ $Q_m = -3.013$

States of ^{16}C observed in this reaction are displayed in Table 16.2. See also Table 16.3 of (1982AJ01).

3. $^{16}\text{O}(\text{K}^-, \pi^+)_{\Sigma}^{16}\text{C}$

(1985BE31) used negative kaons of 450 MeV/c to produce Σ hypernuclear states, which they interpreted as Σ^- particles in the $p_{3/2}$ and $p_{1/2}$ orbits of the $^{16}_{\Sigma}\text{C}$ hypernucleus. Their energy splitting was used to constrain the Σ^- spin-orbit coupling.

(1986HA26) performed a systematic shell-model analysis of Σ -hypernuclear states, in which they deduced a ΣN -spin-orbit interaction about twice as strong as the one for the nucleon. (1986MA1J) reached a similar conclusion after extracting the one-particle spin-orbit splitting $\varepsilon_{\Sigma} = \varepsilon^{\Sigma}_{p_{1/2}} - \varepsilon^{\Sigma}_{p_{3/2}}$. (1987WU05) used the continuum shell-model to study competition between resonant and quasi-free Σ -hypernuclear production. The observed structures in the excitation spectra are essentially accounted for by the quasi-free mechanism alone. (1989DO1I) perform a series of shell model calculations of energy spectra of p-shell Σ hypernuclei, starting with several different parametrizations of the ΣN effective interaction. Production cross sections are estimated using DWBA. They suggest experiments to resolve open questions regarding the ΣN and Σ -nucleus interactions. (1989HA32) uses the recoil continuum shell model to calculate in-flight Σ hypernuclei production of this reaction (and others). They needed to modify the ΣN central interaction to fit data.

Coupled channels (CC) calculations for Σ -hypernuclear spectra give an energy integrated cross section which is about 1.7 times the experimental value (1987HA40). (1988HA44) report CC calculations emphasizing the proper treatment of the Σ continuum states. They find that a weak Σ central potential and a comparable $\Sigma\Lambda$ conversion potential are required to describe experiment.

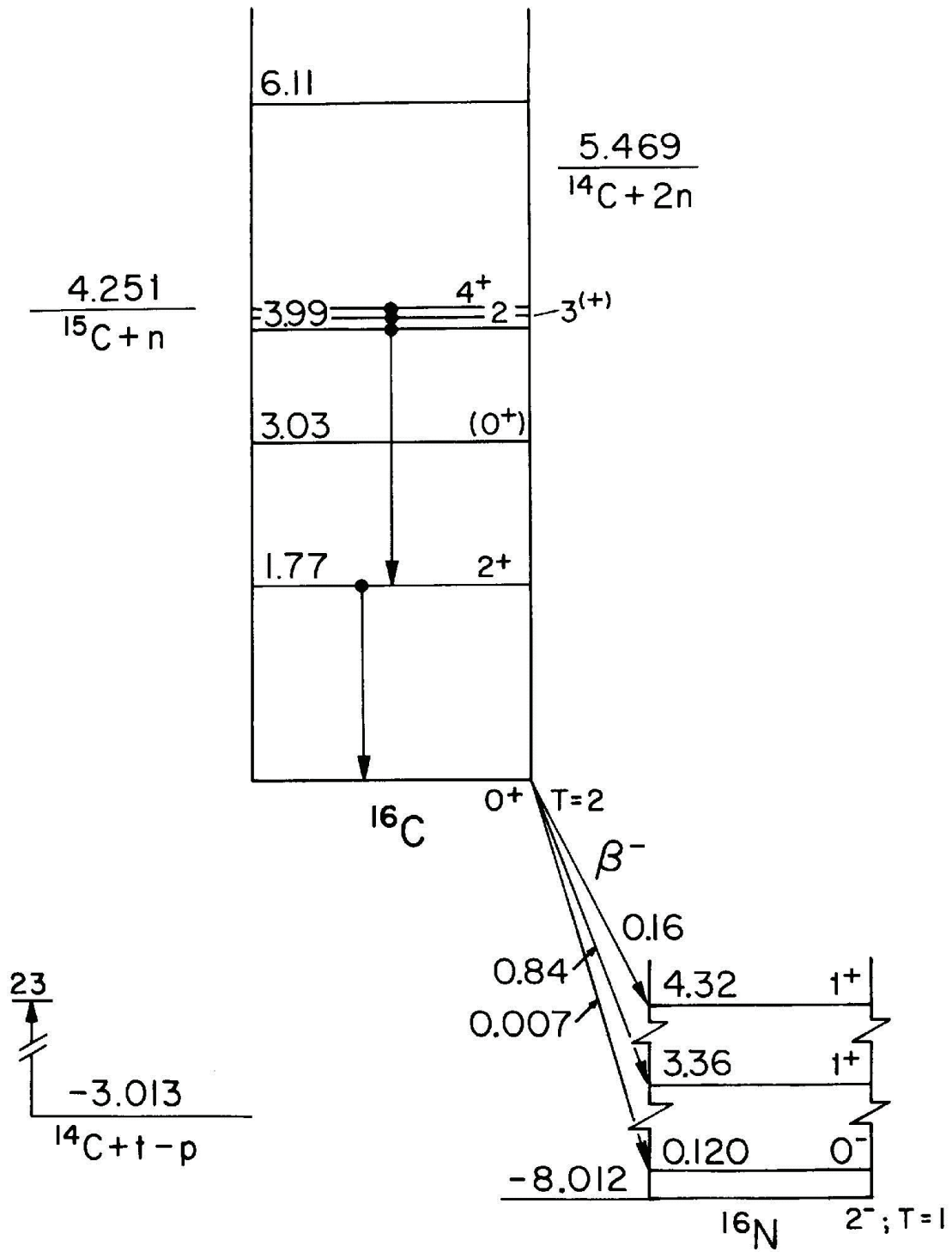


Fig. 1: Energy levels of ^{16}C . For notation see Fig. 2.

Table 16.1: ^{16}C – General

Reference	Description
Complex Reactions	
1986BI1A	Heavy ion secondary beams - Results from GANIL
1987GU04	Exotic emission of ^{14}C & other heavy clusters in the fragmentation of $^{222-224}\text{Ra}$ & ^{232}U
1987RI03	Isotopic distributions of fragments in intermediate energy heavy ion reactions
1987SA25	The LISE spectrometer at GANIL (secondary radioactive beam production)
1987SN01	Partitioning of a 2-component particle system & isotope distribution in fragmentation
1987VI02	Anisotropies in transfer-induced fission of $^{16}\text{O} + ^{232}\text{Th}$
1988RU01	Dynamic treatment of ternary fission - calculates light charged particle formation
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei (exp. results)
Hypernuclei	
1987FA1A	Review of International Conference on a European Hadron Facility
1988MA09	Hypernucleus production by K^- capture at rest on ^{16}O targets
1989BA92	Strangeness production by heavy ions
Other Topics	
1986AN07	Predicted masses & excitation energies in higher isospin multiplets for $9 \leq A \leq 60$
1987BL18	Calc. ground state energy of light nuclei (& excited states for $N = Z$) using H-F method
1989PO1K	Exotic light nuclei and nuclei in the lead region
1989RA16	Predictions of $B(\text{E}2; 0_1^+ - 2_1^+)$ values for even-even nuclei
Ground State Properties	
1987BL18	Calculated ground state energies using Gogny's effective interaction and HF method
1987SA15	Hartree-Fock calculations of light neutron-rich nuclei using Skyrme interactions
1988POZS	Shell model study of light exotic nuclei - compares calculated ground state prop. to data
1989RA16	Predictions of $B(\text{E}2; 0_1^+ - 2_1^+)$ values for even-even nuclei
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei

Table 16.2: Energy Levels of ^{16}C

E_x (MeV \pm keV)	$J^\pi; T$	$\tau_{1/2}$ (sec) or Γ (keV)	Decay	Reactions
0	$0^+; 2$	$\tau_{1/2} = 0.747 \pm 0.008$	β^-	1, 2
1.766 ± 10	2^+		γ	2
3.027 ± 12	(0^+)		(γ)	2
3.986 ± 7	2		γ	2
4.088 ± 7	$3^{(+)}$		γ	2
4.142 ± 7	4^+		γ	2
6.109 ± 15	$(2^+, 3^-, 4^+)$		$\Gamma \leq 25$	

Table 16.3: The β^- decay of ^{16}C

Decay to $^{16}\text{N}^*$ (MeV)	J^π	Branch (%)	$\log ft$
0.120	0^-	$0.68^{+0.09}_{-0.11}$ ^a	$6.70^{+0.07}_{-0.05}$
0.298	3^-	< 0.5 ^b	> 6.83
0.397	1^-	< 0.1 ^a	> 7.46
3.35	1^+	84.4 ± 1.7 ^b	3.551 ± 0.012
4.32	1^+	15.6 ± 1.7 ^b	3.83 ± 0.05

^a (1983GA03). See also (1984GA1A).

^b (1976AL02).

¹⁶N
(Figs. 2 and 5)

GENERAL: See Table 16.4.

For a comparison of analog states in ¹⁶N and ¹⁶O, see (1983KE06, 1983SN03).

1. ¹⁶N(β^-)¹⁶O $Q_m = 10.419$

The half-life of ¹⁶N is 7.13 ± 0.02 sec: see Table 16.3 in (1971AJ02). From the unique first-forbidden character of the β decay [see Table 16.25 and (1984WA07)], ¹⁶N must have $J^\pi = 2^-$: see ¹⁶O, reaction 39. See also (1985HE08, 1988BA15).

The β -decay of ¹⁶N*(0.12) [$J^\pi = 0^-$] has been measured (1983GA18, 1985HA22); adopted value: $\lambda_\beta = 0.489 \pm 0.020 \text{sec}^{-1}$ (1985HE08). The relationship of this rate to that for ¹⁶O(μ^-, ν)¹⁶N(0^-) [see reaction 18] and the fact that the large values of these rates support the prediction (1978GU05, 1978GU07, 1978KU1A) of a large ($\approx 60\%$) enhancement over the impulse approximation (e.g., $\varepsilon_{\text{mec}} = 1.60$) has been the subject of a great deal of theoretical study, see, e.g. (1981TO16, 1986KI05, 1986TO1A, 1988WA1E, 1990HA35). The work of (1990HA35, 1992WA1L) is a culmination of present knowledge on the determination and interpretation of ε_{mec} . See also (1992TO04). A branching ratio $R(0^- \rightarrow 1^-)/(0^- \rightarrow 0^+) = 0.09 \pm 0.02$ has been reported (1988CH30), implying $\log ft = 4.25 \pm 0.10$ for the $0^- \rightarrow 1^-$ transition to the ¹⁶O 7.12-MeV level.

2. ⁷Li(¹¹B, pn)¹⁶N $Q_m = 2.533$

Gamma rays with $E_\gamma = 120.42 \pm 0.12$, 298.22 ± 0.08 and 276.85 ± 0.10 keV from the ground state decays of ¹⁶N*(0.12, 0.30) and the decay of the state at 397.27 ± 0.10 keV to the first excited state have been studied. τ_m for ¹⁶N*(0.30, 0.40) are, respectively, 133 ± 4 and 6.60 ± 0.48 psec. See (1986AJ04). Cross section measurements for ⁷Li + ¹¹B at $E(\text{c.m.}) = 1.45\text{--}6.10$ MeV have been reported (1990DA03).

- | | | |
|--|----------------|----------------|
| 3. (a) ⁹ Be(⁷ Li, n) ¹⁵ N | $Q_m = 18.082$ | $E_b = 20.572$ |
| (b) ⁹ Be(⁷ Li, 2n) ¹⁴ N | $Q_m = 7.249$ | |
| (c) ⁹ Be(⁷ Li, t) ¹³ C | $Q_m = 8.179$ | |
| (d) ⁹ Be(⁷ Li, α) ¹² B | $Q_m = 10.461$ | |
| (e) ⁹ Be(⁷ Li, ⁸ Li) ⁸ Be | $Q_m = 0.368$ | |

At incident ⁷Li energies of 40 MeV, neutron yields at 0° for reactions (a) and (b) are 50 to 70 times smaller than for 40 MeV deuteron-induced reactions on ⁹Be (1987SC11). For reactions (c, d, e) see (1982AJ01).

Table 16.4: ^{16}N – General

Reference Description

Model Calculations

- 1984VA06 Shell-model treatment of $(0 + 1)\hbar\omega$ states in $A = 4-16$ nuclei
- 1987VA26 An effective interaction derived from spectra and static moments for $A = 4-16$
- 1988VA03 Static moments from a phenomenological interaction
- 1988MI1J Shell model transition densities for electron and pion scattering
- 1992WA22 Effective interactions for the $0p1s0d$ nuclear shell-model space

Complex Reactions

- 1986BI1A Heavy ion secondary beams of radioactive nuclei
- 1986GA1P Spin response function obtained in heavy ion charge-exchange reactions
- 1986HA1B Microscopic model of nucleus-nucleus collisions
- 1986PO06 Calc. half-lives & kinetic energies for spontaneous emission of heavy ions from nuclei
- 1987AN1A Achromatic spectrometer LISE at GANIL: produc. & ident. of nuclei far from $Z = N$
- 1987BA1T Spin-isospin excitations in nuclei with relativistic heavy ions
- 1987BA38 Systematics of the $^{14}\text{N} + ^{159}\text{Tb}$ reaction between 6 and 33 MeV/u
- 1987BU07 Projectile-like fragments from $^{20}\text{Ne} + ^{197}\text{Au}$ – counting simultaneously emitted neutrons
- 1987EL14 Isovector excitations in nuclei with composite projectiles: (^3He , t), (d, ^2He) & heavy ions
- 1987RI03 Isotopic distributions of fragments from $^{40}\text{Ar} + ^{68}\text{Zn}$ at $E=27.6$ MeV/u
- 1987VI02 Anisotropies in transfer-induced fission of $^{16}\text{O} + ^{232}\text{Th}$
- 1988SA19 Systematics of isotope production rates: unification of different methods of analysis
- 1989BA92 Strangeness production by heavy ions
- 1989SA10 Total cross sections of reactions induced by neutron-rich light nuclei
- 1989TE02 Dissipative mechanisms in the 120 MeV $^{19}\text{F} + ^{64}\text{Ni}$ reaction
- 1989YO02 Quasi-elastic & deep inelastic transfer in $^{16}\text{O} + ^{197}\text{Au}$ for $E < 10$ MeV/u

Hypernuclei

- 1988RO11 Distorted wave impulse approximation study of hypernuclear photoproduction
- 1989BA92 Strangeness production by heavy ions
- 1989BE02 Kaon photoproduction from nuclei in a relativistic nuclear model
- 1989BE11 Electromagnetic production of Σ hypernuclei
- 1989TA04 Absorptive effects in $K + \Lambda$ photoproduction on nucleons and nuclei
- 1989TA17 Compound-hypernucl. interpretation on $^4_{\Lambda}\text{H}$ formation probab. in stopped- K^- absorption
- 1989TA32 Schmidt diagrams and configuration mixing effects on hypernuclear magnetic moments

Table 16.4: ^{16}N – General (continued)

Reference Description

Reactions involving Pions, Muons & Neutrinos

[1985GR1A](#) Induced weak currents in nuclei

[1989CH31](#) Photoproduction of pions off nucleons and nuclei

Ground State Properties

[1986AN07](#) Predicted masses & excitation energies in higher isospin multiplets for $9 \leq A \leq 60$

[1989RA17](#) Table of nuclear moments (^1H – ^{254}Es)

4. $^9\text{Be}(^9\text{Be}, \text{np})^{16}\text{N}$ $Q_m = 1.652$

Cross sections were measured for characteristic ^{16}N gamma rays for incident ^9Be energies $E_{\text{c.m.}} = 1.4\text{--}3.4$ MeV. The n, p and all other two-particle emission channels are enhanced by a factor of 2–3 relative to predictions of DWBA calculations ([1988LA25](#)).

5. $^{10}\text{B}(^7\text{Li}, \text{p})^{16}\text{N}$ $Q_m = 13.986$

See Table [16.6](#) and ([1982AJ01](#)).

Fig. 2: Energy levels of ^{16}N . 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. Values of total angular momentum J , parity, and isobaric spin T which appear to be reasonably well established are indicated on the levels; less certain assignments are enclosed in parentheses. For reactions in which ^{16}N is the compound nucleus, some typical thin-target excitation functions are shown schematically, with the yield plotted horizontally and the bombarding energy vertically. Bombarding energies are indicated in laboratory coordinates and plotted to scale in cm coordinates. 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 is sometimes 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. Further information on the levels illustrated, including a listing of the reactions in which each has been observed, is contained in the master table, entitled “Energy levels of ^{16}N ”.

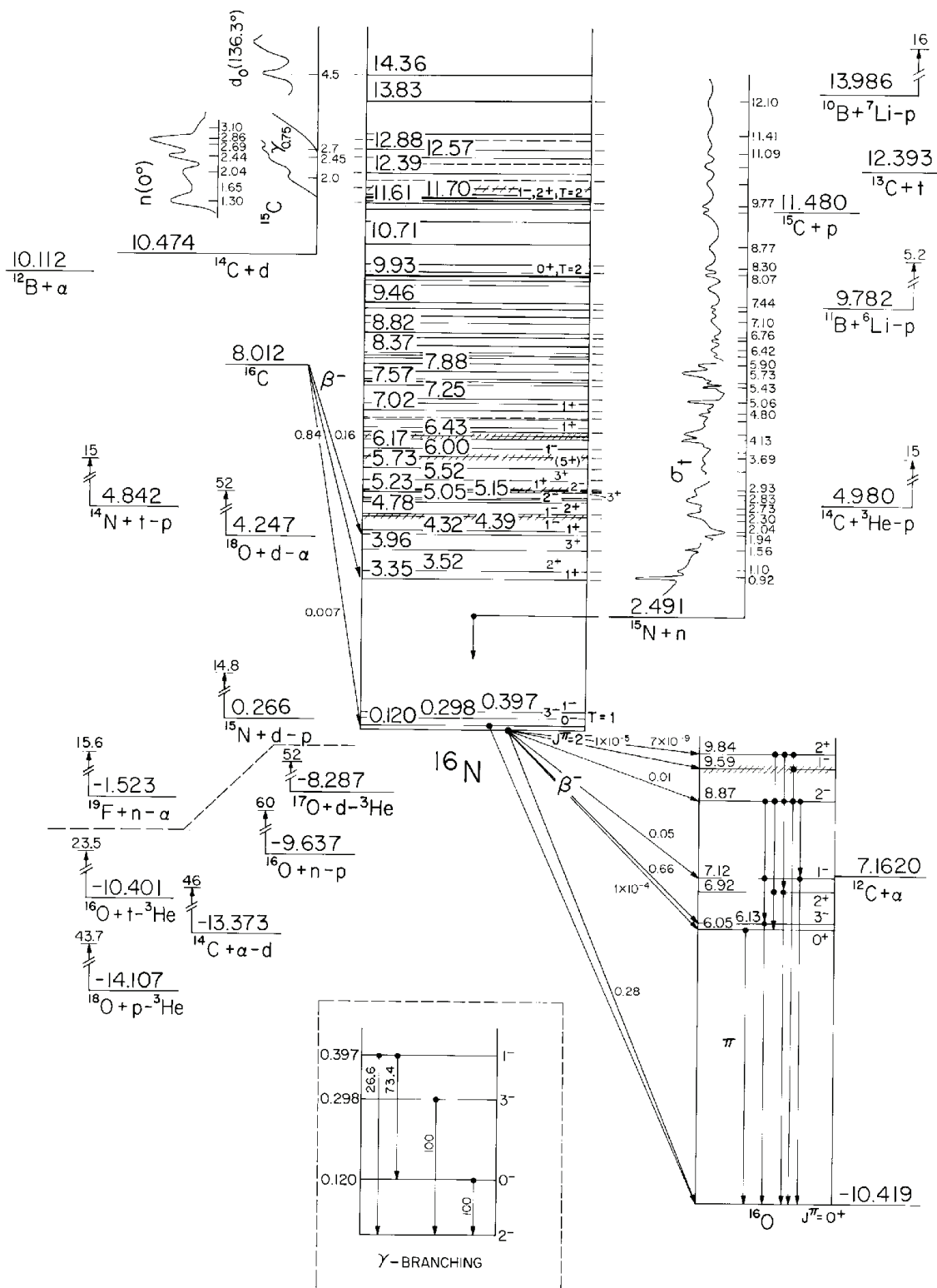


Table 16.5: Energy Levels of ^{16}N

E_x (MeV \pm keV)	$J^\pi; T$	τ or $\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
0	$2^-; 1$	$\tau_{1/2} = 7.13 \pm 0.02$ sec	β^-	1, 2, 4, 5, 7, 9, 11, 12, 16, 19, 20, 21, 22, 23, 24, 25, 27, 28
0.12042 ± 0.12	0^-	$\tau_m = 7.58 \pm 0.09$ μsec	γ, β^-	1, 2, 4, 5, 7, 9, 11, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28
0.29822 ± 0.08	3^-	$\left\{ \begin{array}{l} 131.7 \pm 1.9 \text{ psec} \\ g = 0.532 \pm 0.0200 \end{array} \right.$	γ	2, 4, 5, 7, 9, 10, 11, 16, 19, 20, 21, 22, 23, 24, 25, 27, 28
0.39727 ± 0.10	1^-	$\left\{ \begin{array}{l} \tau_m = 5.63 \pm 0.05 \text{ psec} \\ g = -1.83 \pm 0.130 \end{array} \right.$	γ	2, 4, 5, 7, 9, 11, 16, 18, 19, 20, 21, 22, 27, 28
3.3528 ± 2.6	$(1^+)^c$	$\Gamma = 15 \pm 5$	n	5, 7, 9, 11, 13, 14, 15, 16, 17, 22, 25, 27
3.5227 ± 2.6	2^+	3	n	5, 7, 9, 11, 13, 16, 22, 25, 27
3.9627 ± 2.6	3^+	≤ 2	n	5, 7, 9, 10, 11, 13, 16, 22, 25, 27
4.3204 ± 2.7	1^+	20 ± 5	n	5, 9, 11, 13, 14, 15, 16, 17
4.3914 ± 2.7	1^-	82 ± 20	n	5, 7, 9, 11, 13, 16
4.76 ± 50	1^-	250 ± 50	n	11, 13, 16
4.7828 ± 2.7	2^+	59 ± 8	n	5, 7, 9, 11, 13, 16
5.0537 ± 2.7	2^-	19 ± 6	n	5, 9, 11, 13, 16
5.129 ± 7	$\geq 2^a$	$\leq 7 \pm 4$	n	5, 7, 9, 11, 13, 16, 25
5.150 ± 7	$(3)^-; 1^{a,d}$	$\leq 7 \pm 4$	n	5, 7, 9, 11, 13, 16, 25
5.2301 ± 2.6	3^+	≤ 4	n	5, 9, 11, 13, 16, 27
5.25 ± 70	2^-	320 ± 80	n	11, 16
5.318 ± 3	$(0^-, 1^+)$	(260)	n	5, 13
5.5216 ± 2.5	3^+	$\leq 7 \pm 4$	n	5, 7, 9, 11, 13, 16, 22, 24, 27
5.7317 ± 2.5	$(5^+)^e$	$\leq 7 \pm 4$	n	5, 7, 9, 10, 11, 13, 15, 16, 22, 24, 27
6.003 ± 3	1^-	270 ± 30	n	5, 11, 13, 27

Table 16.5: Energy Levels of ^{16}N (continued)

E_x (MeV \pm keV)	$J^\pi; T$	τ or $\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
6.1707 ± 2.4	$4^-; 1$	$\leq 7 \pm 4$	n	5, 7, 9, 11, 16, 20, 22, 24, 27
6.3739 ± 2.8	$(3^-; 1)$	30 ± 6	n	5, 7, 11, 13, 16, 22, 27
6.426 ± 7		300 ± 30		11, 16
6.5054 ± 2.8	1^+	34 ± 6	(n)	5, 11, 13, 16, 24, 27
6.6085 ± 2.8	(4)	$\leq 7 \pm 4$		5, 7, 11, 16, 27
6.845 ± 4		$\leq 7 \pm 4$		7, 9, 11, 16, 27
(6.84)	≥ 2	> 140	13	
7.02 ± 20	1^+	22 ± 5	n	11, 13, 16, 27
7.134 ± 7		$\leq 7 \pm 4$		9, 11, 16, 27
7.250 ± 7	≥ 2	17 ± 5	n	7, 11, 13, 16, 27
7.572 ± 4	$\geq 3^b$	$\leq 7 \pm 4$	n	7, 9, 10, 11, 13, 16, 27
7.637 ± 4	$(3, 4, 5)^+ b$	$\leq 7 \pm 4$		7, 9, 10, 11, 16, 27
7.674 ± 4	(b)	$\leq 7 \pm 4$	n	7, 9, 11, 13, 16, 24, 27
7.877 ± 9	≥ 4	100 ± 15	n	7, 11, 13, 16, 20, 27
8.048 ± 9		85 ± 15	n	11, 13, 27
8.199 ± 5	$(3, 2)^+$	28 ± 8		9, 11, 27
8.282 ± 8		24 ± 8		11, 27
8.365 ± 8	≥ 1	18 ± 8	n	7, 11, 13, 27
8.49 ± 30	≥ 1	≤ 50	n	13, 27
8.72	≥ 1	40	n	13
8.819 ± 15		≤ 50	n	7, 13, 27
9.035 ± 15		≤ 50		27
9.16 ± 30	≥ 2	100	n	13, 27
9.34 ± 30		≤ 50	n	13, 27
9.459 ± 15	≥ 2	100	n	7, 13, 24, 27
9.760 ± 10	$T = 1$	15 ± 8		7, 9, 27
9.813 ± 10	$T = 1$			9
9.928 ± 7	$0^+; T = 2$	< 12		9, 26
10.055 ± 15	≥ 3	30	n	7, 13, 27
10.37 ± 40	≥ 2	165	n	7, 13

Table 16.5: Energy Levels of ^{16}N (continued)

E_x (MeV \pm keV)	$J^\pi; T$	τ or $\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
10.71	≥ 2	120	n	13
11.16 \pm 40				7
11.49	≥ 3		n	13
11.61	≥ 3	220	n, d	8,13
11.701 \pm 7	$2^+; 2$	< 12		9
11.75 \pm 40		< 50		7
(11.92)		390	n,d	8
(12.09)			n	13
12.39 \pm 60		290	n, p, d	7, 8
12.57 \pm 60		180	n, p, d	7, 8
12.88		155	n, p, d	8, 13
(12.97)		175	n, d	8
13.11 \pm 60			n, (d)	7, 8, 13
13.83			n	13
14.1	$(7^+; 2)^f$			
14.36 \pm 50	$(3)^+$	180	d	7, 8

^a See also Table 16.6.

^b See also Table 16.7.

^c May be a doublet. See (1985BLZY) and see Table 16.15.

^d Probably the analog of $^{16}\text{O}^*(18.029)$, D.J. Millener, private communication.

^e May be a 2^- , 5^+ doublet – the analogs of ^{16}O states at $E_x = 18.454$ and 18.640 MeV, $J^\pi = (2^-)$ and 5^+ , respectively (D.J. Millener, private communication).

^f (1987AZZZ) and D.J. Millener, private communication.

$$6. \text{}^{12}\text{C}(\text{}^{16}\text{O}, \text{}^{16}\text{N})\text{}^{12}\text{N} \quad Q_m = -27.757$$

^{16}N spectra were measured for incident ^{16}O energies of 900 MeV/nucleon. Transitions to the low-lying GDR, the quasi-elastic, and the Δ -regions were observed (1987EL14).

$$7. \text{}^{13}\text{C}(\alpha, \text{p})\text{}^{16}\text{N} \quad Q_m = -7.422$$

Table 16.6: States of ^{16}N from $^{10}\text{B}(^7\text{Li}, \text{p})^{\text{a}}$

E_x^{b} (MeV)	J^{c}	E_x^{b} (MeV)	J^{c}
0		5.142	e
0.124		5.230	f
0.296		5.318	0, 1
0.400		5.525	4, 3 ^g
3.352	c	5.734	h
3.524	c	6.002	1 ^f
3.964	c	6.172	i
4.321	c	6.374	c
4.392	c	6.504	c
4.785	c	6.608	4 ^j
5.054	1, 2 ^d		

^a For references see (1986AJ04).

^b ± 3 keV.

^c Based on the assumption that the angle-integrated cross section is proportional to $2J + 1$. States labelled ^c have J consistent with known values.

^d If a doublet, $J = 1$ and 0 .

^e Doublet (1986AJ04).

^f Narrow state.

^g If a doublet, and if one state is 3^+ , the second member would have $J = 0$.

^h If a doublet of which one member is 5^+ , the other would have $J = 2$ (1, 3).

ⁱ May be a doublet (1986AJ04).

^j $J = 4$, if a single state.

Differential cross sections measured (1986AN30) at $E_\alpha = 118$ MeV were analyzed using DWBA calculations with microscopic form factors to obtain J^π and to locate multiparticle-multihole strength in ^{16}N : see Table 16.7. Measurements at $E_\alpha = 34.9$ MeV are summarized in Table 16.5 of (1986AJ04). See also (1988MIZY, 1988BRZY).

8. (a) $^{14}\text{C}(\text{d}, \gamma)^{16}\text{N}$ $Q_m = 10.474$ $E_b = 10.474$
 (b) $^{14}\text{C}(\text{d}, \text{n})^{15}\text{N}$ $Q_m = 7.984$
 (c) $^{14}\text{C}(\text{d}, \text{p})^{15}\text{C}$ $Q_m = -1.006$
 (d) $^{14}\text{C}(\text{d}, \text{d})^{14}\text{C}$

Table 16.7: States of ^{16}N from $^{13}\text{C}(\alpha, p)$ ^a

E_x (MeV)	Γ (keV)	J^π	E_x (MeV)	Γ (keV)	J^π
0.00		2^-	8.83	45 ± 30	
0.12		0^-	9.08 ^b	195 ± 30	
0.30		3^-	9.35 ^b	90 ± 30	
0.40		1^-	9.49 ^c	70 ± 30	
3.36			9.70 ^d	≤ 30	
3.52			9.81 ^d	90 ± 30	
3.96	≤ 20		10.07	35 ± 20	
4.40	110 ± 30		10.40		
4.77 ^b	170 ± 30		10.80		
5.05 ^b			11.21 ^d	≤ 30	(6^-)
5.14 ^{b, d}			11.66	170 ± 40	
5.23 ^b			11.81 ^d	≤ 20	(7^-)
5.73 ^d	< 20	doublet $4^-, 5^+$	12.27 ^b	≈ 100	
6.17	< 20	4^-	12.46 ^{b, d}	90 ± 30	
6.44	260 ± 50		12.61	100 ± 30	
6.60 ^c	< 20		12.95	170 ± 30	
6.82 ^b	< 20		13.35	60 ± 30	
7.57 ^b	< 20		13.65 ^c	45 ± 30	
7.64 ^b	< 20		14.41 ^a	≈ 100	
7.68 ^b	< 20	unresolved $4^-, 5^-$ $4^-, 5^-$			

^a (1986AN30) $E_d = 118$ MeV; DWBA analysis.

^b Data available at less than four angles.

^c Angular distributions over limited angular range.

^d State is observed strongly in $^{13}\text{C}(^6\text{Li}, ^3\text{He})^{16}\text{N}$ (1977MA1B).

Table 16.8: States of ^{16}N from $^{14}\text{C}(^3\text{He}, \text{p})$ ^a

E_x (MeV \pm keV)	Γ (keV)	$J^\pi; T$	E_x (MeV \pm keV)	Γ (keV)	$J^\pi; T$
0.121 ± 6		0^-	5.724 ± 5		5^+
0.298 ± 6		3^-	6.168 ± 5		
0.396 ± 7			6.843 ± 5		
3.348 ± 7		1^+	7.113 ± 5		
3.517 ± 7		$2^+, (3)^+$	7.570 ± 5		
3.958 ± 7		$(2)^+, 3^+$	7.636 ± 5		
4.313 ± 9		1^+	7.673 ± 5		
4.386 ± 9			8.205 ± 5		
4.768 ± 11			9.760 ± 10	15 ± 8	$T = 1$
5.052 ± 9			9.813 ± 10		$T = 1$
5.137 ± 9			9.928 ± 7	< 12	$0^+; 2$
5.234 ± 9		$(1, 2, 3)^+$	11.701 ± 7	< 12	$1^-, 2^+; 2$
5.512 ± 5		$(1, 2, 3)^+$			

^a For references see Table 16.5 in (1977AJ02).

For reaction (a) see (1971AJ02). Resonances observed in reactions (b, c, d) are displayed in Table 16.5 of (1982AJ01). Total cross sections for reaction (b) have been measured for $0.2 \leq E_{\text{c.m.}} \leq 2.1$ MeV (1992BR05).

$$9. \ ^{14}\text{C}(^3\text{He}, \text{p})^{16}\text{N} \quad Q_{\text{m}} = 4.980$$

Proton groups have been observed to ^{16}N states with $E_x < 12$ MeV and angular distributions [with $E(^3\text{He}) \leq 15$ MeV] lead to the J^π assignments shown in Table 16.8.

$$10. \ ^{14}\text{C}(\alpha, \text{d})^{16}\text{N} \quad Q_{\text{m}} = -13.373$$

At $E_\alpha = 46$ MeV the angular distributions of the groups to $^{16}\text{N}^*(0.30, 3.96, 5.73, 7.60)$ have been determined: the most strongly populated state is the (5^+) state $^{16}\text{N}^*(5.73)$. See (1971AJ02).

$$11. \ ^{14}\text{N}(\text{t}, \text{p})^{16}\text{N} \quad Q_{\text{m}} = 4.842$$

Table 16.9: States in ^{16}N from $^{14}\text{N}(t, p)$ ^a

E_x (MeV \pm keV)	Γ (keV)	L	J^π
0		3	2^- ^f
0.120 ± 10		1	0^- ^f
0.300 ± 10		3	3^- ^f
0.399 ± 10 ^b		1	1^- ^f
3.359 ± 10	15 ± 5	0	1^+ ^f
3.519 ± 10	$\leq 7 \pm 4$	^d	
3.957 ± 10	$\leq 7 \pm 4$	2	3^+ ^f
4.318 ± 10	20 ± 5	0	1^+ ^f
4.391 ± 10	82 ± 20	1	1^- ^f
4.725 ± 10 ^c	290 ± 30	1	1^-
4.774 ± 10	59 ± 8	2	2^- ^f
5.053 ± 10	19 ± 6	(1 + 3)	2^-
5.130 ± 10	$\leq 7 \pm 4$	^d	
5.150 ± 10	$\leq 7 \pm 4$		
5.226 ± 10	$\leq 7 \pm 4$	2	(1, 2, 3) ⁺
5.305 ± 10 ^c	260 ± 30	^d	
5.520 ± 10	$\leq 7 \pm 4$	(0, 1) + 2 + 4 ^e	
5.730 ± 10	$\leq 7 \pm 4$	(1, 3) + 4 ^e	
6.009 ± 10	270 ± 30	1	1^-
6.167 ± 10	$\leq 7 \pm 4$	(3)	(4 ⁻)
6.371 ± 10	30 ± 6	(3)	(3 ⁻)
6.422 ± 10	300 ± 30	0 + (2, 4) ^e	
6.512 ± 10	34 ± 6	0 + (2, 3)	1^+
6.613 ± 10	$\leq 7 \pm 4$	(2 + 4) or 3	
6.854 ± 10	$\leq 7 \pm 4$	3 or (2 + 4)	
7.006 ± 10	22 ± 5	0(+2)	1^+
7.133 ± 10	$\leq 7 \pm 4$	(3, 2)	
7.250 ± 10	17 ± 5	(2 + 4) or 3	
7.573 ± 10	$\leq 7 \pm 4$	3 or (2 + 4)	3, 4 ⁻
7.640 ± 10	$\leq 7 \pm 4$	4	(3, 4, 5) ⁺
7.675 ± 10	$\leq 7 \pm 4$	(1 + 4)	

Table 16.9: States in ^{16}N from $^{14}\text{N}(t, p)$ ^a (continued)

E_x (MeV \pm keV)	Γ (keV)	L	J^π
7.876 ± 10	100 ± 15	$1 + 4$ ^e	
8.043 ± 10	85 ± 15	$(2 + 4)$ or 3	
8.183 ± 10	28 ± 8	$2(+4)$	$(3, 2)^+$
8.280 ± 10	24 ± 8	(1)	$((0, 1, 2)^-)$
8.361 ± 10	18 ± 8	$(1 + 4)$ ^e	

^a For references see Table 16.7 in (1982AJ01).

^b $\tau_m = 5.1 \pm 0.3$ psec.

^c The errors listed here for E_x for these two broad peaks are probably underestimates (1986AJ04).

^d Results are ambiguous.

^e May be a doublet.

^f Identified with shell-model counterparts.

Observed proton groups are displayed in Table 16.9. See also (1986AJ04).

$$12. \ ^{15}\text{N}(n,\gamma)^{16}\text{N} \quad Q_m = 2.490$$

The thermal cross section is 24 ± 8 μb : see (1981MUZQ).

$$13. \ ^{15}\text{N}(n,n)^{15}\text{N} \quad E_b = 2.490$$

The scattering amplitude (bound) $a = 6.44 \pm 0.03$ fm, $\sigma_{\text{free}} = 4.59 \pm 0.05$ b, $\sigma_{\text{inc}}^{\text{spin}}$ (bound nucleus) < 1 mb (1979KO26). The total cross section has been measured for $E_n = 0.4$ to 32 MeV: see (1977AJ02, 1981MUZQ). Observed resonances are displayed in Table 16.10. See also (1986AJ04, 1988MCZT, 1989FU1J).

$$14. \ ^{15}\text{N}(n,p)^{15}\text{C} \quad Q_m = -8.99$$

The activation cross section was measured for neutron energies between 14.6 and 15.0 MeV (1986RO1C).

Table 16.10: Resonances in $^{15}\text{N}(n, n)^{15}\text{N}$ ^{a, b}

E_n (MeV \pm keV)	Γ_{lab} (keV)	E_x (MeV)	J^π
0.921	14	3.354	1^+ ^c
1.095	3	3.517	1
1.563	≤ 2	3.955	1
1.944	29	4.312	1^+ ^d
2.038	56	4.400	1^- ^d
2.30 ± 70 ^e	410 ± 100 ^e	4.65	1^- ^d
2.399	107	4.738	2^+ ^d
2.732	35	5.050	1^-
2.830	12	5.142	$3^{(-)}$
2.84 ± 70 ^f	70 ± 100 ^f	5.15	2^- ^d
2.915	4	5.222	≥ 2
2.93	260	5.24	1^+
3.225		5.512	
3.454	24	5.727	1^+
3.69	297	5.95	1^-
3.987	88	6.226	(1^+)
4.126	78	6.356	(3^-)
4.252	113	6.474	(2^+)
4.64	> 150	6.84	≥ 2
4.80	37	6.99	≥ 1
5.055	25	7.227	≥ 2
5.43	30	7.58	≥ 3
5.56		7.70	
5.73	165	7.86	≥ 4
5.90		8.02	
6.28		8.37	≥ 1
6.42		8.51	≥ 1
6.65	45	8.72	≥ 1
6.76		8.82	
7.10	110	9.14	≥ 2
7.31		9.34	

Table 16.10: Resonances in $^{15}\text{N}(n, n)^{15}\text{N}$ ^{a, b} (continued)

E_n (MeV \pm keV)	Γ_{lab} (keV)	E_x (MeV)	J^π
7.44	105	9.46	≥ 2
7.71	150	9.71	≥ 2
8.07	30	10.05	≥ 3
8.30	175	10.27	≥ 2
8.77	130	10.71	≥ 2
9.61		11.49	≥ 3
9.77		11.64	≥ 3
10.25		12.09	
10.64		12.46	
11.09		12.88	
11.41		13.12	
12.10		13.83	

^a For references see Table 16.7 in (1977AJ02).

^b Below $E_n = 4.5$ MeV, the multilevel R-matrix formalism was used to determine E_λ , Γ_λ and whenever possible J^π by a χ^2 fitting and minimization technique. Above this energy the $2J + 1$ dependence was used; the parity cannot be determined because no marked interference effects are observed between resonance and potential scattering. Above 5.65 MeV all J -values are lower limits because the inelastic channel is open. [A channel radius $a = 4.69$ fm was used.]

^c Parity determined from angular distribution.

^d J^π also obtained by phase-shift analysis.

^e The phase-shift analysis indicates that the resonance is at $E_n = 2.42 \pm 0.08$ MeV with $\Gamma = 250 \pm 50$ keV. This is one of two ($d_{3/2}p_{1/2}^{-1}$) single-particle resonances.

^f The phase-shift analysis finds $E_\lambda = 2.94 \pm 0.1$ MeV, $\Gamma = 320 \pm 80$ keV. This is the other ($d_{3/2}p_{1/2}^{-1}$) single-particle resonance.

15. $^{15}\text{N}(p, \pi^+)^{16}\text{N}$

$$Q_m = -137.8595$$

This reaction was studied with 200 MeV protons for $E_x \leq 30$ MeV (1987AZZZ). A strong transition to a state with $J^\pi = 5^+$ was observed at $E_x = 5.7$ MeV. Strong states were also observed at $E_x = 14.2$ and 16.1 MeV with cross sections falling sharply with angle.

16. $^{15}\text{N}(\text{d},\text{p})^{16}\text{N}$ $Q_{\text{m}} = 0.266$

Levels derived from observed proton groups and γ -rays are shown in Table 16.11. Gamma transitions are shown in the inset of fig. 2. The very strong evidence for $J^\pi = 2^-, 0^-, 3^-$ and 1^- , respectively for $^{16}\text{N}^*(0, 0.12, 0.30, 0.40)$ is reviewed in (1971AJ02). These states provide a probe of the residual interaction relating the 1p and 2s 1d shells. See (1984BI03) for a comparison of experiment and theory for M1 observables. See also (1986AJ04, 1986ME1A, 1988VIIA).

17. $^{16}\text{C}(\beta^-)^{16}\text{N}$ $Q_{\text{m}} = 8.012$

See ^{16}C .

18. $^{16}\text{O}(\mu^-, \nu)^{16}\text{N}$ $Q_{\text{m}} = 95.239$

Partial μ^- -capture rates have been observed to $^{16}\text{N}^*(0.12, 0.40)$ [$J^\pi = 0^-, 1^-$] (1979GU06). The rate for capture by the $J^\pi = 0^-$ state [“best” value: $\lambda_\mu = 1560 \pm 94 \text{ sec}^{-1}$ (1985HE08)] and the “reverse” reaction $^{16}\text{N}^*(0^-) \xrightarrow{\beta} ^{16}\text{O}(0^+)$ [see Reaction 1] were the first reactions which verify the prediction (1978GU05, 1978GU07, 1978KU1A) of a large meson-exchange contribution to the weak, rank-zero axial charge. See ^{16}N , Reaction 1 and (1981TO16, 1986NO04, 1990HA35, 1992WAIL). See also the measurement reported in (1990BL1H) and the calculation of (1990CH13).

19. $^{16}\text{O}(\gamma, \pi^+)^{16}\text{N}$ $Q_{\text{m}} = -149.986$

Pion spectra have been obtained with virtual photons in the energy range $E_\gamma = 200\text{--}350 \text{ MeV}$ (1987JE02). Cross sections corresponding to the population of the four lowest states of ^{16}N (unresolved) were measured. Angular distributions were measured (1987YA02, 1987YA1D) at a photon energy of 320 MeV and the results compared to DWIA calculations. Measurements at $E_e = 200 \text{ MeV}$ and $E_{\pi^+} = 30 \text{ MeV}$ are cited in (1986AJ04).

20. $^{16}\text{O}(\text{n},\text{p})^{16}\text{N}$ $Q_{\text{m}} = -9.637$

At $E_n = 59.6 \text{ MeV}$ differential cross sections for the protons to the first four states of ^{16}N (unresolved) and to $^{16}\text{N}^*(6.2, 7.8)$ have been analyzed by DWBA. Comparisons are made with results from the $^{16}\text{O}(\gamma, \text{n})$ and $^{16}\text{N}(\text{p}, \gamma_0)$ reactions in the GDR region of ^{16}O (1982NE04, 1984BR03). See also (1983SCZR, 1988NO1B, 1989BOYV). Other (n, p)-like charge exchange reactions are reviewed in (1989GA26), and data on (^{16}O , ^{16}N) is presented in (1988HE1I).

Table 16.11: Levels of ^{16}N from $^{15}\text{N}(\text{d}, \text{p})$ and $^{18}\text{O}(\text{d}, \alpha)$ ^a

E_x ^b (MeV \pm keV)	l_n ^b	E_x ^c (MeV \pm keV)	J^π ^a
0		0	2^-
0.1201 ± 0.5 ^d		0.119 ± 15	0^-
0.2962 ± 1.0 ^e		0.301 ± 15	3^-
0.3973 ± 1.0 ^e		0.400 ± 15	1^-
3.365 ± 10		3.358 ± 15	1^-
3.523 ± 10	2 or 1 + 3	3.524 ± 15	2^+
3.964 ± 10	3	3.964 ± 15	3^+ ^h
4.325 ± 10	1	4.324 ± 15	1^+
4.40	0	4.383 ± 15	$(0, 1)^-$
4.715 ± 10	1		$(1, 2, 3)^+$
4.780 ± 10		4.787 ± 15	
(4.90 ± 10)			
5.032 ± 10	2	5.065 ± 15	2^-
5.128 ± 10	≥ 2		≥ 2
		5.139 ± 15	
5.150 ± 10	2		$(2, 3)^-$
5.231 ± 10	3	5.240 ± 15	3^+
5.310 ± 10			
5.523 ± 10	3	5.528 ± 15	3^+
5.739 ± 10	2	5.740 ± 15	$(1, 2)^i$
		6.01 ± 15	
6.170 ± 10	≥ 3	6.168 ± 15	4^- ^h
(6.28 ± 10)	1		$(0, 1, 2)^+$
6.376 ± 10	2	6.37 ± 15	$(1, 2, 3)^-$
6.431 ± 10			
6.514 ± 10	1	6.512 ± 15	$(0, 1, 2)^+$
6.609 ± 10		6.620 ± 15	
(6.79 ± 10)			
6.847 ± 10		6.852 ± 15	
7.034 ± 10		7.01 ± 15	
7.135 ± 10		7.141 ± 15	

Table 16.11: Levels of ^{16}N from $^{15}\text{N}(\text{d}, \text{p})$ and $^{18}\text{O}(\text{d}, \alpha)$ ^a (continued)

E_x ^b (MeV \pm keV)	l_n ^b	E_x ^c (MeV \pm keV)	J^π ^a
7.250 \pm 10		7.247 \pm 15	
7.577 \pm 10		7.596 \pm 15	
7.638 \pm 10		7.64 \pm 15	
7.676 \pm 10		7.683 \pm 15	
7.840 \pm 10		7.88 \pm 15	
		8.06 \pm 15	
		8.18 \pm 15	
		8.286 \pm 15	
		8.374 \pm 15	
		8.49 \pm 30 ^f	
		8.819 \pm 15 ^g	
		9.035 \pm 15	
		(9.16 \pm 30)	
		(9.34 \pm 30)	
		9.459 \pm 15	
		(9.66 \pm 40)	
		9.794 \pm 15 ^g	
		9.90 \pm 30	
		10.055 \pm 15 ^g	
		(10.17 \pm 30)	
		(10.26 \pm 30)	

^a For the earlier references and additional information see Table 16.9 in (1982AJ01).

^b $^{15}\text{N}(\text{d}, \text{p})^{16}\text{N}$.

^c $^{18}\text{O}(\text{d}, \alpha)^{16}\text{N}$.

^d $\tau_m = 7.58 \pm 0.09 \mu\text{sec}$.

^e $\tau_m = 131.7 \pm 1.9$ and 5.63 ± 0.05 psec, respectively, for $^{16}\text{N}^*(0.30, 0.40)$; $|g| = 0.532 \pm 0.020$ for $^{16}\text{N}^*(0.30)$ (1984BI03).

^f Γ for this level and the ones listed below $\leq 40 - 50$ keV.

^g These levels appear to be correlated with thresholds for neutron emission to excited states of ^{15}N .

^h (1982MA25): $E_d = 52$ MeV.

ⁱ A closely spaced doublet appears to be present. At least one of the states has unnatural parity.

$$21. \ ^{16}\text{O}(t, ^3\text{He})^{16}\text{N} \quad Q_m = -10.400$$

At $E_t = 23.5$ MeV $^{16}\text{N}^*(0, 0.30)$ [$J^\pi = 2^-, 3^-$] are strongly populated relative to $^{16}\text{N}^*(0.12, 0.40)$ [$J^\pi = 0^-, 1^-$]: see (1982AJ01). See also (1988CL04).

$$22. \ ^{16}\text{O}(^7\text{Li}, ^7\text{Be})^{16}\text{N} \quad Q_m = -11.280$$

Measurements at $E(^7\text{Li}) = 50$ MeV to $^{16}\text{N}^*(0, 0.12, 0.30, 0.40, 3.35, 3.52, 3.96, 5.52, 5.73, 6.17)$ are reviewed in (1986AJ04). A microscopic DWBA Coupled-Channels analysis of data at $E(^7\text{Li}) = 50$ MeV is reported in (1986CL03). See also the review of charge-exchange reactions with ^7Li ions in (1989GA26).

$$23. \ ^{17}\text{O}(\gamma, p)^{16}\text{N} \quad Q_m = -13.780$$

Bremsstrahlung-weighted integrated cross sections have been measured (1989OR07). About 90% of the photoproton emission populates the ground state (2^-) and the 0.298 MeV (3^-) levels. The 0.120 MeV (0^-) and 0.397 MeV (1^-) levels are also populated. See also (1986OR1A). Measurements with quasimonoenergetic photons at $E_\gamma = 13.50\text{--}43.15$ MeV were carried out by (1992ZU01) to study the GDR in ^{17}O .

$$24. \ ^{17}\text{O}(d, ^3\text{He})^{16}\text{N} \quad Q_m = -8.286$$

See Table 16.10 in (1982AJ01).

$$25. \ ^{18}\text{O}(\pi^+, 2p)^{16}\text{N} \quad Q_m = 118.526$$

Coincidence measurements for $E_\pi = 116$ MeV, $\theta_{p_1} = 50^\circ$, θ_{p_2} variable have been reported by (1986SC28, 1986SCZX). Transitions to the unresolved cluster of 4 states below 0.4 MeV excitation were observed to account for $6.1 \pm 0.6\%$ of the estimated two-nucleon absorption cross section below 20 MeV excitation. The results were compared with a model of pion absorption on quasi-deuteron pairs.

$$26. \ ^{18}\text{O}(p, ^3\text{He})^{16}\text{N} \quad Q_m = -14.106$$

At $E_p = 43$ MeV, the angular distribution of the ${}^3\text{He}$ nuclei corresponding to a state at $E_x = 9.9$ MeV fixes $L = 0$ and therefore $J^\pi = 0^+$ for ${}^{16}\text{N}^*(9.9)$: it is presumably the $T = 2$ analog of the ground state of ${}^{16}\text{C}$. See (1982AJ01, 1986AJ04). See also (1985BLZY).

$$27. {}^{18}\text{O}(d, \alpha){}^{16}\text{N} \quad Q_m = 4.248$$

Alpha particle groups observed in this reaction are displayed in Table 16.11. For polarization studies see (1982AJ01) and ${}^{20}\text{F}$ in (1983AJ01, 1987AJ02). τ_m for ${}^{16}\text{N}^*(0.40) = 6.5 \pm 0.5$ psec and $|g| = 1.83 \pm 0.13$: see (1982AJ01).

$$28. {}^{19}\text{F}(n, \alpha){}^{16}\text{N} \quad Q_m = -1.522$$

See (1982AJ01) and ${}^{20}\text{F}$ in (1983AJ01).

¹⁶O
(Figs. 3 and 5)

GENERAL: See Table 16.12.

$$\begin{aligned} \langle r^2 \rangle^{1/2} &= 2.710 \pm 0.015 \text{ fm (1978KI01)} \\ \text{Abundance} &= (99.762 \pm 0.015)\% \text{ (1984DE53)} \\ |g| &= 0.556 \pm 0.004 \text{ (1984AS03)} \end{aligned}$$

1. ${}^9\text{Be}({}^9\text{Be}, 2n){}^{16}\text{O}$ $Q_m = 11.289$

Total reaction cross sections and characteristic γ -ray cross sections for ${}^9\text{Be} + {}^9\text{Be}$ were measured for $E_{c.m.} = 1.4\text{--}3.4$ MeV (1988LA25). Gamma rays were observed from levels at 6.13 (3^-), 6.917 (2^+), and 7.1117 (1^-) MeV populated by the ${}^9\text{Be}({}^9\text{Be}, 2n){}^{16}\text{O}$ reaction. Cross sections calculated with optical models agreed with elastic scattering data, but the total reaction cross section was underpredicted by a factor of 2 to 3.

2. ${}^9\text{Be}({}^{11}\text{B}, {}^{16}\text{O}){}^4\text{H}$ $Q_m = 33.834$

Energy spectra of the ${}^{16}\text{O}$ nuclei were measured (1986BE35) for incident ${}^{11}\text{B}$ energies of 88 MeV to obtain information on the ${}^4\text{He}$ system.

3. ${}^9\text{Be}({}^{14}\text{C}, {}^7\text{He}){}^{16}\text{O}$ $Q_m = -7.006$

This reaction was studied by (1988BEYJ).

4. (a) ${}^{10}\text{B}({}^6\text{Li}, \gamma){}^{16}\text{O}$	$Q_m = 30.8734$	
(b) ${}^{10}\text{B}({}^6\text{Li}, p){}^{15}\text{N}$	$Q_m = 18.7459$	$E_b = 30.8734$
(c) ${}^{10}\text{B}({}^6\text{Li}, d){}^{14}\text{N}$	$Q_m = 10.1371$	
(d) ${}^{10}\text{B}({}^6\text{Li}, t){}^{13}\text{N}$	$Q_m = 5.8410$	
(e) ${}^{10}\text{B}({}^6\text{Li}, {}^3\text{He}){}^{13}\text{C}$	$Q_m = 8.0800$	
(f) ${}^{10}\text{B}({}^6\text{Li}, \alpha){}^{12}\text{C}$	$Q_m = 23.7115$	
(g) ${}^{10}\text{B}({}^6\text{Li}, {}^6\text{Li}){}^{10}\text{B}$	$Q_m = -5.975$	

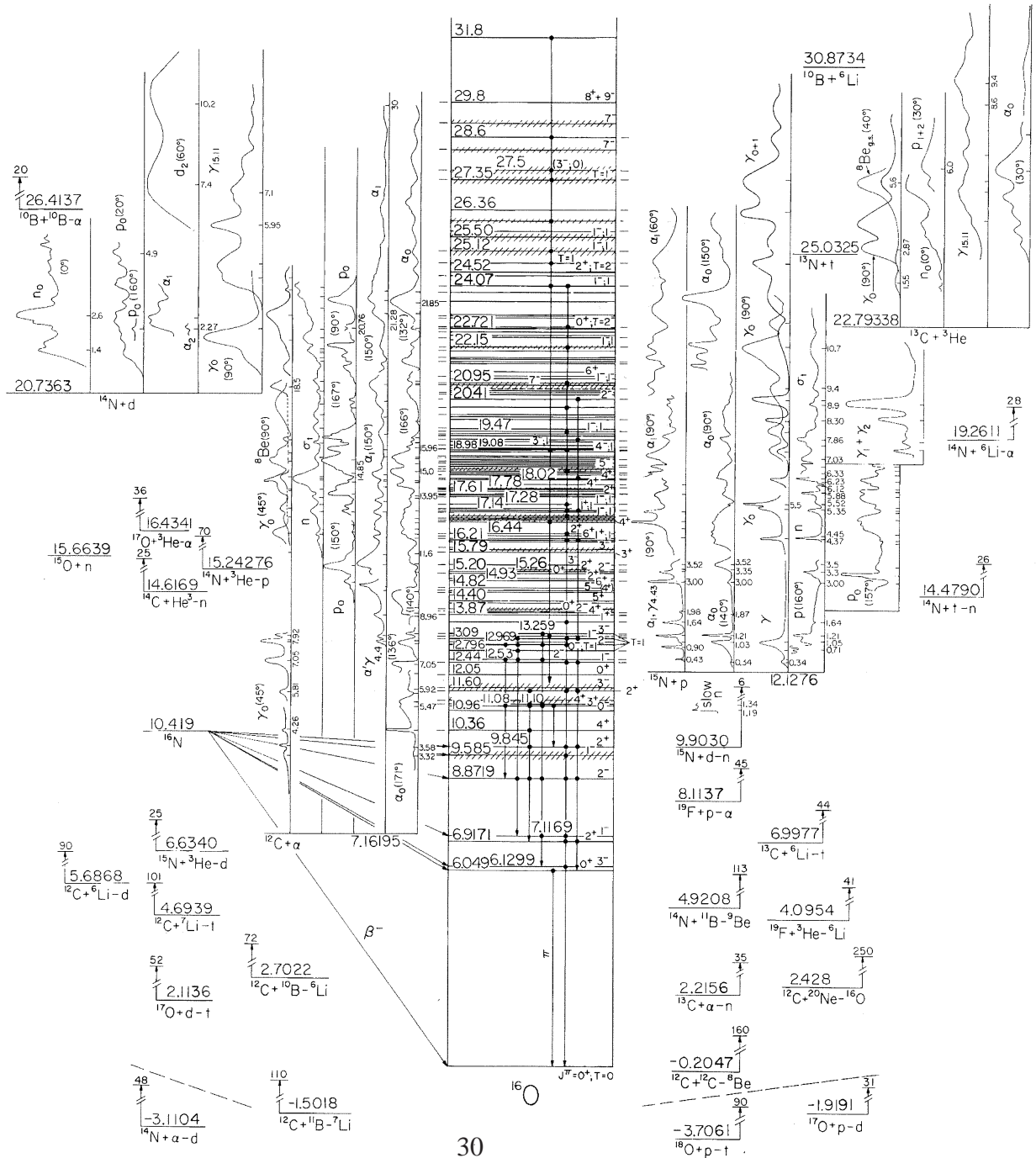


Figure 3: Energy levels of ^{16}O . For notation see Fig. 2.

Table 16.12: ^{16}O – General

Reference	Description
Shell Model	
Review:	
1987KIIC	Microscopic studies of electric dipole resonances in 1p shell nuclei
Other Articles:	
1986DE1E	Gamow-Teller strength from spin-isospin saturated nuclei (A)
1986FU1B	Relativistic shell model calculations
1986HA26	Shell model analysis of Σ -hypernuclear spectra for $A = 12$ & 16
1986KL06	Interplay between giant res. & background - investigated with continuum shell model
1986LE1A	Extended basis shell-model calculations for three-nucleon transfer (A)
1986YE1A	Hartree-Fock calculations with extended Skyrme forces for ^{16}O and ^{40}Ca
1987AV08	Neutron and proton hole states in double magic nuclei
1987MA30	Contrib. of particle-particle, hole-hole & particle-hole ring diagrams to binding energies
1987SU12	Nuclear ground-state properties & nuclear forces in unitary-model-operator approach
1987YA1B	Effective shell-model matrix elements calculated for the sd-shell
1988BL02	Quantized TDHF for giant monopole vibrations in ^{16}O , ^{40}Ca & ^{110}Zr
1988BL1I	Relativistic Hartree-Fock calculations for nuclear matter & closed-shell nuclei
1988BO10	Temperature-dependent shell effects in ^{16}O & ^{40}Ca with realistic effective Hamiltonian
1988BO40	Nuclear charge form factor in the topological soliton model
1988FI01	Effective interactions from sd-shell-model calculations
1988GU13	Correlated basis functions computation of spectra of light nuclei
1988HO10	Shell-model calculation with Hartree-Fock condition
1988MI1J	Shell model transition densities for electron & pion scattering
1988WO04	Expansion of the shell-model space for light nuclei
1989GU06	Hartree-Fock & shell-model charge densities of $^{16,18}\text{O}$, $^{32,34}\text{S}$; & $^{40,48}\text{Ca}$
1990HA35	Weak-interaction rates in ^{16}O ; nonspurious $4\hbar\omega$ shell model calculation
1990WO09	p-shell nuclei in a $(0 + 2)\hbar\omega$ model space, Part 1: Method
1990WO10	1990WO09 continued, Part 2: Results
1991BO02	Meson exchange effects on magnetic dipole moments of p-shell nuclei
1991GM02	Relativistic mean-field fit to microscopic results in nuclear matter
1991GO12	Method of multiple interactions - realistic NN potential (A)
1991KA09	Non-orthogonality problem in continuum RPA studied by orthogonality condition
1991KN04	RPA calculations of nuclear response in the continuum using a finite-range interaction
1991MA33	Super-RPA ground-state correlations
1991MU04	Effects of correlations on calc. of binding energy & radii of nuclei
1991YA08	$\alpha + ^{16}\text{O}$ studied with complex effective interact. & antisymmetrized many-body theory
1991ZH16	Retardation effect in finite nuclei in relativistic mean field theory
1992MI01	Comments on 1990WO09 & 1990WO10; inconsistency problems
1992WA25	Large-basis shell-model treatment of A=16 nuclei

Table 16.12: ^{16}O – General (continued)

Reference	Description
Collective, Deformed and Rotational Models	
Review:	
1987TA1C	Microscopic cluster theory in nuclear physics
Other articles:	
1986GO16	Deformed excited 0^+ states of ^{16}O & ^{40}Ca studied with the Hartree-Fock method
1986LE16	Relativistic Hartree calculations for axially deformed nuclei
1987DE21	Microscopic description of the ^{16}O spectrum in a multiconfiguration cluster model
1987PR03	Self-consistent Hartree descrip. of deformed nuclei in a relativistic quantum field theory
1987RO06	Coupling of valence shell and particle-hole degrees of freedom in a partial RPA
1988ZH07	Many-particle-many-hole deformed state energies from HF with Skyrme interactions
1989BU15	Configurational quasidegeneracy and the liquid drop model
1991AB1C	Perturbative calculation of periodic solutions
1991BA1M	Symmetry & surface energy coefficients with an effective interaction (A)
1991DE11	Generalization of Frenkel-Dirac variational principle for systs. outside thermal equilib.
1991KA12	Single-particle states with an excited core in ^{13}N & ^{16}O
1991KN04	RPA calculations of nuclear response in the continuum using a finite-range interaction
1991KO18	Relativistic investigation of the spin-orbit field in superdeformed nuclei
1991SH31	Systematics of superdeformation for $8 > A > 248$
1991ZH05	Relativistic model incorporating vacuum polarization
Cluster and α -particle models	
1986CO15	DWBA analysis for (^7Li , t) reactions producing α -cluster states in ^{16}O & ^{20}Ne
1986OR1C	Faddeev-Yakubovsky calc. of 4α particle system with realistic alpha-alpha interactions
1986SU13	Unitary-model-operators & calculation of energies of grnd. & one-body states
1986SU16	(1986SU13 cont.) Three-body-cluster effects on properties of ^{16}O
1987DE21	Microscopic description of the ^{16}O spectrum in a multiconfiguration cluster model
1987OS03	Four-body problem for four bound α particles in ^{16}O
1987SU12	Nucl. ground-state properties & nucl. forces in unitary-model-operator approach to ^{16}O
1987ZE05	Microscopic evaluation of clustering in ^4He , ^{12}C and ^{16}O
1988CS01	Core-plus-alpha-particle states of ^{20}Ne and ^{16}O in terms of vibron models
1988KA1Z	Systematic construction method of multi-cluster Pauli-allowed states
1988TA1P	Measurement of a fragmentation event of a relativistic O nucleus (A)
1989FU1N	Three- α potential in 3α and 4α orthogonality condition models
1989KU31	Effective numbers of d-, t-, ^3He - and α -clusters and their distributions (in Russian)
1989SU01	Isoscalar E0 & E2 strength of ^{16}O in an $\alpha + ^{12}\text{C}$ cluster & symplectic mixed basis
1991BAZW	4α breakup of ^{16}O ; comparisons with prompt & sequential mechanisms (A)

Table 16.12: ^{16}O – General (continued)

Reference	Description
Cluster and α -particle models – continued	
1991CS01	Cluster spectroscopic factor in the vibron model
1991KA12	Single-particle states with an excited core in the nuclei ^{13}N and ^{16}O
1991OR02	4α model calculation for the ^{16}O nucleus by the four-body integral equation
Special States	
Reviews:	
1985AD1A	Parity violation in the nucleon-nucleon interaction
1986HA1E	Breaking of isospin symmetry in compound-nucleus reactions
1986VO07	0^+ states and E0 transitions in even-even nuclides
1987CA1E	New spin excitation modes in nuclei
1989SP01	Reduced electric-octupole transition probabilities for even-even nuclides
Other Articles:	
1986AN07	Predicted masses and excitation energies in higher isospin multiplets for $9 \leq A \leq 60$
1986AN08	Nucleon momentum & density distributions in the generator co-ordinate method
1986AY01	Effect of higher states on the ground & low-lying excited 0^+ states of ^{16}O & ^{40}Ca
1986BE1F	Inelastic scattering to unnatural parity states in light nuclei using elementary probes
1986GO16	Deformed excited 0^+ states of ^{16}O & ^{40}Ca studied with the Hartree-Fock method
1986EK1A	Highly excited & high-spin states in ^{16}O populated by (^{12}C , $^8\text{Be}_{\text{g.s.}}$) reaction
1986KL06	Interplay between giant res. & background — investigated with continuum shell model
1986OR1C	Faddeev-Yakubovshy calculation of 4α particle system with realistic α - α interactions
1986RO26	Self-organization in nuclei
1986TOZQ	Axial charge transitions in relativistic nucl. models & nonrelativ. meson exch. currents
1987AV08	Neutron & proton hole states in doubly magic nuclei
1987BL18	Excited states of light $N = Z$ nuclei with a specific spin-isospin order
1987CO31	Simple parametrization for low energy octupole modes of s-d shell nuclei
1987DE21	Microscopic description of the ^{16}O spectrum in a multiconfiguration cluster model
1987KI1C	Microscopic studies of electric dipole resonances in 1p shell nuclei
1987PR03	Self-consistent Hartree descrip. of deformed nuclei in a relativistic quantum field theory
1987SK02	TDH solution of the Suzuki model of nuclear monopole oscillation
1988AM03	Study of the isoscalar dipole excitation (7.12 MeV) in ^{16}O
1988BL10	RPA for light nuclei based on fully relativistic Hartree-Fock calculations
1988BL11	Relativistic Hartree-Fock calculations for nuclear matter & closed shell nuclei
1988DE22	Search for elusive neutral particles in the $0^+ \rightarrow 0^+$ transition at 6.05 MeV in ^{16}O
1988GU13	Correlated basis functions calculation of spectra of light nuclei
1988KU18	Nuclear structure of ^{16}O in a mean-field boson approach

Table 16.12: ^{16}O – General (continued)

Reference	Description
Special States – continued	
1988MI1J	Shell model transition densities for electron & pion scattering
1988MU20	Reduction of stretched-magnetic-transition strengths by core polarization
1988PR05	Nuclear linear response to electroweak interactions in a relativistic theory for ^{16}O
1988RO09	Order out of chaos in atomic nuclei; microscopic calcs. of nucleon-induced rxns.
1989BI1A	Search for the emission of a neutral particle in the decay of the first excited state in ^{16}O
1989DE22	Addendum to 1988DE22
1989FO1D	Cold fusion results still unexplained
1989SU01	Isoscalar E0 & E2 strength of ^{16}O in an $\alpha + ^{12}\text{C}$ cluster & symplectic mixed basis
1991AB1C	Perturbative calculation of periodic solutions of the time-dependent mean-field eqs.
1991DE11	Generalization of Frenkel-Dirac variational principle for systs. outside thermal equilib.
1991KA09	Non-orthogonality problem in continuum RPA studied by orthogonality condition

Electromagnetic Transitions

1984VA06	Shell model treatment of $(0 + 1)\hbar\omega$ states in $A = 4-16$ nuclei
1986HI07	Neutron-proton correlation in energy systematics of E1 & M2 states
1986TK01	Microscopic calculation of properties of the low-lying M1 resonances in ^{16}O
1986VO07	0^+ states and E0 transitions in even-even nuclides (reviews various models)
1987CA1E	New spin excitation modes in nuclei
1987DE21	Microscopic description of the ^{16}O spectrum in a multiconfiguration cluster model
1987RA01	Transition probability from ground to first-excited 2^+ state of even-even nuclides
1987TO1B	Quenching of spin matrix elements in nuclei
1988AD08	Sum rules in extended RPA theories
1988MU20	Reduction of stretched-magnetic-transition strengths by core polarization
1989HAZY	Two-photon decay of the $0^+(6.05 \text{ MeV})$ state in ^{16}O (A)
1989KA28	Microscopic model incorporating 2p-2h configs. in magic nucl.; calc. of M1 excitations
1989LI1G	Sum rules & giant resonances in nuclei
1989RA16	Predictions of $B(E2; 0_1^+ - 2_1^+)$ values for even-even nuclei
1989SU01	Isoscalar E0 and E2 strength of ^{16}O in an $\alpha + ^{12}\text{C}$ cluster and symplectic mixed basis
1991LE14	Theoretical evaluation of the Coulomb sum rule in nuclei
1991LI29	Sum rules for nuclear excitations with the Skyrme-Landau interaction

Giant Resonances

1986HI07	Neutron-proton correlation in energy systematics of E1 & M2 states
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Table 16.12: ^{16}O – General (continued)

Reference	Description
Giant Resonances – continued	
1986KL06	Interplay between giant res. & background - investigated with continuum shell model
1987BU06	Alpha decay of giant electric quadrupole resonances
1987KIIC	Microscopic studies of electric dipole resonances in 1p shell nuclei
1987QU02	Giant dipole transitions in the nuclear WSp(6, R) Model
1987TH03	Exotic isoscalar dipole resonances in the Walecka model
1988BE24	Simple microscopic approach to the nuclear giant monopole & quadrupole resonances
1988BL02	Quantized TDHF for giant monopole vibrations
1988CA07	Charge transition densities for excitation & nucleon decay of the ^{16}O GDR
1988CO1G	Charge response in ^{12}C & ^{40}Ca ; also includes RPA calc. for ^{16}O
1988DI07	Scaling- & antisca.-type oscillations in isoscalar & isovector nucl. monopole vibrations
1988DR02	Quantized TDHF for isoscalar giant quadrupole resonances in spherical nuclei
1988HO10	Shell-model + Hartree-Fock condition calc. of excitation energies of giant resnecs. in ^{16}O
1988LI13	Surface & temperature effects in isovector giant resonances
1988PA05	Time-depend. Hartree-Fock calc. of escape width of giant monopole resonance in ^{16}O
1989LH02	Isoscalar giant resonances in a relativistic model of doubly-closed-shell nuclei
1989LI1G	Sum rules & giant resonances in nuclei
1991BO39	Compressibility of nuclei in relativistic mean field theory
1991LI28	Self-consistent RPA calc. of giant multipole resnecs. using Skyrme-Landau interaction

Astrophysics

Reviews:

- 1986WO1A The physics of supernova explosions
 1990RO1C Radiative capture reactions in nuclear astrophysics

Other Articles:

- 1986BA50 Coulomb dissociation as a source of information on radiative capture processes
 1986LA1C The chemical composition of 30 cool Carbon stars in the galactic disk
 1986MA1E Effects of the new $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ rate on chemical evolution of the solar neighborhood
 1986SM1A Chemical composition of red giants: He burning and the *s*-process in the MS & S stars
 1986TR1C Frequency of occurrence of O-Ne-Mg white dwarfs in classical nova systems
 1987AD1A Direct meas. of the charge state of the anomalous O component of cosmic rays (A)
 1987AL1B Carbon, nitrogen and oxygen abundances in Procyon, Sun and Arcturus
 1987BE1H $^{12}\text{C}/^{13}\text{C}$ & $^{16}\text{O}/^{18}\text{O}$ ratios in Venus' atmosphere from high-res. 10-mm spectroscopy
 1987CU1A Interstellar medium composition der. from anomalous cosmic ray component meas. (A)
 1987DO1A $^{12}\text{C}/^{13}\text{C}$ & $^{16}\text{O}/^{17}\text{O}$ isotopic ratios in seven evolved stars (types MS, S & SC)
 1987DW1A Cosmic-ray elemental abundances from 1 to 10 GeV/amu for Boron through Nickel

Table 16.12: ^{16}O – General (continued)

Reference	Description
Astrophysics – continued	
1987FA1C	^{16}O excess in hibonites discredits late supernova injection origin of isotopic anomalies
1987HA1C	$^{12}\text{C}/^{13}\text{C}$ and $^{16}\text{O}/^{18}\text{O}$ ratios in the solar photosphere
1987HA1D	Oxygen isotopic abundances in 26 evolved Carbon stars
1987HA1E	Search for $^{14}\text{C}^{16}\text{O}$ in the atmospheres of evolved stars - none found
1987LA1C	Line shapes and linear polarizations of certain γ -rays emitted from solar flares (A)
1987MC1A	Oxygen isotopes in refractory stratospheric dust: proof of extraterrestrial origin
1987ME1B	Solar coronal isotopic abundances derived from solar energetic particle meas. (A)
1987PL03	Scattering of α particles from ^{12}C and the $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ stellar reaction rate
1987PR1A	Neutron capture nucleosynthesis during core Helium burning in massive stars
1987RA1D	Nuclear processes and accelerated particles in solar flares
1987SA1D	Linear polarization of $^{12}\text{C}^*$ & $^{16}\text{O}^*$ γ -rays as particle direction indicators in solar flares
1988AN1D	Evolution of Fe, r , and s -elements in our galaxy
1988CL1C	Isotopic anomalies: Chemical memory of galactic evolution
1988CUZX	Elemental composition of anomalous cosmic-ray component (A)
1988DU1B	Spectrophotometry & chemical composition of the O-poor bipolar nebula NGC 6164-5
1988DU1G	Abundances of Carbon & Nitrogen in I Zw 18 (an Oxygen-poor galaxy)
1988FO1E	Nuclear line spectroscopy of solar flares; deduced elemental abundances
1988KA1G	Steady state models of white dwarfs accreting Helium or Carbon/Oxygen-rich matter
1988RE1E	Bimodal abundances in the energetic particles of solar and interplanetary origin
1989AB1J	Oxygen abundances in unevolved metal-poor stars: interpretation & consequences
1989BE2H	Effect of enhanced α -elements in Helium-burning population II stars
1989CH1X	Stability analysis of C-N-O nuclear reaction inside stars
1989CU1E	Observed radial & latitudinal gradients of anomalous cosmic ray Oxygen (A)
1989FU02	Reaction cross section for “solar flare neutrinos” with ^{37}Cl and ^{16}O targets
1989GU06	Hartree-Fock & shell-model charge densities of $^{16,18}\text{O}$, $^{32,34}\text{S}$ and $^{40,48}\text{Ca}$
1989GU28	Thermonuclear breakup reactions of light nuclei. I. Processes & effects
1989GU1J	(cont. from 1989GU28) Part II. Gamma-ray line production & other applications
1989GU1Q	Abundances of light nuclei at the cosmic-ray source from fragmentation cross sections
1989JI1A	Nucleosynthesis inside thick accretion disks around massive black holes
1989LI1I	Anthropic significance of the existence of an excited state of ^{12}C
1989ME1C	Isotope abundances of solar coronal material derived from solar energetic particle meas.
1989SP1G	Oxygen and Carbon abundances in a few F supergiants of the small Magellanic cloud
1989TA26	Microscopic calc. of rates of electron capture which induce collapse of O+Ne+Mg cores
1990AB1E	Early nucleosynthesis of O and Fe
1991AL02	N- \bar{N} oscillation times estimated from Paris NN \bar{N} potential
1991AN1E	^{26}Al and ^{16}O in the early solar system: clues from meteoritic Al_2O_3
1991BE05	Direct projectile break-up & its relation to the astrophysically relevant fusion reactions

Table 16.12: ^{16}O – General (continued)

Reference	Description
Astrophysics – continued	
1991PA1C	Extremum problem treatment of C, N & O abundances in late-type star atmospheres (A)
1991RA1C	Carbon burning and galactic enrichment in massive stars
Applications	
1986MU1A	Analysis of Oxygen on & in Beryllium using 2 MeV Helium ions (A)
1986ZA1A	Passage of Nitrogen and Oxygen ions through Carbon and celluloid films
1987BO16	Analytical possibilities of $3 < E < 12$ MeV Tritium beams & appl. to analysis of O in InP
1987NA1D	Sputtering of Carbon by Oxygen and Neon
1987ZU1A	Oxygen isotope effect in high-temperature Oxide superconductors
1988AL1K	Analysis of “Desert Rose” (geological sample) using RBS and PIXE techniques
1988BL1H	Surface analysis of high Z oxides using 3.05 MeV ^4He - ^{16}O backscattering resonance
1988GOZR	Non-Rutherford elastic backscattering for light element cross section enhancement (A)
1988ILZZ	Light element materials study by Rutherford backscattering spectroscopy (A)
1988RO1L	Ion implantation in targets for nuclear physics studies (A)
Complex Reactions	
Reviews:	
1987MC1B	Introduction to quark-gluon plasma and high energy heavy ion collisions (A)
1989GRZQ	Cluster radioactivities
Other Articles:	
1986AB06	Calculation of mass yields for proton-nucleus spallation reactions
1986AL25	Incomplete & complete fusion in intermediate energy heavy ion reactions
1986AV1A	Search for anomalous & fragments with fractional charge in ^{16}O fragmentation
1986BA1E	Multistep fragmentation of heavy ions in peripheral collisions at relativistic energies
1986BO1B	Observation of fission of relativistic ^{24}Mg & ^{28}Si into two fragments of \sim equal charge
1986HA1B	Microscopic model of nucleus-nucleus collisions
1986KI1C	Apparent anomalously short mean free paths observed in relativistic heavy-ion collis.
1986MA13	Experimental search for nonfusion yield in the heavy residues emitted from $^{11}\text{B} + ^{12}\text{C}$
1986ME06	Quasi-elastic, deep-inelastic, quasi-compound nucleus mechanisms from $^{89}\text{Y} + ^{19}\text{F}$
1986NA1B	Correlation of linear momentum & angular momentum transfer in $^{154}\text{Sm} + ^{16}\text{O}$
1986PL02	Element distributions after binary fission of ^{44}Ti
1986PO06	Calc. half-lives & kinetic energies for spontaneous emission of heavy ions from nuclei
1986SA30	Nucleus-nucleus scattering and interaction radii of stable & unstable nuclei

Table 16.12: ^{16}O – General (continued)

Reference	Description
Complex Reactions – continued	
1986SC29	Partition of excitation energy in peripheral heavy-ion reactions
1986SHZY	Equilibration in orbiting reactions; ^{12}C & ^{16}O yields from $^{14}\text{N} + ^{28}\text{Si}$ (A)
1986SH1F	Measurements of projectile-like fragments produced by $^{27}\text{Al} + ^{16}\text{O}$
1986SH25	Equilibration in orbiting reactions; ^{12}C & ^{16}O yields from $^{14}\text{N} + ^{28}\text{Si}$
1986SO10	Particle-bound excited state yields produced in the reaction of 181 MeV $^{19}\text{F} + ^{159}\text{Tb}$
1986ST13	Microscop. calc. of ener. & transitional densities of giant monopole resonances in nucl.
1986VA18	Excitation-energy sharing in ^{20}Ne induced reactions
1986VA23	Peripheral reactions induced by ^{20}Ne at 11 and 15 MeV/nucleon
1987AN1C	Fast frags. of target in interactions of relativistic nuclei with nuclei of nucl. emulsion
1987BA02	Energy spectra of fragments calculated using statistical multifragmentation model
1987BA1T	Spin-isospin excitations in nuclei with relativistic heavy ions
1987BA31	Isotope distribution in nuclear multifragmentation
1987BA38	Systematics of the $^{14}\text{N} + ^{159}\text{Tb}$ reaction between 6 and 33 MeV/u Part I. Inclusive Data
1987BE58	Target fragmentation at ultrarelativistic energies using oxygen beams
1987BO1K	Collectivity in composite fragment emission from relativistic heavy ion collisions
1987BO23	Intermediate-mass fragments from nonbinary processes in $^{14}\text{N} + \text{Ag}$ at $E/A = 35$ MeV
1987BU07	Projectile-like fragments from $^{20}\text{Ne} + ^{197}\text{Au}$ — counting simultaneously emitted neutrons
1987DEZV	^{16}O breakup in the $^{27}\text{Al} + ^{16}\text{O}$ interaction at 96 MeV (A)
1987FA09	Source properties of intermediate-mass frags. emitted in $^{14}\text{N} + ^{232}\text{Th}$ at $E/A = 35$ MeV
1987FE1A	Study of deep inelastic collisions in $^{12}\text{C} + ^{27}\text{Al}$ at 61.8 MeV
1987GE1A	Charges & angular distributions of fast fragments produced in 3.2-TeV $^{16}\text{O} + \text{Pb}$
1987GO1E	Photon and charged particle spectra in $^{16}\text{O} + \text{W}$ at 200 GeV/nucleon (A)
1987JA1B	Model of transverse energy production in high energy nucleus-nucleus collisions
1987KO15	Intermediate mass fragments in $^6\text{Li} + ^{46}\text{Ti}$ at $E/A = 26$ MeV
1987LI04	Multistep effects in $^{17}\text{O} + ^{208}\text{Pb}$ near the Coulomb barrier
1987LY04	Fragmentation & the emission of particle stable and unstable complex nuclei
1987MA1B	Peripheral like interaction model of spectator residue with central fireball
1987MI1B	Projectile fragmentation of ^{16}O at medium energies (A)
1987MU03	Study of the emission of clusters by excited compound nuclei
1987NA01	Linear momentum & angular momentum transfer in $^{154}\text{Sm} + ^{16}\text{O}$
1987PA01	Complete & incomplete fusion in $^{20}\text{Ne} + ^{93}\text{Nb}$
1987PA1D	Recoil accelerator mass spectrometry of nuclear reaction products
1987RI03	Isotopic distributions of fragments from $^{40}\text{Ar} + ^{68}\text{Zn}$ at $E = 27.6$ MeV/u
1987RO10	Projectile fragmentation in heavy-ion reactions at intermediate energies
1987SH23	Dissipative phenomena and α -particle emission in $^{16}\text{O} + ^{27}\text{Al}$ between 46 and 85 MeV
1987SU07	Correlated fluctuations in the $^{89}\text{Y}(^{19}\text{F}, x)\text{y}$ excitation functions
1987VI14	Mechanisms of momentum & energy transfer in intermediate-energy collisions

Table 16.12: ^{16}O – General (continued)

Reference	Description
Complex Reactions – continued	
1988AN1C	Multiple angular scattering of $^{16,17}\text{O}$, ^{40}Ar , ^{86}Kr and ^{100}Mo at 20–90 MeV/u
1988AR1D	Interactions of 60 & 200 A GeV ^{16}O ions in nuclear emulsion
1988AY03	Transport description for capture processes in nuclear collisions
1988BO13	Deeply inelastic collisions as a source of intermediate mass fragments at $E/A = 27$ MeV
1988BR1N	Fragmentation cross sections of ^{16}O at 60 & 200 GeV/nucleon
1988CA27	Experimental indications of selective excitations in dissipative heavy ion collisions
1988FE1A	Meas. C, O, & Fe charge changing σ in He & H at high E ; appl. to cosmic-ray propag.
1988GA11	Neutron pickup & 4-body processes in reactions of $^{16}\text{O} + ^{197}\text{Au}$ at 26.5 & 32.5 MeV/u
1988GA12	Stripping- & pickup-induced breakup in 11- & 17-MeV/u $^{20}\text{Ne} + ^{197}\text{Au}$ reactions
1988GO11	Emissions of complex frags. & effective temps. for collisions of $^{58}\text{Ni} + ^{58}\text{Ni}$ at 11 MeV
1988HA03	Spin dependence of neutron transfer in heavy ion reactions
1988KH1B	Excit.-decay vs. fragment production for $^{12}\text{C}(^{16}\text{O}, ^{15}\text{N} + \text{p})$; $E = 1.05$ & 2.1 A GeV (A)
1988MI28	Multifragmentation as a possible signature of liquid-gas phase transitions
1988MO05	Dynamical model for projectile break-up & incomplete fusion in $^{20}\text{Ne} + ^{197}\text{Au}$
1988POZZ	Multifragmentation of the projectiles ^{16}O , ^{14}N , and ^{12}C at 32.5 MeV/A (A)
1988SH03	$^{28}\text{Si} + ^{14}\text{N}$ orbiting interaction (experimental data) & importance of phase space
1988SH1H	Coincidence meas. between α -particles & projectile-like frags. in 82.7 MeV $^{16}\text{O} + ^{27}\text{Al}$
1988SI01	Fragmentation of ^{16}O projectiles at 100 MeV/nucleon
1988TE03	Incomplete deep-inelastic scattering in $^{20}\text{Ne} + ^{197}\text{Au}$ collisions at 20 MeV/nucleon
1988UT02	Quasi-free stripping mechanism of Serber model extended to complex projectiles
1988WI1F	Electromagnetic spallation of 3.2 TeV ^{16}O nuclei (A)
1989AD1B	Production of He projectile fragments in ^{16}O -emulsion interactions at $E/A = 2$ –200 GeV
1989BR14	Dynam. anal. of deep inelas. interac. in $^{19}\text{F} + ^{24}\text{Mg}$ at 1.3 MeV/u above Coulomb barrier
1989CA15	Fusion & binary reactions in the collision of ^{32}S on ^{26}Mg at $E_{\text{lab}} = 163.5$ MeV
1989FI05	Non-eq. vs. equilibrium complex. frag. emiss.; $^{14}\text{N} + \text{Ag}$ & $^{14}\text{N} + \text{Au}$ at $E/A = 20$ –50 MeV
1989GE11	Complex fragments emitted in excited states
1989GR13	Compound nucleus emission of intermediate mass fragments in $^6\text{Li} + \text{Ag}$ at 156 MeV
1989MA45	Target excitation & angular momentum transfer in $^{28}\text{Si} + ^{181}\text{Ta}$ from multiplicity meas.
1989PO06	Approach to criticality in the fragmentation of Xe by 1–19 GeV protons
1989PO07	Excitation & multiple dissociation of ^{16}O , ^{14}N , and ^{12}C projectiles at 32.5 MeV/u
1989RE08	Large transient magnetic fields for single electron O ions on a 10 fs time scale (O + Gd)
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1989TE02	Dissipative mechanisms in the 120 MeV $^{19}\text{F} + ^{64}\text{Ni}$ reaction
1989YO02	Quasi-elastic & deep inelastic transfer in $^{16}\text{O} + ^{197}\text{Au}$ for $E < 10$ MeV/u
1989YO09	Energy damping feature in light heavy-ion reactions (including 118 MeV $^{16}\text{O} + ^{48}\text{Ti}$)
1989ZHZY	Mass measurement of $Z = 7$ –19 neutron-rich nuclei using the TOFI spectrometer (A)
1990BO01	Critical excitation energy in fusion-evaporation reactions

Table 16.12: ^{16}O – General (continued)

Reference	Description
Complex Reactions – continued	
1990SE18	Total reaction cross section for the interaction of light nuclei in Glauber-Sitenko theory
1990YE02	Intermediate mass fragment emission in the $p + \text{Ag}$ reaction at 161 MeV

Muon and Neutrino capture and reactions

Reviews:

- 1985GR1A Induced weak currents in nuclei
 1986TO1D Meson-exchange currents in time-like axial-charge transitions

Other Articles:

- 1986DO06 Experimental results on radiative muon capture in complex nuclei
 1986GM02 Continuity-equation constraint for electron scattering & radiative muon capture
 1986LI13 Signature for the existence of η -mesic nucleus
 1986MA16 Emission of nucleons & nucleon pairs following muon capture in ^{12}C , ^{16}O & ^{27}Al
 1986NA14 Sum rule approach to total muon capture rates
 1986TO1A Weak interaction probes of light nuclei
 1987GM01 Radiative capture of polarized muons on ^{16}O & ^{40}Ca
 1987OH1B Energetic neutrons after muon capture modeled using realistic nuclear Fermi motion
 1988DO05 Radiative muon capture in ^{12}C , ^{16}O , ^{27}Al , ^{40}Ca , $^{\text{nat}}\text{Fe}$, ^{165}Ho & ^{209}Bi
 1988FR19 Radiative muon absorption in ^{16}O
 1988HA22 Neutrino reactions on oxygen & a proposed measurement of the Weinberg angle
 1988PR05 Nuclear linear response to electroweak interactions in a relativistic theory for ^{16}O
 1989FU02 Reaction cross section for “solar flare neutrinos” with ^{37}Cl & ^{16}O targets
 1989KA35 Second class meson exchange currents & neutrino mass in μ^- -capture by light nuclei
 1989NA01 Some relations for radiative-pion-capture & muon-capture rates

Pion, Kaons & Other Mesons

Reviews:

- 1986BA1C Pion-nucleus double charge exchange: the modern era
 1986DO1B Strange probes of the nucleus
 1986PE1E Scattering of electrons, nucleons, and pions as probes of nuclear structure
 1987FA1A Conclusions & outlook (from Proc. of the Int. Conf. on a European Hadron Facility)
 1987GI1C Pion-nucleus interactions
 1988FA1B Strange particles: a probe for new physics in particles and nuclei
 1988JO1E Pions & the nuclear spin-isospin response

Table 16.12: ^{16}O – General (continued)

Reference	Description
Pion, Kaons & Other Mesons – continued	
1988KR1E	Meson exchange models of the nuclear response function
1988KY1A	Studies of pion absorption at SIN; includes quasi-deuteron absorption in ^{16}O
1988PE1F	The (π, η) and (π^+, K^+) reactions in nuclei
1988RO1M	Nuclear scattering & reactions with low-energy pions
1988WA1B	Production of hypernuclei in the (K, π) reaction
1989CH32	Recent experiments in novel nuclear excitations at the BNL AGS
1989JO07	Phenomenological optical-model anal. of pion elastic & charge-exchange scat.
1989KH08	Problems of pion-nucleus interaction
1989RI1E	Exchange currents
Other Articles:	
1986BE22	Stability of the ground state of finite nuclei against neutral pion condensation
1986BE42	$(K^+, K^+\pi)$ in light nuclear-emulsion nuclei with small momentum transfer to nucleus
1986BL04	Pion condensates in excited states of finite nuclei & nuclear matter
1986CE04	Inclusive n, p & d energy spectra from stopped π -absorption in ^6Li , ^9Be , ^{16}O , & ^{27}Al
1986CH39	Compar. of $\pi\Delta$ interact. mechan. & dbl. chrg. exch. (exp. data on self-conjugate nucl.)
1986CO1B	$(e, e'K^+)$ & low-lying hypernuclear states using relativistic field theory (A)
1986DI07	Analytic distorted wave approx. for electro- & photopion produc. on ^{12}C near threshold
1986FI1A	Conversion width of the Σ^- & Ξ^- -hyperons in nuclei & one-meson exchange
1986FR20	Kemmer-Duffin-Petiau eq. for pionic atoms & anomalous strong interaction effects
1986GI13	Nuclear-structure aspects of nonanalog pion double charge exchange
1986HA26	Shell model analysis of Σ -hypernuclear spectra for $A = 12$ & 16
1986HA39	Strangeness exchange reactions with the recoil corrected continuum shell model
1986KI1D	Quasifree process in hypernuclear formation
1986LE22	Test of effective cluster interactions by pion scattering
1986LI1B	Evidence & search for the eta-mesic nucleus
1986LI1C	Extraction of particle-hole strengths for $1\hbar\omega$ stretched states
1986MEZX	Total reaction cross sections of 50 & 65 MeV pions on nuclei (A)
1986OS03	Theoretical study of inclusive $(\pi, 2\pi)$ reactions in nuclei
1986SCZX	$^{16,18}\text{O}(\pi^+, 2p)^{14,16}\text{N}$ reactions at $T = 116$ MeV with energy resolution < 2 MeV (A)
1986SI11	Effects of nuclear correlations on low-energy pion charge-exchange scattering
1986TO1A	Weak interaction probes of light nuclei
1986WH03	Energy dependence of the low energy pion-nucleus optical potential
1987AM1A	Spectroscopic aspects of the reaction $^{16}\text{O}(\pi^+, 2p)^{14}\text{N}$ at $T = 116$ MeV (A)
1987BU20	p & d production in nucl. (in inclusive reactions) induced by 1.5 GeV/c π^+ & π^- mesons
1987CH10	Continuum effects & the interpretation of Σ hypernuclei
1987CH1D	Search for the bound states of an η -meson in the nuclear potential (A)
1987CO09	$(e, e'K^+)$ & low hypnucl. excits. using relativistic transit. operator & nucl. struc. model

Table 16.12: ^{16}O – General (continued)

Reference	Description
Pion, Kaons & Other Mesons – continued	
1987CO1G	Studies of the nuclear $(e, e'K^+)$ reaction in a relativistic model (A)
1987CO25	The $(\vec{p}, n\pi)$ ground state reaction in a relativistic framework
1987GI01	The isoscalar pion-nucleus interaction from pionic atoms
1987GM02	Momentum-space second-order optical potential for pion-nucleus elastic scattering
1987GM04	Pion-nucleus scattering at low & resonance energies
1987GO05	$^{16}\text{O}(\pi^+, pp)^{14}\text{N}$ at 60 MeV — testing the quasi-deuteron mechanism
1987HA40	Coupled channel calculation of Σ -hypernuclear spectra from ^{12}C , ^{16}O , & ^6Li
1987JE02	Photoproduction of charge pions on ^{16}O to bound states of the nuclei ^{16}N and ^{16}F
1987KA39	Delta-hole approach to pion double charge exchange
1987KH1B	New approach to the description of pion-nucleus scattering at low energies
1987KO1F	Σ -hypernuclear spectra from (K^-, π) inclusive reactions (A)
1987KO30	Σ -hypernuclear spectra from (K^-, π) inclusive reactions
1987LE1B	Strong interaction studies via meson-nucleus reactions
1987MA1I	Inclusive pion double charge exchange in light nuclei (A)
1987MA1M	E & θ dependence of non-analog pion double charge exchange reaction (A)
1987NA04	Sum rule approach to radiative pion capture: full hamiltonian calc. for 1p shell nuclei
1987PI1B	Studies of hypernuclei by associated production (A)
1987TE01	Inclusive π^+ & π^- prod. in nucleon-nucleus & ^4He -nucleus collisions in the GeV region
1988CH49	Search for bound states of the η meson in light nuclei
1988DH1A	Delta-hole model in the local density approximation (see 1988ER04)
1988DO05	Radiative muon capture in nuclei; also measured pion capture
1988EL06	s-wave repulsion of pion-nucl. interaction, data contradicts relativistic mean-field calc.
1988ER04	Delta-hole model in the local-density approximation
1988FR02	Strong-interaction finite-range effects in light pionic atoms
1988GR1E	Systematics of inclusive double charge exchange
1988HA12	Charge exchange reactions used to study giant resonances: (π^\pm, γ) , (π^\pm, π^0)
1988HA44	Phenomenological analysis of Σ -hypernuclear spectra from (K^-, π^+) reactions
1988HYZY	Coincidence measurements of the reaction $^{16}\text{O}(\pi^+, 2p)^{14}\text{N}$ at 165 MeV (A)
1988HYZZ	Measurement of the reactions $^{16}\text{O}(\pi^+, p)$ & $^{16}\text{O}(\pi^+, 2p)^{14}\text{N}$ at 165 MeV (A)
1988IT02	Pi-mesonic decay of hypernuclei & pion wave function
1988JO1F	The $(\pi, 2\pi)$ reaction; experimental data compared to calc. of 1986OS03
1988KH01	Pion-nucleus dynamics at low energies
1988KR09	RPA correlation effects in radiative pion capture
1988KR1E	Meson exchange models of the nuclear response function
1988LI1P	Large-angle elastic scattering of π^+ & π^- from ^{16}O at 114 MeV (A)
1988MA09	Study of hypernucleus production by K^- capture at rest
1988MA27	Non-analog double charge exchange transition: $^{16}\text{O}(\pi^+, \pi^-)^{16}\text{Ne}(\text{g.s.})$

Table 16.12: ^{16}O – General (continued)

Reference	Description
Pion, Kaons & Other Mesons – continued	
1988MA37	Observation of pionic atom anomaly in low-energy pion scattering
1988MAZM	Dominance of the two-nucleon mechanism in $^{16}\text{O}(\pi^+, 2p)$ at 115 MeV (A)
1988MI1N	Λ -nucleus single-particle potential obtained from analysis of Λ -hypernuclei spectra data
1988MO1B	The (π^+, K^+) reaction to probe Λ and Σ states in hypernuclei
1988MO23	Hypernuclear production by the (π^+, K^+) reaction
1988OS1C	Meson exchange currents in p decay in nuclei
1988PE1H	Associated production of hypernuclei with (π^+, K^+) reaction
1988PI1E	Search for bound states of the η -meson in light nuclei
1988SA24	Computer simulation of inclusive pion nuclear reactions
1988SC14	Exclusive quasi-deuteron absorption of pions in ^{16}O & ^{18}O at 116 MeV
1988TA21	One-nucleon knockout by pions and deltas
1988WI1B	Large angle pion-nucleus scattering from ^{12}C & ^{16}O (A)
1988WI1I	Pion double charge exchange above the $\Delta(3, 3)$ resonance (A)
1989BA06	Polarization of hypernuclei in the (π^+, K^+) reaction
1989BA63	Slow π^- meson capture by C, N, & O in nucl. emulsion with prod. of 3 charged particles
1989BA92	Strangeness production by heavy ions
1989BE02	Kaon photoproduction from nuclei in a relativistic nuclear model
1989BE11	Electromagnetic production of Σ hypernuclei
1989CA04	Quantized meson-exchange picture of the nuclear interactions
1989CH04	J dependence in the reaction $^{16}\text{O}(\pi^+, 2p)^{14}\text{N}$ at 116 MeV
1989CH31	Photoproduction of pions off nucleons & nuclei
1989FE07	Skyrme-Hartree-Fock calculation of Λ -hypernuclear states from (π^+, K^+) reactions
1989GA09	Pionic distortion factors for radiative pion capture studies
1989HA07	Shell model calculation of Λ -hypernuclear spectra from (π^+, K^+) reactions (talk)
1989HA29	Shell model calculation of Λ -hypernuclear spectra from (π^+, K^+) reactions
1989HY1B	Inclusive & exclusive measurements of $^{16}\text{O}(\pi^+, p)$ & $^{16}\text{O}(\pi^+, 2p)^{14}\text{N}$ at 165 MeV (A)
1989KA37	Finite-range effects in pionic atoms
1989KH01	On the reactive content of the pion-nucleus optical potential at low-energies
1989LI1H	Proton-induced production of η on nuclei
1989MO17	(π, K^+) hypernucl. production & struc.; DWIA calc. based on Kapur-Peierls framework
1989NA01	Some relations for radiative-pion-capture & muon-capture rates
1989PI11	Study of hypernuclei from $^9_\Lambda\text{Be}$ to $^{89}_\Lambda\text{Y}$ using the (π^+, K^+) reaction
1989SI09	Mechanism of (K^+, K^+p) on light nuclei at kaon energies 130 & 283 MeV
1989TA04	Absorptive effects in $K^+\Lambda$ photoproduction on nucleons & nuclei
1989TA16	Formation of $^4_\Lambda\text{H}$ hypernuclei from K^- absorption at rest on light nuclei
1989TA17	Compound-hypernucl. interpretation on $^4_\Lambda\text{H}$ formation probab. in stopped- K^- absorption
1989TA19	$^4_\Lambda\text{H}$ formation from K^- absorption at rest on ^4He , ^7Li , ^9Be , ^{12}C , ^{16}O , & ^{40}Ca

Table 16.12: ^{16}O – General (continued)

Reference	Description
Pion, Kaons & Other Mesons – continued	
1989TO11	Structure & formation of deeply-bound pionic atoms
1989VI01	Inclusive pion-nucleus double charge exchange
1989WI20	Pion double charge exchange in the D33 resonance region
1990MO36	Meson exchange current corrections to magnetic moments in quantum hadro-dynamics
1991CI08	Momentum-space method for pionic atoms
1991LE13	Cross sections for production of eta nuclei by photons
1991PI07	Study of hypernuclei by associated production through the (π^+, K^+) reaction
Hypernuclei	
Reviews:	
1986CH1I	Summary — hypernuclear sessions of “Interactions Between Particle & Nuclear Physics”
1986CO1B	(e, e'K ⁺) & low-lying hypernuclear states using relativistic field theory (A)
1986GA1H	Hypernuclear interactions
1988CH48	Studies of hypernuclei by associated production
1988GA1A	Recent developments in hypernuclear spectroscopy
1988GA1I	Issues in hypernuclear physics
1988HA41	Nuclear physics with strange probes
1988PO1H	Flavour and the structure of hadrons and nuclei
1988WA1B	Production of hypernuclei in the (K, p) reaction
1989CH32	Recent experiments in novel nuclear excitations at the BNL AGS
1989DO1I	On the production & spectroscopy of hypernuclei
1989RE1C	Relativistic mean-field description of nuclei and nuclear dynamics
1989ZO03	Hypernuclear physics
Other articles:	
1986BA1H	Pionic decay of hypernuclei
1986GA14	Calc. of (K ⁻ , π) hypernuclear yields for stopped kaons in ^{12}C & $1p_\Lambda$ states in $^{16}_\Lambda\text{O}$
1986HA26	Shell model analysis of Σ -hypernuclear spectra for $A = 12$ & 16
1986HA39	Strangeness exchange reactions with the recoil corrected continuum shell model
1986MA1C	Decay properties of hypernuclear resonances
1986MO1A	The ΛN interaction & structures of the $^{16-18}\text{O}$ hypernuclei
1987CO09	(e, e'K ⁺) & low hypnucl. excits. using relativistic transit. operator & nucl. struc. model
1987MI38	Semiphenomenological studies of the ground state binding energies of hypernuclei
1987PI1C	Hypernuclei studied with the (π^+, K^+) reaction (A)
1987RU1A	Single-particle spectra of Λ hypnucl. & enhanced interact. radii of multi-strange objects
1987WU05	Resonant and quasi-free mechanisms of Σ -production on nuclei

Table 16.12: ^{16}O – General (continued)

Reference	Description
Hypernuclei – continued	
1987YA1C	Density-dependent effective ΛN & ΛNN interaction applied to light hypernuclei
1988HA44	Phenomenological analysis of Σ -hypernuclear spectra from (K^-, π^+) reactions
1988MA09	Study of hypernucleus production by K^- capture at rest
1988MA1G	Non-mesonic hypernuclear weak decays — systematic testing in the shell model
1988MI1N	Λ -nucleus single-particle potential from analysis of Λ -hypernuclei spectra data
1988MO1B	(π^+, K^+) reaction used to probe Λ and Σ states in hypernuclei
1988MO23	Hypernuclear production by the (π^+, K^+) reaction
1988PE1H	Associated production of hypernuclei with (π^+, K^+) reaction
1989BA06	Polarization of hypernuclei in the (π^+, K^+) reaction
1989BA92	Strangeness production by heavy ions
1989BA93	Production of hypernuclei in relativistic ion beams
1989FE07	Skyrme-Hartree-Fock calculation of Λ -hypernuclear states from (π^+, K^+) reactions
1989HA29	Shell model calculation of Λ -hypernuclear spectra from (π^+, K^+) reactions
1989HA32	Σ -hypernuclear production in flight
1989KO37	Relativistic motion of the Λ in hypernuclei using Woods-Saxon & Gaussian potentials
1989LA1I	Indirect methods of study of decays of excited hypernuclei — hypernuclear spectroscopy
1989MA30	On Λ -hyperon(s) in the nuclear medium; relativistic mean field theory analysis
1989MO17	(π, K^+) hypernucl. production & struc.; DWIA calc. based on Kapur-Peierls framework
1989PI11	Study of hypernuclei from ${}^9_{\Lambda}\text{Be}$ to ${}^{89}_{\Lambda}\text{Y}$ using the (π^+, K^+) reaction
1989TA16	Formation of ${}^4_{\Lambda}\text{H}$ hypernuclei from K^- absorption at rest on light nuclei
1989TA17	Compound-hypernucl. interpretation on ${}^4_{\Lambda}\text{H}$ formation probab. in stopped- K^- absorption
1989TA19	${}^4_{\Lambda}\text{H}$ formation from K^- absorption at rest on ${}^4\text{He}$, ${}^7\text{Li}$, ${}^9\text{Be}$, ${}^{12}\text{C}$, ${}^{16}\text{O}$, & ${}^{40}\text{Ca}$
1989TA32	Schmidt diagrams & configuration mixing effects on hypernuclear magnetic moments
1991BE01	Electromagnetic production of polarization in hypernuclei
1991FE06	Effective ΛN -interaction & spectroscopy of low-lying states of 1p-shell hypernuclei
1991PI07	Study of hypernuclei by associated production through the (π^+, K^+) reaction

Antinucleon Interactions

Reviews:

- 1987GR1I Low energy antiproton physics in the early LEAR era
 1987YA1E Why study (\bar{p}, \bar{n}) on nuclei?

Other Articles:

- 1986DU10 Microscopic calculation of antiproton atomic-like bound states in light nuclei
 1986FR10 Fourier-Bessel potential description of antiproton-nucleus elastic scattering data
 1986KO1E Search for \bar{p} -atomic X-rays; observed spin-dependence of \bar{p} -nucleus interaction

Table 16.12: ^{16}O – General (continued)

Reference	Description
Antinucleon Interactions – continued	
1986MA46	Relativistic impulse approx. analysis of elastic \bar{p} scattering at intermediate energies
1986RO23	Measurement of the $4f$ strong interaction level width in light antiprotonic atoms
1986ZA06	Sensitivity of σ_R & forward scattering amp. to form of nucl. optical pot. for N & \bar{N}
1987AD04	Microscopic analysis of antiproton-nucleus elastic scattering
1987BA18	Optical model analysis of antiprotonic Oxygen atom data
1987BA21	Neutron-antineutron oscillations in ^{16}O
1987BE26	\bar{p} -neutron scattering amplitude from \bar{p} -nucleus elastic scattering data; Glauber model
1987CU1B	Nucleus excitation and deexcitation following \bar{p} -annihilation at rest
1987DA1D	Glauber-Sitenko description of low-energy antiproton-nucleus interactions
1987GR20	Widths of $4f$ antiprotonic levels in the Oxygen region
1987MA04	Spin effects in elastic \bar{p} -nucleus scattering; Glauber analysis
1987SP05	Spin and isospin effects in a relativistic treatment of \bar{p} -atom shifts and widths
1987ZA08	Strong absorption and noneikonal effects in antiproton-nucleus scattering
1988JA09	Residual mass distribution following \bar{p} -nucleus annihilation
1988LI10	Optical potential analysis of antiproton-nucleus elastic scattering (A)
1989CH13	Phenomenological model analysis of elastic & inelastic scat. of 180 MeV \bar{p} from nuclei
1989HE21	Microscopic calculation of antiproton elastic scattering on even-even nuclei
1989TA24	Spin & \bar{N} annihilation effects in elastic antiproton-nucleus scattering (Glauber theory)
1990TA31	Elastic scattering & spin effects of antiprotons from nuclei
1991AL02	N- \bar{N} oscillation times estimated from Paris NN potential
1991BA44	Finite-range effects in kaonic and antiprotonic atoms
1991LA02	Geometries of the antiproton-nucleus optical potentials at 180 MeV

Other Topics

Review:

1988HE1G A summary of theoretical discussion regarding hadronic parity violation

Other Articles:

- 1986BE23 Realistic many-body wave functions & nucleon momentum distributions in finite nuclei
- 1986DE11 Nuclear spin-isospin polarizability & the spatial non-locality of the mean field
- 1986IS04 Anomalous absorption of proton partial waves by the optical potential
- 1986KU11 The dynamical origin of nuclear mass number dependence in EMC-effect
- 1986PA23 Methods of in-beam internal-pair spectroscopy applied to nucl. structure investigations
- 1986RO26 Self-organization in nuclei
- 1987AB21 Evid. of subshell closures from binding-ener. systematics & ener. lvls. of dbl. even nucl.
- 1987CH11 Lifetimes of monopole resonances in time-dependent Hartree-Fock theory

Table 16.12: ^{16}O – General (continued)

Reference	Description
Other Topics – continued	
1987FUZZ	Relativistic RPA calculations of finite nuclei including negative-energy states (A)
1987KR1F	Local scale transform. meth. with > 1 scalar func. for descr. of monopole excits. in nucl.
1988KO23	Information on three-body interactions from inversion of the energy equations
1988TO09	Damping of quadrupole motion in time-dependent density-matrix theory
1988TO1C	Quenching of Gamow-Teller strength
1988ZH1G	Self-consistent calculation of relativistic microscopic optical potential (in Chinese) (A)
1989CEZZ	Composite particle production in intermediate energy nuclear reactions (A)
1989PO05	Isobaric multiplets reconstructed from equidistance rule for separation & decay energies
1989SH13	Continuum RPA with exchange term & appls. to spin-isosp. & longitudinal resp. funcs.
1990BL16	Microscopic approach to the calculation of the vertex constants of neutron cleavage
1990HO24	Relativistic RPA for finite nuclei with Skyrme type interaction
1990ZHZV	Effects of central, spin-orbit & tensor interactions in nuclei (A)
1991UM01	Nuclear Hartree-Fock calculations with splines

Ground State Properties

Review:

1988MA1X Relativistic theory of nuclear matter and finite nuclei

Other Articles:

- 1985SH1A Unified microscopic description of elastic & inel. cross sections of heavy-ion reactions.
- 1986AN08 Nucleon momentum & density distributions in the generator co-ordinate method
- 1986ANZM A multi harmonic oscillator calculation of binding energies & charge radii
- 1986AY01 Effect of higher states on the ground & low-lying excited 0^+ states of ^4He & ^{16}O
- 1986DE33 Correlations in the Sp(1, R) model for the monopole oscillations
- 1986FU1B Relativistic shell model calculations
- 1986GL1A Effects of particle-hole excitations in light nuclei
- 1986HE26 Nuclear single-particle energies as functions of the binding energies for $4 \leq A \leq 90$
- 1986MAZE Form & relative importance of first-order contributions to density distribution of ^{16}O
- 1986PE22 Effects of the Dirac sea on finite nuclei
- 1986QU1A Relativistic self-consistent field calculations for closed-shell nuclei
- 1986SU13 Unitary-model-operators & the ground-state & one-body energies of ^{16}O
- 1986SU16 (1986SU13 cont.) Three-body-cluster effects on properties of ^{16}O
- 1986TO16 Hartree-Fock calculations of nuclear matter saturation density
- 1986YE1A Hartree-Fock calculations with extended Skyrme forces for ^{16}O and ^{40}Ca
- 1987AB03 Measurement & folding-potential analysis of the elastic α -scattering on light nuclei

Table 16.12: ^{16}O – General (continued)

Reference	Description
Ground State Properties – continued	
1987BL18	Calc. ground & excited states of light $N = Z$ nuclei; also spin-isospin order for excited
1987BL20	Relativistic Hartree-Fock calculations for ^{16}O and ^{40}Ca
1987BO11	Relativistic description of nuclear systems in the Hartree-Fock approximation
1987BO42	Monte Carlo test of the convergence of cluster expansions in Jastrow correlated nuclei
1987CA27	Mean field approach to the momentum distribution
1987ES06	Consistent description of effect of long-range residual interaction on the RMS radius
1987HA37	Excitation of $\Delta(3, 3)$ resonance in compressed finite nuclei (early version of 1987HA42)
1987HA42	Exc. of $\Delta(3, 3)$ resonance in compressed finite nucl. from constrained mean-field method
1987KR1B	Microscopic calc. of model for ^{16}O : 16 nucleons interacting via Malfliet-Tjon potential
1987MA30	Contrib. of particle-particle, hole-hole & particle-hole ring diagrams to binding energies
1987PR03	Self-consistent Hartree descrip. of deformed nuclei in a relativistic quantum field theory
1987SU08	Effects of self-consistent single-particle potential on nuclear effective interaction
1987SU12	Nuclear ground-state properties & nuclear forces in unitary-model-operator approach
1987TZ1A	Particle-particle ring diagrams in ^{16}O & Skyrme effective interactions (A)
1987ZE05	Microscopic estimation of clustering in ^4He , ^{12}C and ^{16}O
1988AL1N	Scaling in electron scattering from a relativistic Fermi gas
1988AN18	Generator coordinate calcs. of nucleon momentum & density dists. in ^4He , ^{16}O & ^{40}Ca
1988BO04	Correlated basis functions theory of light nuclei: general description & ground states
1988DE09	^{15}N ground state studied with elastic electron scattering; also calc. ^{16}O charge density
1988GU03	Charge-density distribution of 1s-1p & 1d-2s shell nuclei & filling numbers of the states
1988HO10	Shell-model with Hartree-Fock condition calc. of giant resnecs. & spectroscopic factors
1988KU18	Nuclear structure of ^{16}O in a mean-field boson approach
1988LU1A	Relativistic Hartree calculations of ^{16}O & ^{40}Ca using effective interactions
1988ME09	Three-dimensional, spherically symmetric, saturating model of an N -boson condensate
1988MU04	Dirac-Brueckner-Hartree-Fock approach to finite nuclei
1988RA1G	Clustering phenomena and shell effects in nuclear structure & reactions
1988RU04	Optimal parametrization for the relativistic mean-field model of the nucleus
1988SA03	Thermodynamic coefficients of hot nuclei
1988SO03	Model ground state calculations with two-variable integro-differential equations for ^{16}O
1988VA03	Static moments from a phenomenological interaction
1988WO04	An expansion of the shell-model space for light nuclei
1988YE1A	Calc. charge density distribs. & radii from Hartree-Fock method with Skyrme forces
1989AN10	1- & 2-nucleon momentum distributions in nuclei in coherent density fluctuation model
1989CA04	Quantized meson-exchange picture of nuclear interactions; application to ^{16}O & ^{40}Ca
1989DO04	Kuchta mean-field boson approach used to describe structure of ^{16}O
1989DO05	Relativistic Coulomb sum rules — expansions in moments of nucl. momentum density
1989FI04	Systematic study of potential energy surfaces of light nuclei in relativistic Hartree calcs.

Table 16.12: ^{16}O – General (continued)

Reference	Description
Ground State Properties – continued	
1989LE24	Nuclei with diffuse surfaces for future Boltzmann-Uehling-Uhlenbeck calculations
1989LI01	Self-consistent semiclassical calculation of rms radii of spherical nuclei
1989MA41	Descr. of nucleon high-momentum components due to short-range correlations in nuclei
1989MC05	Finite nucleus Dirac mean field theory & RPA using finite B splines for ^{16}O & ^{40}Ca
1989PI1F	Ground state of closed-shell nuclei (A)
1990MU15	Dirac-Brueckner-Hartree-Fock calculation of the ground state properties of ^{16}O
1991BO02	Meson exchange effects on magnetic dipole moments of p-shell nuclei
1991CR1A	Finite velocity meson exchange in nuclei
1991GM02	Relativistic mean-field fit to microscopic results in nuclear matter
1991KO23	Scalar coupling in relativistic mean field theory & properties of nuclei & nuclear matter
1991MA33	Super-RPA ground-state correlations
1991MU04	Effects of correlations on calc. of binding energy & radii of nuclei
1991RA14	Thermal properties of finite nuclei based on a realistic interaction
1991SC26	Meson exchange potentials & the problem of saturation in finite nuclei
1991TO03	Properties of nuclei far from stability & spherical nuclei in relativistic Hartree theory

(A) denotes that only an abstract was available for this reference.

Table 16.13: Energy Levels of ^{16}O ^a

E_x (MeV \pm keV)	$J^\pi; T$	K^π	$\Gamma_{\text{c.m.}}$ or τ_m (keV)	Decay	Reactions
0	$0^+; 0$		stable		5, 7, 11, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23, 24, 30, 32, 33, 34, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82
6.0494 ± 1.0	$0^+; 0$	0^+	$\tau_m = 96 \pm 7$ psec	π	5, 7, 11, 12, 13, 15, 17, 19, 21, 23, 30, 32, 33, 34, 38, 39, 43, 44, 47, 54, 55, 57, 66, 67, 70, 71, 73, 79, 81
6.129893 ± 0.04	$3^-; 0$		$\tau_m = 26.6 \pm 0.7$ psec;	γ	1, 5, 7, 11, 12, 13, 15, 17,

Table 16.13: Energy Levels of ^{16}O ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	K^π	$\Gamma_{\text{c.m.}}$ or τ_m (keV)	Decay	Reactions
			$g = +0.556 \pm 0.004$		18, 19, 21, 30, 31, 32, 33, 34, 37, 38, 39, 43, 44, 45, 46, 49, 50, 51, 53, 54, 66, 67, 68, 70, 71, 73, 79, 81
6.9171 ± 0.6	$2^+; 0$	0^+	$\tau_m = 6.78 \pm 0.19$ fsec	γ	1, 5, 7, 11, 12, 13, 15, 17, 19, 30, 31, 32, 33, 34, 37, 38, 42, 43, 44, 45, 46, 47, 49, 50, 53, 54, 55, 67, 68, 70, 71, 73, 78, 80
7.11685 ± 0.14	$1^-; 0$		$\tau_m = 12.0 \pm 0.7$ fsec	γ	1, 5, 7, 11, 12, 13, 17, 30, 31, 32, 33, 34, 37, 38, 39, 42, 43, 44, 46, 47, 50, 66, 67, 68, 70, 71, 73, 81
8.8719 ± 0.5	$2^-; 0$		$\tau_m = 180 \pm 16$ fsec	γ, α	5, 7, 11, 12, 16, 19, 30, 31, 33, 37, 38, 39, 43, 45, 46, 47, 49, 50, 67, 68, 73, 81
9.585 ± 11	$1^-; 0$	0^-	$\Gamma = 420 \pm 20$	γ, α	7, 9, 11, 12, 30, 38, 39, 45, 46, 47, 49, 50, 54, 55
9.8445 ± 0.5	$2^+; 0$	$2^+{}^b$	0.625 ± 0.100	γ, α	5, 7, 9, 11, 12, 19, 30, 31, 33, 37, 38, 39, 43, 46, 47, 49, 50, 54, 55, 66, 68, 70, 73, 78, 81
10.356 ± 3	$4^+; 0$	0^+	26 ± 3	γ, α	5, 7, 9, 11, 12, 13, 14, 16, 19, 21, 30, 31, 33, 38, 43, 46, 47, 49, 50, 54, 55, 61, 66, 68, 71, 73, 81
10.957 ± 1	$0^-; 0$		$\tau_m = 8 \pm 5$ fsec		5, 30, 37, 38, 46, 47, 68, 73
11.080 ± 3	$3^+; 0$	$2^+{}^b$	$\Gamma < 12$	γ	5, 30, 37, 38, 68, 73
11.0967 ± 1.6	$4^+; 0$		0.28 ± 0.05	γ, α	5, 7, 9, 11, 13, 14, 16, 19, 30, 31, 43, 46, 47, 49, 50, 54, 55, 73
$(11.26)^c$	$(0^+; 0)$		(2500)	(α)	9, 38
11.520 ± 4	$2^+; 0$		71 ± 3	γ, α	5, 7, 9, 19, 30, 43, 44, 46, 47, 49, 50, 54, 55, 61
11.60 ± 20	$3^-; 0$	0^-	800 ± 100	α	9, 14, 54, 55
12.049 ± 2	$0^+; 0$		1.5 ± 0.5	γ, α	9, 19, 23, 30, 43, 46, 47, 49, 50, 54, 55
12.440 ± 2	$1^-; 0$		91 ± 6	γ, p, α	7, 8, 9, 30, 34, 36, 37, 38, 43, 47, 50, 54, 55
12.530 ± 1	$2^-; 0$		$(97 \pm 10) \times 10^{-3}$	γ, p, α	5, 19, 30, 34, 36, 37, 38, 43, 46, 47, 50, 67
12.796 ± 4	$0^-; 1$		40 ± 4	p	30, 36, 37, 38, 46

Table 16.13: Energy Levels of ^{16}O ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	K^π	$\Gamma_{\text{c.m.}}$ or τ_m (keV)	Decay	Reactions
12.9686 \pm 0.4	2 ⁻ ; 1		1.34 \pm 0.04	γ, p, α	19, 30, 34, 36, 37, 38, 43, 66, 67, 68
13.020 \pm 10	2 ⁺ ; 0		150 \pm 10	γ, p, α	7, 9, 43, 46, 47, 49, 50, 54, 55, 61
13.090 \pm 8	1 ⁻ ; 1		130 \pm 5	γ, p, α	7, 8, 9, 11, 30, 37, 38, 43, 68
13.129 \pm 10	3 ⁻ ; 0		110 \pm 30	γ, p, α	6, 7, 8, 9, 30, 38
13.259 \pm 2	3 ⁻ ; 1		21 \pm 1	γ, p, α	7, 8, 9, 30, 36, 37, 38, 43, 46, 66, 67, 68, 70, 72
13.664 \pm 3	1 ⁺ ; 0		64 \pm 3	γ, p, α	30, 34, 36, 47
13.869 \pm 20	4 ⁺ ; 0		89 \pm 2	p, α	5, 9, 30, 36, 43, 45, 49, 50, 54, 55
13.980 \pm 2	2 ⁻		20 \pm 2	p, α	5, 30, 31, 36
14.032 \pm 15	0 ⁺		185 \pm 35	γ, α	9, 43
14.1 \pm 100	3 ⁻		750 \pm 200	α	9
14.302 \pm 3	4 ⁽⁻⁾		34 \pm 12		19, 30, 31
14.399 \pm 2	5 ⁺		27 \pm 5		5, 12, 19, 30, 31
14.620 \pm 20	4 ⁽⁺⁾		490 \pm 15	α	9, 11
14.660 \pm 20	5 ⁻	0 ⁻	670 \pm 15	α	9, 11, 12, 13, 14, 54, 55
14.8153 \pm 1.6	6 ⁺ ; 0		70 \pm 8	α	5, 9, 11, 19, 30, 31, 49, 50, 54, 55
14.926 \pm 2	2 ⁺		54 \pm 5	p, α	5, 30, 36, 43
15.097 \pm 5	0 ⁺		166 \pm 30	p, α	8, 9, 30, 36
15.196 \pm 3	2 ⁻ ; 0		63 \pm 4	p, α	30, 31, 36, 43, 46, 49, 66, 67, 68
15.26 \pm 50	2 ⁺ ; (0)		300 \pm 100	p, α	36, 43, 46, 49
15.408 \pm 2	3 ⁻ ; 0		132 \pm 7	p, α	8, 9, 30, 31, 36, 43, 46, 50, 54, 55, 61, 66, 67, 68
15.785 \pm 5	3 ⁺		40 \pm 10		19, 30, 31
15.828 \pm 30	3 ⁻		700 \pm 120	α	9, 43
16.20 \pm 90	1 ⁻ ; 0		580 \pm 60	γ, p, α	7, 30, 36
16.209 \pm 2	1 ⁺ ; 1		19 \pm 3	γ, n, p	30, 31, 34, 35, 36, 41, 43
16.275 \pm 7	6 ⁺	0 ⁺ ^b	420 \pm 20	α	5, 9, 11, 12, 13, 14, 21, 31, 54, 55, 61
16.352 \pm 8	(2 ⁺) ^d		61 \pm 8	p, α	8, 9, 30, 36, 46, 49, 50, 70
16.4423 \pm 1.6	2 ⁺ ; 1		25 \pm 2	γ, n, p, α	7, 8, 9, 30, 36, 43
16.817 \pm 2	(3 ⁺ ; 1) ^{b,e}		28 \pm 3	γ, p, α	19, 30, 34, 36
16.844 \pm 21	4 ⁺		570 \pm 60	α	9
16.93 \pm 50	2 ⁺		\approx 280	$\alpha, {}^8\text{Be}$	9, 10

Table 16.13: Energy Levels of ^{16}O ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	K^π	$\Gamma_{\text{c.m.}}$ or τ_m (keV)	Decay	Reactions
17.09 \pm 40	1 ⁻ ; 1		380 \pm 40	γ, p	34, 36
17.129 \pm 5	2 ⁺		107 \pm 14	n, p, α	8, 9
17.140 \pm 10	1 ⁺ ; 1		34 \pm 3	γ, n, p, α	9, 34, 35, 36, 43
17.197 \pm 17	2 ⁺		160 \pm 60	$\alpha, ^8\text{Be}$	5, 9, 10, 31, 38, 46, 49, 50
17.282 \pm 11	1 ⁻ ; 1		78 \pm 5	γ, n, p, α	8, 34, 35, 36, 41, 43
17.510 \pm 26	1 ⁻		180 \pm 60	α	9
17.555 \pm 21	(6 ⁺)		180 \pm 70	n, α	8, 9
17.609 \pm 7	2 ⁺ ; (1)		114 \pm 14	p, α	8, 9, 36
17.72	(0 ⁺ , 2 ⁺)		\approx 75	p, $\alpha, ^8\text{Be}$	9, 10
17.775 \pm 11	4 ⁻ ; 0		45 \pm 7	p	19, 43, 44, 46, 49, 50, 67, 68
17.784 \pm 15	4 ⁺		400 \pm 40	n, $\alpha, ^8\text{Be}$	8, 9, 10, 43, 54, 55
17.877 \pm 6	(2 ⁻); 1 ^b		24 \pm 3	$\gamma, p, (\alpha)$	34, 36, 41
18.016 \pm 1	4 ⁺ ; (0)		14 \pm 2	n, p, $\alpha, ^8\text{Be}$	8, 9, 10, 19
18.029 \pm 5	3 ⁽⁻⁾ ; 1		26 \pm 4	γ, n, p, α	19, 34, 35, 36, 43, 67
18.089 \pm 25	(0 ⁺)		288 \pm 44	(γ), n, p, α	7, 8, 9, 35, 46, 50
18.202 \pm 8	2 ⁺		220 \pm 50	γ, p	36, 43, 46, 50
18.29			\approx 380	γ, p, α	7, 8, 9
18.404 \pm 12	5 ⁻		550 \pm 40	α	9
18.430 \pm 15	2 ⁺ ; 0		90 \pm 40	p	36, 46, 49, 50
18.484 \pm 6	(1 ⁻ , 2 ⁻)		35 \pm 6	p	36
18.6	(1 ⁻ , 5 ⁻)		\approx 150	α	9
18.6	(4 ⁺)		\approx 300	$\alpha, ^8\text{Be}$	9, 10
18.640 \pm 15	(5 ⁺)		22 \pm 7	(n, p)	5, 19, 43
18.773 \pm 22	1 ⁻		215 \pm 45	p, α	8, 9
18.785 \pm 6	4 ⁺		260 \pm 20	n, p, $\alpha, ^8\text{Be}$	8, 9, 10
18.79 \pm 10	1 ⁺ ; 1		120 \pm 20	γ, p	34, 36, 43
18.977 \pm 6	4 ⁻ ; 1		8.2 \pm 3.8	γ, p, α	19, 34, 36, 43, 44, 46, 49, 67, 68
19.001 \pm 24	2 ⁻ ; 1		420 \pm 50	γ, p	34, 36, 43
19.08 \pm 30	2 ⁺ ; (1)		\approx 120	$\gamma, (n), p, \alpha$	8, 9, 14, 34, 36
19.206 \pm 12	3 ⁻ ; 1		68 \pm 10		43, 67, 68
19.253 \pm 30	(5 ⁻)		50 \pm 45	n, α	8, 9
19.257 \pm 9	2 ⁺ ; (1)		155 \pm 25	γ, p, α	8, 9, 34, 36
19.319 \pm 14	(6 ⁺)		65 \pm 35	p, $\alpha, ^8\text{Be}$	8, 9, 10
19.375 \pm 2	4 ⁺		23 \pm 4	p, α	8, 9
19.47 \pm 30	1 ⁻ ; 1		200 \pm 70	γ, p	34, 36, 43
19.539 \pm 19	2 ⁺ ; 0		255 \pm 75	n, α	5, 8, 9, 46, 50

Table 16.13: Energy Levels of ^{16}O ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	K^π	$\Gamma_{\text{c.m.}}$ or τ_m (keV)	Decay	Reactions
19.754 \pm 16	2 ⁺		290 \pm 50	p, α	8, 9
19.808 \pm 11	4 ⁻ ; 0		32 \pm 4		19, 44, 46, 67, 68
19.895 \pm 7	3; 1		42 \pm 9	γ , p, α	5, 34, 36
20.055 \pm 13	2 ⁺ ; 0		400 \pm 32	γ , n, p, α	7, 8, 9, 49, 50
20.412 \pm 17	(2 ⁻ , 4 ⁺); 1		190 \pm 20	γ , n, p	34, 35, 36, 43, 67, 68
20.510 \pm 0.025	(4 ⁻ ; 1)	50 \pm 30	γ	43	
20.541 \pm 2	5 ⁻ ; 1		11 \pm 2	p, α	5, 8, 9
20.560 \pm 2	even π		< 5	p, α	8, 9
20.615 \pm 3	even π		< 10	α	9
(20.8)			(\approx 60)	n, p, α	8
20.857 \pm 14	7 ⁻	0 ⁻	900 \pm 60	α	9, 11, 12, 13, 14
20.945 \pm 20	1 ⁻ ; 1		300 \pm 10	γ , n, p	34, 35, 36, 43
21.05 \pm 50	(2 ⁺ ; 0)		298 \pm 43		46, 50
21.052 \pm 6	6 ⁺		205 \pm 15	α	9
21.175 \pm 15					5
21.50	(1 \rightarrow 4)		120	p	36
21.623 \pm 11	7 ⁻		60 \pm 30	n, p, α	8, 9
21.648 \pm 3	6 ⁺		115 \pm 8	n, α	8, 9, 11
21.776 \pm 9	3 ⁻		43 \pm 20	n, p, α	5, 8, 9
22.04	0 ⁺		60	n, d, α	8, 25
22.150 \pm 10	1 ⁻ ; 1		680 \pm 10	γ , n, p, d, α	14, 24, 26, 29, 34, 35, 36, 40, 41, 42
22.35	2 ⁺		175	n, d, α	25, 29
22.5 \pm 100	3 ⁻		400 \pm 50	p, d, α	26, 29, 50
22.65 \pm 30			60	n, α , ^8Be	5, 8, 10
22.721 \pm 3	0 ⁺ ; 2		12.5 \pm 2.5	n, p, d, α	8, 9, 23, 26, 29, 70
22.89 \pm 10	1 ⁻ ; 1		300 \pm 10	γ , p, d	24, 26, 34, 36
23.0 \pm 100	6 ⁺		\lesssim 500	(d), α , ^8Be	10, 11, 29
23.1			\approx 20	(n), d, α , ^8Be	9, 10, 25, 29
23.235 \pm 62	(1 ⁻ ; 1)		560 \pm 150	n, p, d	25, 26, 27, 35, 46
23.51 \pm 30	(5 ⁻)		300	p, d, α	5, 9, 14, 26, 27, 29, 49, 50
23.879 \pm 6	6 ⁺		26 \pm 4	p, α , ^8Be	8, 9, 10, 11
24.07 \pm 30	1 ⁻ ; 1		550 \pm 40	γ , p, ^3He	17, 34, 36, 46
24.36 \pm 70	(2 ⁺ , 3 ⁻); 0		424 \pm 45	n, p	35, 50
24.522 \pm 11	2 ⁺ ; 2		< 50		23, 70
24.76 \pm 50	(2, 4) ⁺ ; 1		340 \pm 60	γ , n, p	34, 35, 36
25.12 \pm 50	1 ⁻ ; 1		3000 \pm 300	γ , p, ^3He , α	17, 34, 36, 42, 49
25.50 \pm 150	1 ⁻ ; 1		1300 \pm 300	γ	43, 46

Table 16.13: Energy Levels of ^{16}O ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	K^π	$\Gamma_{\text{c.m.}}$ or τ_m (keV)	Decay	Reactions
25.6	(3 ⁻); 1		450	$^3\text{He}, \alpha$	9, 17
26.0 \pm 100	1 ⁻ ; (1)		500–1000	$\gamma, ^3\text{He}, \alpha$	17
26.363 \pm 62	(2, 4) ⁺ ; 1		550 \pm 70	$\gamma, \text{n}, \text{p}, \alpha$	9, 34, 35, 36
27.35 \pm 100	(2, 4) ⁺ ; 1		830 \pm 110	$\gamma, \text{p}, ^3\text{He}, \alpha, ^8\text{Be}$	17, 34, 36
27.5	(3 ⁻ ; 0)		\approx 2500	$\gamma, ^3\text{He}$	17
28.2	7 ⁻		1000	α	9, 11
28.6 \pm 200				$\gamma, ^3\text{He}$	17
29.0	7 ⁻		1000	p, α	9, 11
29.8 \pm 100	9 ⁻ + 8 ⁺		500 – 1000	$^3\text{He}, \alpha$	14, 17
31.8 \pm 600				γ, α	11, 42
34	10 ⁺ (9 ⁻)		2300	α	9, 11
35				α	11

^a See also Tables 16.14 and 16.26.

^b D.J. Millener, private communication.

^c See (1986AJ04).

^d See reaction 70 and (1986VO10).

^e (1983SN03). See also Table 16.22.

 Table 16.14: Radiative decays in ^{16}O ^a

E_i (MeV)	$J_i^\pi; T$	E_f (MeV)	$J_f^\pi; T$	Branch (%)	Γ_{rad} (eV)
6.05	0 ⁺ ; 0	0	0 ⁺ ; 0	100	3.55 \pm 0.21 ^b
6.13	3 ⁻ ; 0	0	0 ⁺ ; 0	100	(2.60 \pm 0.13) \times 10 ⁻⁵
6.92	2 ⁺ ; 0	0	0 ⁺ ; 0	> 99	0.097 \pm 0.003 ^c
		6.05	0 ⁺ ; 0	(2.7 \pm 0.3) \times 10 ⁻²	(2.7 \pm 0.3) \times 10 ⁻⁵
		6.13	3 ⁻ ; 0	\leq 8 \times 10 ⁻³	
7.12	1 ⁻ ; 0	0	0 ⁺ ; 0	> 99	0.055 \pm 0.003 ^c
		6.05	0 ⁺ ; 0	< 6 \times 10 ⁻⁴	
		6.13	3 ⁻ ; 0	(7.0 \pm 1.4) \times 10 ⁻²	
8.87	2 ⁻ ; 0	0	0 ⁺ ; 0	7.2 \pm 0.8	(2.6 \pm 0.4) \times 10 ⁻⁴
		6.05	0 ⁺ ; 0	0.122 \pm 0.033	(3.1 \pm 1.0) \times 10 ⁻⁶
		6.13 ^f	3 ⁻ ; 0	77.7 \pm 1.6 ⁱ	(2.8 \pm 0.3) \times 10 ⁻³ ^d

Table 16.14: Radiative decays in ^{16}O ^a (continued)

E_i (MeV)	$J_i^\pi; T$	E_f (MeV)	$J_f^\pi; T$	Branch (%)	Γ_{rad} (eV)
9.59	$1^-; 0$	6.92	$2^+; 0$	3.6 ± 0.5^i	$(1.5 \pm 0.3) \times 10^{-4}$
		7.12	$1^-; 0$	11.4 ± 0.5^i	$(4.2 \pm 0.8) \times 10^{-4}^e$
		0	$0^+; 0$	≈ 100	$(2.5 \pm 0.4) \times 10^{-2}$
9.84	$2^+; 0$	6.92	$2^+; 0$		$(2.9 \pm 1.0) \times 10^{-3}$
		0	$0^+; 0$	61 ± 4	$(5.7 \pm 0.6) \times 10^{-3}$
		6.05	$0^+; 0$	18 ± 4	$(1.9 \pm 0.4) \times 10^{-5}$
10.36	$4^+; 0$	6.92	$2^+; 0$	21 ± 4	$(2.2 \pm 0.4) \times 10^{-5}$
		0	$0^+; 0$		$(5.6 \pm 2.0) \times 10^{-8}$
		6.13	$3^-; 0$		$< 1.0 \times 10^{-3}$
10.96	$0^-; 0^g$	6.92	$2^+; 0$	≈ 100	$(6.2 \pm 0.6) \times 10^{-2}$
		7.12	$1^-; 0$	> 99	0.08 ± 0.05
11.10	$4^+; 0$	6.13	$3^-; 0$		$(3.1 \pm 1.3) \times 10^{-3}$
		6.92	$2^+; 0$		$(2.5 \pm 0.6) \times 10^{-3}$
		0	$0^+; 0$	91.7	0.61 ± 0.02
11.52	$2^+; 0$	6.05	$0^+; 0$	4.2 ± 0.7	$(3.0 \pm 0.5) \times 10^{-2}$
		6.92	$2^+; 0$	4.0 ± 1.0	$(2.9 \pm 0.7) \times 10^{-2}$
		7.12	$1^-; 0$	≤ 0.8	
12.05	$0^+; 0$	0	$0^+; 0$		4.03 ± 0.09^b
12.44	$1^-; 0$	0	$0^+; 0$	≈ 100	12 ± 2
		6.05	$0^+; 0$	1.2 ± 0.4	0.12 ± 0.04
12.53	$2^-; 0$	0	$0^+; 0$		$(3.3 \pm 0.5) \times 10^{-2}^j$
		6.13	$3^-; 0$	60 ± 6	2.1 ± 0.2
		6.92	$2^+; 0$	< 10	< 0.34
12.80	$0^-; 1$	7.12	$1^-; 0$	15 ± 3	0.5 ± 0.1
		8.87	$2^-; 0$	25 ± 3	0.9 ± 0.1
		7.12	$1^-; 0$	≈ 100	2.5 ± 0.2
		0	$0^+; 0$		$(3.4 \pm 0.9) \times 10^{-2}^j$
12.97	$2^-; 1$	6.13	$3^-; 0$	63 ± 6	2.3 ± 0.2
		7.12	$1^-; 0$	12 ± 3	0.44 ± 0.10
		8.87	$2^-; 0$	25 ± 3	0.90 ± 0.10
13.09 ^h	$1^-; 1$	0	$0^+; 0$	≈ 100	32 ± 5

Table 16.14: Radiative decays in ^{16}O ^a (continued)

E_i (MeV)	$J_i^\pi; T$	E_f (MeV)	$J_f^\pi; T$	Branch (%)	Γ_{rad} (eV)
		6.05	$0^+; 0$	0.58 ± 0.12	
		7.12	$1^-; 0$	3.1 ± 0.8	1.4 ± 0.4

^a See Tables 16.12 in (1971AJ02), 16.15 in (1977AJ02) and 16.12 in (1982AJ01) for the earlier work and for references. See also Table 16.15 here.

^b Monopole matrix element in fm^2 .

^c Weighted mean of earlier measurements and of a newer one reported in reaction 42 (1985MO10).

^d $(3.0 \pm 0.4) \times 10^{-4}$ [M1], $(2.5 \pm 0.2) \times 10^{-3}$ [E2] (1982VE04).

^e $(8 \pm 3) \times 10^{-5}$ [M1], $(3.4 \pm 0.5) \times 10^{-4}$ [E2] (1982VE04).

^f $E_\gamma = 2471.5 \pm 0.5$ keV for $(8.87 \rightarrow 6.13)$ transition.

^g Pairs due to this transition are not observed.

^h For the radiative decay of higher states see Tables 16.15, 16.22, and 16.26.

ⁱ (1982VE04). See also for δ .

^j (1986ZI08).

At $E(^6\text{Li}) = 4.9$ MeV, the cross sections for reactions (b) to (f) leading to low-lying states in the residual nuclei are proportional to $2J_f + 1$: this is interpreted as indicating that the reactions proceed via a statistical compound nucleus mechanism. For highly excited states, the cross section is higher than would be predicted by a $2J_f + 1$ dependence: see (1982AJ01, 1986AJ04).

5. $^{10}\text{B}(^{10}\text{B}, \alpha)^{16}\text{O}$ $Q_m = 26.413$

States of ^{16}O observed at $E(^{10}\text{B}) = 20$ MeV are displayed in Table 16.10 of (1977AJ02). At the higher excitation energies, states are reported at $E_x = 17.200 \pm 0.020, 17.825 \pm 0.025, 18.531 \pm 0.025, 18.69 \pm 0.03, 18.90 \pm 0.035, 19.55 \pm 0.035, 19.91 \pm 0.02, 20.538 \pm 0.015, 21.175 \pm 0.015, 21.84 \pm 0.025, 22.65 \pm 0.03$ and 23.51 ± 0.03 MeV. The reaction excites known $T = 0$ states: σ_t follows $2J_f + 1$ for 11 of 12 groups leading to states of known J . The angular distributions show little structure: see (1977AJ02).

6. $^{11}\text{B}(^7\text{Li}, \text{nn})^{16}\text{O}$ $Q_m = 12.170$

Cross section measurements at $E_{\text{c.m.}} = 1.46\text{--}6.10$ MeV were reported in (1990DA03).

7. $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ $Q_m = 7.161$

Table 16.15: Resonances in $^{12}\text{C} + \alpha$ ^a

No.	E_α (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles ^b (x)	Γ_x	Γ_{α_0}/Γ	$^{16}\text{O}^*$ (MeV \pm keV)	$J^\pi; T$
1	3.324	480 ± 20	γ_0 γ_3 γ_4 α_0	15.6 ± 1.2 meV ^c 1.4 ± 1.4 meV ^c 7.8 ± 1.6 meV ^c	≈ 1	8.87 9.580 ± 12	1^-
2	3.5770 ± 0.5	0.625 ± 0.100	γ_0 γ_3 α_3	5.7 ± 0.6 meV 2.2 ± 0.4 meV		9.8440 ± 0.5	2^+
3	4.259	27 ± 3	γ_0 γ_3 α_0	≤ 0.4 meV 62 ± 6 meV	1	10.356 ± 6	4^+
4	5.245 ± 8	0.28 ± 0.05	γ_2 γ_3 α_0	3.1 ± 1.3 meV 2.5 ± 0.6 meV		11.094	4^+
5	5.47	2500	α_0			(11.26)	(0^+)
6	5.809 ± 18	73 ± 5	γ_0 γ_3 α_0	0.65 ± 0.08 eV 29 ± 7 meV	1	11.52	2^+
7	5.92 ± 20	800 ± 100	α_0		1	11.60	3^-
8	6.518 ± 10	1.5 ± 0.5	α_0			12.049	0^+
9	7.043 ± 4	99 ± 7	γ_0 γ_1 p α_0 α_1	9.5 ± 1.7 eV ^d 0.12 ± 0.06 eV ^d 1.1 keV 92 ± 8 keV 0.025 keV	1.0	12.442 ± 4	$1^-; 0$
10	7.82 ± 10	150 ± 11	γ_0 α_0	^e 150 ± 11 keV	≈ 1.0	13.02	2^+
11	7.904 ± 11	130 ± 5	γ_0	44 ± 8 eV ^f		13.088 ± 11	$1^-; 1$

Table 16.15: Resonances in $^{12}\text{C} + \alpha$ ^a (continued)

No.	E_α (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles ^b (x)	Γ_x	Γ_{α_0}/Γ	$^{16}\text{O}^*$ (MeV \pm keV)	$J^\pi; T$
12	7.960 ± 10	110 ± 30	γ_4	1.35 ± 0.4 eV	0.3	13.129	$3^-; 0$
			p	100 keV			
			α_0	45 ± 18 keV			
			α_1	1 keV			
			γ_0	> 0.01 eV			
13	8.130 ± 15	26 ± 7	p	1 keV	0.7	13.257	$3^-; 1$
			α_0	90 ± 14 keV			
			α_1	≈ 20 keV			
			γ				
			p	4.5 keV			
14	8.960 ± 10	75 ± 7	α_0	9 ± 4 keV	0.65 ± 0.05	13.879 ± 8	4^+
			α_1	7.5 keV			
			$\gamma_{4.4}$	49 keV			
			α_1	23 keV			
15	9.1	4800	α_0			(14.0)	(0^+)
16	9.164 ± 15	200 ± 15	α_0	≈ 200 keV	> 0.9	14.032	0^+
17	9.3 ± 100	750 ± 200	α_0		0.2 ± 0.1	14.1	3^-
			α_1				
18	9.948	487 ± 12	α_0		0.8^{h}	$14.620 \pm 11^{\text{g}}$	(4^+)
			α_1				
19	10.002	672 ± 11	α_0		0.94	$14.660 \pm 11^{\text{g}}$	5^-
			α_1				
20	10.195 ± 7	70 ± 8	α_0	22 keV	0.45 ± 0.05	14.805	6^+
			α_1	48 keV			
21	10.544	166 ± 30	$\alpha_0, \alpha_1, \text{p}_0$		0.35	15.066 ± 11	0^+
22	10.999	133 ± 7	$\alpha_0, \alpha_1, \text{p}_0$		0.58	15.408 ± 2	3^-
23	11.560	703 ± 113	$\alpha_0, (\alpha_1), \gamma_{4.4}$		0.21	15.828 ± 30	3^-

Table 16.15: Resonances in $^{12}\text{C} + \alpha$ ^a (continued)

No.	E_α (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles ^b (x)	Γ_x	Γ_{α_0}/Γ	$^{16}\text{O}^*$ (MeV \pm keV)	$J^\pi; T$
24	11.6	≈ 600	γ_0	$\Gamma_\alpha\Gamma_\gamma/\Gamma \approx 0.4$ eV		15.9	2^+
25	12.156	422 ± 14	α_0		0.93	16.275 ± 7	6^+
26	12.272	65 ± 45	$\alpha_0, (\alpha_1, \alpha_2), p_0$		0.07	16.362 ± 20	$(0^+, 1^-)$
27	12.380	22 ± 3	$\gamma_0, n, p_0, \alpha_0, \alpha_1, \alpha_2, \gamma_{4.4}$	$\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.45$ eV	0.28	16.443 ± 2	$2^+; (1)$
28	12.5	730	p_0, α_0			(16.5)	
29	12.915	567 ± 60	α_0		0.28	16.844 ± 21	4^+
30	13.0	700	α_0			(16.9)	5^-
31	13.05	≈ 280	$\alpha_2, {}^8\text{Be}$			16.94	2^+
32	13.296	107 ± 14	$n, p_0, \alpha_0, \alpha_1, \gamma_{4.4}$		0.37	17.129 ± 5	2^+
33	13.32	36 ± 5	α_0, α_1			17.15	
34	13.35	160 ± 60	$\alpha_2, {}^8\text{Be}$			17.17	2^+
35	13.50	< 100	n			17.28	
36	13.805	182 ± 56	$\alpha_0, (\alpha_1), \alpha_2$		0.16	17.510 ± 26	1^-
37	13.865	178 ± 66	$n, (\alpha_0, \alpha_1)$		0.07	17.555 ± 21	(6^+)
38	13.948	175 ± 55	p_0, α_0		0.32	17.618 ± 20	$(0^+, 1^-)$
39	14.08	(≈ 75)	$(p_0), {}^8\text{Be}$			17.72	$(0^+, 2^+)$
40	14.170	396 ± 41	$n, \alpha_0, \alpha_1, \gamma_{4.4}, {}^8\text{Be}$		0.34	17.784 ± 15	4^+
41	14.480	14 ± 2	$(n), p_0, \alpha_0, \alpha_1, \gamma_{4.4}, {}^8\text{Be}$		0.36	18.016 ± 1	$4^+; (0)$
42	14.577	248 ± 90	$(\gamma_0), n_0, p_0, \alpha_0$		0.31	18.089 ± 25	(0^+)
43	(14.62)	(≈ 45)	α_0			(18.12)	($\neq 4^+$)
44	14.85	≈ 380	$\gamma_0, p_0, (\alpha_1, \gamma_{4.4})$	$\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.95$ eV		18.29	
45	14.997	544 ± 39	α_0		0.40	18.404 ± 12	5^-
46	15.2	≈ 150	$\alpha_0, \alpha_1, \alpha_2, \gamma_{4.4}$			18.6	$(1^-, 5^-)$
47	15.2	≈ 300	$\alpha_2, {}^8\text{Be}$			18.6	(4^+)
48	15.490	215 ± 45	p_0, α_0		0.26	18.773 ± 22	1^-
49	15.506	260 ± 16	$n, p_0, \alpha_0, (\alpha_1), {}^8\text{Be}$		0.48	18.785 ± 6	4^+
50	15.8	≈ 550	$(\alpha_0), \alpha_1, \gamma_{4.4}$			19.0	(5^-)
51	15.96	41	$(n), \alpha_0$			(19.12)	$(2^+, 4^+)$

Table 16.15: Resonances in $^{12}\text{C} + \alpha$ ^a (continued)

No.	E_α (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles ^b (x)	Γ_x	Γ_{α_0}/Γ	$^{16}\text{O}^*$ (MeV \pm keV)	$J^\pi; T$
52	16.130	50 ± 45	(n), (α_0)		0.04	19.253 ± 30	(5^-)
53	16.137	155 ± 23	$p_0, \alpha_0, (\alpha_1)$		0.34	19.257 ± 9	2^+
54	16.219	63 ± 33	$p_0, (\alpha_0), \alpha_1, \alpha_2, {}^8\text{Be}$		0.07	19.319 ± 14	(6^+)
55	16.293	23 ± 4	$p_0, \alpha_0, \alpha_1, \alpha_2$		0.23	19.375 ± 2	4^+
56	16.496	255 ± 75	(n), $\alpha_0, (\alpha_1, \alpha_2)$		0.20	19.527 ± 26	2^+
57	16.799	286 ± 44	p_0, α_0, α_1		0.29	19.754 ± 16	2^+
58	(16.92)	(≈ 175)	α_2			(19.85)	
59	(17.05)	(≈ 30)	(α_0)			(19.94)	($\neq 3^-$)
60	17.201	432 ± 40	$\gamma_0, \text{n}, (p_0), \alpha_0, (\alpha_1)$		0.43	20.055 ± 13	2^+
61	(17.27)	(≈ 45)	(α_0)			(20.11)	($\neq 3^-$)
62	17.5	≈ 1500	p_0			(20.3)	
63	(17.66)	(≈ 150)	$\text{n}, (p_0), \alpha_0, \alpha_2$			(20.40)	(4^+)
64	(17.8)	(≈ 300)	(α_0), α_1			(20.5)	
65	17.849	11 ± 2	$p_0, \alpha_0, \alpha_1, \alpha_2$		0.14 ± 0.02	20.541 ± 2	5^-
66	17.875	< 5	α_0			20.560 ± 2	even
67	17.948	< 10	α_0			20.615 ± 3	even
68	(18.2)	(≈ 60)	$\text{n}, (p_0)$			(20.8)	
69	18.271	904 ± 55	α_0		0.60	20.857 ± 14	7^-
70	(18.3)		α_0			(20.9)	2^+
71	(18.48)	(≈ 50)	$\text{n}, p_0, (\alpha_0)$			(21.01)	
72	18.50 ± 25	240 ± 80	$\gamma_0, (\alpha_0, \alpha_1)$		0.20	21.03	(1^-)
73	18.5	900	α_0		i	(21.0)	5^-
74	18.531	205 ± 14	α_0		0.50	21.052 ± 6	6^+
75	18.593	306 ± 46	(α_0)		0.20	(21.098)	4^+
76	19.294	61 ± 32	$\text{n}, p_0, \alpha_0, \alpha_2$		< 0.05	21.623 ± 11	7^-
77	19.327^j	115 ± 8	$\text{n}, \alpha_0, \alpha_1, \alpha_2$		0.41	21.648 ± 3	6^+
78	19.498^j	43 ± 20	$\text{n}, p_0, \alpha_0, \alpha_1, \alpha_2$		0.07	21.776 ± 9	3^-
79	19.85	60	n			22.04	

Table 16.15: Resonances in $^{12}\text{C} + \alpha$ ^a (continued)

No.	E_α (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles ^b (x)	Γ_x	Γ_{α_0}/Γ	$^{16}\text{O}^*$ (MeV \pm keV)	$J^\pi; T$
80	19.89	340	n			22.07	
81	19.95	< 150	n, ^8Be			22.11	
82	20.49	375	n			22.52	
83	20.71	60	n, ^8Be			22.68	
84	20.760 \pm 5	12.5 \pm 2.5	n ₀ , p ₀ , α_0 , α_2			22.721	0 ⁺ ; T = 2
85	21.28	\approx 20	α_1 , α_2 , ^8Be			23.11	
86	21.3	\leq 500	^8Be			23.1	6 ⁺
87	21.67	< 40	n, α_0 , α_2		\approx 0.31	23.40	(5 ⁻)
88	21.85	300	α_0 , α_1			23.54	
89	22.0	1500	$\gamma_{12.71}$			23.6	
90	22.14	120	n			23.75	
91	22.306 \pm 6	26 \pm 4	p ₀ , α_0 , α_1 , α_2 , ^8Be	^k	0.06 \pm 0.02	23.879	6 ⁺
92	22.37	165	n			23.93	
93 ^m	22.75	\leq 500	^8Be			24.21	
94	23.2	750	$\gamma_{12.71}$, $\gamma_{15.11}$			24.5	T = 1
95	24.1	450	$\gamma_{15.11}$			25.2	T = 1
96	24.6	450	$\gamma_{15.11}$			25.6	T = 1
97	25.5	450	$\gamma_{15.11}$			26.3	T = 1
98	25.6	1200	α_0 , $\gamma_{12.71}$	$\Gamma_\alpha \Gamma_\gamma / \Gamma = 1.2$ eV		26.3	2 ⁺
99	28.1	1000	α_0		0.35	28.2	7 ⁻
100	29.1	1000	α_0 , α_1 , p ₃		0.35	29.0	7 ⁻
101	35.8 n	2300	α_0 , α_2		0.1 ¹	34.0	10 ⁺ ; (9 ⁻)

- ^a References are listed in Tables 16.11 (1971AJ02), 16.12 (1977AJ02), 16.13 (1982AJ01), and 16.12 (1986AJ04).
- ^b p_0 corresponds to $^{15}\text{N}(0)$. α_0, α_1 corresponds to $^{12}\text{C}^*(0, 4.4)$ and $\gamma_{4.4}$ corresponds to the γ -ray from the decay of $^{12}\text{C}^*(4.4)$; $\gamma_0, \gamma_1, \gamma_2, \gamma_3, \gamma_4$ correspond to the transitions to $^{16}\text{O}^*(0, 6.05, 6.13, 6.92, 7.12)$.
- ^c These are observed widths from (1987RE02). We are indebted to Dr. F.C. Barker who informed us of these and other recent observed width determinations. $\Gamma_{\gamma_3}^0 = 2.4 \pm 1.4$ meV (1987RE02), $\Gamma_{\gamma_3} = 2.4$ meV, $\Gamma_{\gamma_4} = 8.0$ meV (1991BA1K), $\Gamma_{\gamma_0} = 16.4$ meV (*R*-matrix fit by (1991HU10)).
- ^d Branching ratios to $^{16}\text{O}^*(0, 6.05) = 98.8\%, 1.2\%$.
- ^e $\Gamma_{\gamma_0} = 0.7 \pm 0.2$ eV, based on $\Gamma_{\alpha_0}/\Gamma = 1.0$ and $\Gamma_{\text{c.m.}} = 190 \pm 40$ keV.
- ^f $\Gamma_{\alpha_0} \Gamma_{\gamma_0}/\Gamma^2 = (1.49 \pm 0.17) \times 10^{-4}$.
- ^g Uncertainties in E_x may be larger.
- ^h For this and the states below Γ_{α}/Γ is ± 0.10 for isolated narrow levels.
- ⁱ $\Gamma_{\alpha_2}/\Gamma = 0.16$ (1982KA30).
- ^j A resonance is reported at $E_{\alpha} = 19.4$ MeV: 4^+ is dominant, $\Gamma_{\alpha}/\Gamma \ll 1$, $\Gamma \geq 0.48$ (1982KA30).
- ^k $\Gamma_{8\text{Be}}, \Gamma_{\alpha_0}$, and $\Gamma_{\alpha_2} \approx 3.5, 1.5 \pm 0.5$ and ≈ 6 keV, respectively.
- ^l $\Gamma_{\alpha_2}/\Gamma = 0.2$ (1983AR12).
- ^m Broad maxima are reported in the activation cross section at $E_{\alpha} = 22.8, 24.3, 25.3$ and 26.9 MeV (1983KOZD; prelim.).
- ⁿ See (1981SA07) for $(\alpha, \gamma_{14.8})$ measurements which indicate an 8^+ GQR built on the 6_1^+ state $^{16}\text{O}^*(14.82)$.

Table 16.16: Astrophysical factors for $^{12}\text{C}(\alpha, \gamma)$ ^a

Reference	$S_{E1}(E_0)$ (MeV·b)	$S_{E2}(E_0)$ (MeV·b)
(1987RE02)	$0.20^{+0.27}_{-0.11}$ ^b	$0.096^{+0.024}_{-0.030}$
	$0.09^{+0.10}_{-0.06}, 0.14^{+0.12}_{-0.08}$ ^c	
(1987PL03)	0.20 ± 0.08 ^b	0.089 ± 0.030
	0.16 ± 0.10 ^c	
(1987BA53)	$0.14^{+0.13}_{-0.05}, 0.18^{+0.16}_{-0.10}$ ^b	$0.03^{+0.05}_{-0.03}$
(1988KR06)	$0.01^{+0.13}_{-0.01}$ ^b	
	0.08 ^c	
(1989FI08)	$0.03^{+0.14}_{-0.03}$ ^d	$0.007^{+0.024}_{-0.005}$ ^d
(1991BA1K)	$0.15^{+0.17}_{-0.07}, 0.26^{+0.14}_{-0.16}$ ^b	$0.12^{+0.06}_{-0.07}$
(1991HU10)	$0.043^{+0.020}_{-0.016}$ ^d	

^a We are indebted to Dr. F.C. Barker for providing this list of recent values.

^b 3-level R fitting.

^c Hybrid R fitting.

^d K fitting.

The yield of capture γ -rays has been studied for E_α up to 42 MeV [see Table 16.11 in (1977AJ02) and (1982AJ01)]. See also (1986AJ04). Observed resonances are displayed in Table 16.15 here.

This reaction plays an important role in astrophysical processes. The cross sections at astrophysical energies have been obtained by fitting measured cross sections and extrapolating them to low energies utilizing standard R-matrix, Hybrid R-matrix and K-matrix procedures. A list of recent values of the E2 and E1 astrophysical factors for $E_0 = 300$ keV obtained from fits to the data is given in Table 16.16.

The influence of vacuum polarization effects on subbarrier fusion is evaluated in (1988AS03), and the relevance of Coulomb dissociation of ^{16}O into $^{12}\text{C} + \alpha$ is studied in (1986BA50, 1989BA64, 1992SH11). Calculations to test the sensitivity of stellar nucleosynthesis to the level in ^{12}C at 7.74 MeV are described in (1989LI29). For other astrophysical studies see (1982AJ01, 1986AJ04) and (1985TA1A, 1986FI15, 1986MA1E, 1986WO1A, 1987AR1C, 1987BO1B, 1987DE32, 1987RO25, 1988CA26, 1988PA1H, 1988TRZZ, 1990BL1K, 1990BR1Q, 1990JI02).

At higher energies the E2 cross section shows resonances at $E_x = 13.2, 15.9, 16.5, 18.3, 20.0,$ and 26.5 MeV [see Table 16.16]. Some E2 strength is also observed for $E_x = 14$ to 15.5 and 20.5 to 23 MeV. In the range $E_\alpha = 7$ to 27.5 MeV the $T = 0$ E2 strength is $\sim 17\%$ of the sum-rule value. It appears from this and other experiments that the E2 centroid is at $E_x \sim 15$ MeV, with a 15 MeV spread. Structures are observed in the yield of γ -rays from the decay to $^{16}\text{O}^*(14.8 \pm 0.1)$

for $E_x = 34\text{--}39$ MeV. It is suggested that these correspond to a giant quadrupole excitation with $J^\pi = 8^+$ built on the 6_1^+ state at $E_x = 14.815$ MeV: see (1982AJ01, 1986AJ04).

8. (a) $^{12}\text{C}(\alpha, n)^{15}\text{O}$	$Q_m = -8.502$	$E_b = 7.161$
(b) $^{12}\text{C}(\alpha, p)^{15}\text{N}$	$Q_m = -4.966$	
(c) $^{12}\text{C}(\alpha, d)^{14}\text{N}$	$Q_m = -13.575$	

For reaction (a) cross section measurements from threshold to $E_\alpha = 24.7$ MeV [see (1986AJ04)], and at $E_\alpha = 10.5$ to 20 MeV (see Table 16.16 here). For excitation functions from $E_\alpha = 21.8$ to 27.2 MeV, see (1986AJ04). Thick-target neutron yields have been measured for $E_\alpha = 1.0$ to 9.8 MeV (1989HE04) and for 4–7 MeV (1982WE16). For reaction (b) cross section measurements from threshold to 33 MeV, see (1986AJ04). The excitation curve for p_3 (to $^{15}\text{N}^*(6.32)$), measured for $E_\alpha = 24$ to 33 MeV, shows a large peak at $E_x \approx 29$ MeV, $\Gamma \approx 4$ MeV. It is suggested that it is related to the GQR in ^{16}O : see (1982AJ01). For reaction (c) deuteron spectra have been measured for $E_\alpha = 200, 400, 600, 800$ MeV/nucleon (1991MO1B). For the observed resonances see Table 16.16 here.

9. $^{12}\text{C}(\alpha, \alpha)^{12}\text{C}$	$E_b = 7.161$
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The yield of α -particles leading to $^{12}\text{C}^*(0, 4.4, 7.7)$ and 4.4, 12.7 and 15.1 MeV γ -rays has been studied at many energies in the range $E_\alpha = 2.5$ to 42 MeV [see (1986AJ04)], and at $E_\alpha = 0.4\text{--}1.8$ MeV (1990TO09). Observed resonances are displayed in Table 16.15. Attempts have been made to observe narrow states near $^{16}\text{O}^*(8.87, 9.85)$. No evidence has been found for a narrow (100 eV) 0^+ state in the vicinity of the 2^- state at 8.87 MeV [see (1982AJ01)] nor for a 3^- state near the 2^+ state at 9.84 MeV (1986AJ04).

For total cross section measurements see (1986AJ04) and for $E_\alpha = 100$ MeV (1986DU15). For integral cross sections for inelastic scattering at 50.5 MeV, see (1987BU27). For elastic scattering differential cross sections at $E_\alpha = 96.6$ MeV see (1990KO2C), at 90 MeV (1990GL02), at 90 and 98 MeV (1991GO25). For diffraction scattering at momentum 17.9 GeV/c, see (1991AB1F). For inelastic scattering and polarization of ^{12}C (9.64 MeV, 3^-) see (1989KO55, 1991KO40), who report that the reaction at $E_\alpha = 27.2$ MeV proceeds mostly via an 8^+ state in the compound system. For pion production at momenta 4.5 GeV/c per nucleon see (1990AB1D), at 4.2 GeV/c per nucleon (1987AG1A), at energies of 3.6 GeV per nucleon (1987AN20), and at 200 to 800 MeV per nucleon (1987LH01), at $E_\alpha = 0.8, 1.6$ GeV (1991LE06). Differential cross sections at $E_\alpha = 1\text{--}6.6$ MeV measured to obtain information on $^{12}\text{C}(\alpha, \gamma)$ stellar reaction rates are reported by (1987PL03).

Calculations of total cross sections for $E_\alpha = 96.6\text{--}172.5$ MeV are presented in (1989KU30) and distributions of α -particle strengths in (1988LE05). Energy dependence at high energies (~ 1 GeV/nucleon) is studied in (1988MO18). The iterative-perturbative method for S-matrix to potential inversion was applied to $\alpha + ^{12}\text{C}$ phase shifts at $E_{\text{lab}} = 1.0\text{--}6.6$ MeV in (1990CO29). See

also (1991LI25). Nucleus-nucleus scattering and interaction radii were studied in (1986SA30). Core-plus alpha particle states in ^{16}O populated in $\alpha + ^{12}\text{C}$ scattering are studied in terms of vibron models in (1988CS01). See also (1991AB10, 1991DE15, 1991ES1B, 1991RU1B, 1992SA26). The effects of electron screening on low energy fusion reactions of astrophysical interest are explored in (1987AS05, 1990TO09). The nature of the $\alpha + ^{12}\text{C}$ potential at low energy is explored in (1990AL05). For other theoretical work see (1986MI24, 1986SU06, 1987BA83, 1989BA92, 1990DA1Q).

10. (a) $^{12}\text{C}(\alpha, ^8\text{Be})^8\text{Be}$	$Q_m = -7.4585$	$E_b = 7.16195$
(b) $^{12}\text{C}(\alpha, 2\alpha)^8\text{Be}$	$Q_m = -7.365$	

The yield of ^8Be from reaction (a) shows a number of resonances: see Table 16.16. There is no evidence below $E_x \sim 24$ MeV for $J^\pi = 8^+$ states although the existence of such states below this energy cannot be ruled out since it is possible that the L of the entrance channel inhibits the formation of such states. Above 26 MeV $L = 8$ becomes dominant: see (1982AJ01, 1986AJ04). See also the angular distribution measurements of (1991GL03) at $E_\alpha = 90$ MeV. For differential cross sections for reaction (b) at $E_\alpha = 27.2$ MeV see (1987KO1E). See also (1977AJ02).

11. $^{12}\text{C}(^6\text{Li}, \text{d})^{16}\text{O}$	$Q_m = 5.6868$
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This reaction has been studied at many energies: see (1977AJ02) and Table 16.17 here. At higher energies the spectra are dominated by states with $J \geq 4$ and natural parity (1986AJ04). A kinematic coincidence technique was applied in (1986CA19) to study the unresolved doublet at $E_x = 11.09$ MeV enabling clear observation of the γ -decaying 3^+ member at 11.080 MeV although it contributes only $\sim 15\%$ of the singles yield of the doublet which is dominated by the 4^+ member at 11.096 MeV. Angular correlation measurements (1980CU08) suggested that the 11.096 4^+ state is populated via a two-step process, and this interpretation was confirmed in calculations by (1988SE07). See also (1986AJ04). An interference effect was observed in the angular correlation function for the 7^- level at $E_x = 20.9$ MeV in measurements by (1987AR28). See also (1986AR1A, 1987BE1C, 1987GO1C, 1988ARZU).

Inclusive deuteron spectra from the break-up of ^6Li ions at 156 MeV are described in (1989JE07). See also (1986AJ04).

A numerical method for evaluation of $(^6\text{Li}, \text{d})$ stripping into the 5^- (15.6 MeV) and 6^+ (16.3 MeV) states is presented in (1989SE06). See also (1991SE12). An extensive discussion of alpha clustering in nuclei is presented in (1990HO1Q). Cluster stripping and heavy-group substitution in the reaction is discussed in (1988BE49), and the effect of including Coulomb forces in the Faddeev formalism is studied in (1988OS05).

Table 16.17: States of ^{16}O from $^{12}\text{C}(^6\text{Li}, \text{d})$ and $^{12}\text{C}(^7\text{Li}, \text{t})$

E_x^{a} (MeV \pm keV)	$\Gamma_{\text{c.m.}}^{\text{b}}$ (keV)	$\theta_{\alpha}^2/\theta_{\alpha}^2(2^+)^{\text{c}}$	Γ_{α_0}/Γ	$J^{\pi}; K^{\pi}$
0		0.93, 0.18		0^+
6.05		0.38, 1.10		$0^+; 0^+$
6.13		0.23, 0.22		3^-
6.92		$\equiv 1.0$		$2^+; 0^+$
7.12		0.53, 0.39		1^-
8.87	< 20			2^-
$9.63 \pm 30^{\text{d}}$	400 ± 10	0.30, 0.60		$1^-; 0^-$
9.84	< 20	$\leq 0.05, \leq 0.01$		2^+
$10.346 \pm 6^{\text{e}}$	35 ± 5	0.25, 0.47	0.86 ± 0.09	$4^+; 0^+$
10.96				0^-
11.10^{e}	< 30	$\leq 0.06, \leq 0.03$	0.31 ± 0.03 ($J = 4^+$)	$3^+ + 4^+$
11.59 ± 20	700 ± 100	≈ 0.4		$3^-; 0^-$
13.09	≈ 230			1^-
14.363 ± 15	< 120			$> 5, \pi = \text{nat.}$
14.66 ± 20	500 ± 50		1.03 ± 0.1	$5^-; 0^-$
14.82	45 ± 10			(6^+)
16.30 ± 20	300 ± 50		1.07 ± 0.11	$6^+; 0^+$
17.65 ± 50	100 ± 50			
17.85 ± 50	≈ 200			
(18.6) ^f				(5^-)
19.30 ± 50	≈ 200			
$20.8 \pm 100^{\text{e}}$	500 ± 100		1.16 ± 0.23	$7^-; 0^-$
21.6 ± 100	≤ 100		0.67 ± 0.14	6^+
23.0 ± 100	≈ 200			(6^+)
23.8 ± 100	1980 ± 250			(6^+)
26.9 ± 100	1700 ± 250			(7^-)
27.7^{f}				(7^-)
(29.3) ^f				(7^-)
32^{g}	broad			
34^{h}				$10^+(9^-)$
35^{g}	broad			

^a E_x quoted without errors are from Table 16.13. For the earlier references see Table 16.14 (1982AJ01). Angular distributions are reported in both reactions for the first nine states.

^b Line widths, not corrected for α -penetrabilities.

^c Ratio of dimensionless reduced α -width calculated at a channel radius of 5.4 fm, relative to that for $^{16}\text{O}^*(6.92)$. (N, L) here are taken to be (2, 0) and (4, 1) respectively, for $^{16}\text{O}^*(0, 7.12)$. The first number listed is the value reported at $E(^6\text{Li}) = 42$ MeV, the second at $E(^6\text{Li}) = 90.2$ MeV.

^d On the basis of studies of the $^{12}\text{C}(^6\text{Li}, \text{d})$, $^{12}\text{C}(^7\text{Li}, \text{t})$, $^{12}\text{C}(^{10}\text{B}, ^6\text{Li})$ and $^{19}\text{F}(\text{p}, \alpha)$ reactions, the energy of $^{16}\text{O}^*(9.6)$ is 9619 ± 15 keV with $\Gamma = 400 \pm 100$ keV (line width). $\Gamma_{\text{R}} = 430 \pm 10$ keV as inferred from the best fit B-W line shape. This value is corrected for penetrability (1981OV02; Becchetti, private communication.).

^e Angular distributions are reported at $E(^6\text{Li}) = 35.5 - 35.6$ MeV to $^{16}\text{O}^*(10.36)$ and to the unresolved 3^+ and 4^+ states at 11.1 MeV (1986AJ04). More recent coincidence measurements (1986CA19) have indicated that while the 4^+ state is dominantly populated and decays by α emission, the 3^+ state decays by γ emission. Angular correlation measurements (1980CU08) and analysis (1988SE07) indicate the the 4^+ state is populated by a two-step process.

^f (1982AR20); decay primarily by α_0 .

^g (1982AR20); decay primarily by α_1 .

^h (1982AR20, 1983AR12); decays primarily by α_2 .

12. $^{12}\text{C}(^7\text{Li}, \text{t})^{16}\text{O}$ $Q_{\text{m}} = 4.695$

This reaction has been studied extensively: see (1977AJ02, 1982AJ01) and Table 16.17 here. Measurements of α -t angular correlations for the process $^{12}\text{C}(^7\text{Li}, \text{t})^{16}\text{O}(\alpha)^{12}\text{C}$ are reported in (1988AR22) for the 7^- (20.9 MeV), 6^+ (16.3 MeV), and 5^- (14.6 MeV) levels in ^{16}O . Analyses of the $(^7\text{Li}, \text{t})$ reaction for cluster states in ^{16}O are reported in (1986CO15, 1988BE49). See also (1987BE1C, 1988BE1D, 1988BEYB, 1989AL1D, 1990HO1Q) and the sections on ^{19}F in (1983AJ01, 1987AJ02).

13. $^{12}\text{C}(^{10}\text{B}, ^6\text{Li})^{16}\text{O}$ $Q_{\text{m}} = 2.7022$

Angular distributions at $E(^{10}\text{B}) = 18$ and 45 MeV have been studied involving $^{16}\text{O}^*(0, 6.1, 7.1, 8.9, 9.9, 10.4)$. At $E(^{10}\text{B}) = 68$ MeV angular distributions to $^{16}\text{O}^*(0, 6.1, 6.9, 10.4, 11.1, 14.7, 16.2, 20.9)$ are forward peaked and fairly structureless. $^{16}\text{O}^*(0, 6.9, 11.1)$ are weakly excited: see (1982AJ01, 1986AJ04, 1990HO1Q).

14. $^{12}\text{C}(^{12}\text{C}, ^8\text{Be})^{16}\text{O}$ $Q_{\text{m}} = -0.2047$

Angular distributions have been reported at $E(^{12}\text{C})$ to 63 MeV [see (1977AJ02)] and at 4.9 to 10.5 MeV, and 11.2 to 12.6 MeV [see (1986AJ04)]. Angular correlations at $E(^{12}\text{C}) = 78$ MeV confirm $J^\pi = 4^+, 5^-, 6^+$ and 7^- for $^{16}\text{O}^*(10.36, 14.59, 16.3, 20.9)$. $\Gamma_{\gamma_0}/\Gamma = 0.90 \pm 0.10, 0.75 \pm 0.15$ and 0.90 ± 0.10 , respectively, for the first three of these states. In addition a state is reported at $E_x = 22.5 \pm 0.5$ MeV which may be the 8^+ member of the $K^\pi = 0^+, 4p-4h$ rotational band (1979SA29). For further work at $E(^{12}\text{C}) = 90, 110$ and 140 MeV see (1986SH10). At $E(^{12}\text{C}) = 120$ MeV α_0 decays of $^{16}\text{O}^*(16.3, 20.9)$ [$J^\pi = 6^+, 7^-$] and α_1 decays of $^{16}\text{O}^*(19.1, 22.1, 23.5)$ are observed as is a broad structure in both channels corresponding to $^{16}\text{O}^*(30.0)$ with $J^\pi = 9^- + 8^+$. A gross structure $^{12}\text{C}-^{12}\text{C}$ resonance at $E_{\text{c.m.}} = 25$ MeV in the reaction leading to the ^{16}O 11.09 MeV 4^+ state is reported in (1987RA22). For other work on alpha cluster resonances see (1986ALZN, 1986RAZI, 1987RA02, 1990HO1Q). Measurements of differential cross sections at sub-barrier energies $2.43 \leq E_{\text{c.m.}} \leq 5.24$ MeV are reported in (1989CU03) and a statistical model calculation is discussed in (1990KH05). See also (1991CE09). For the decay of ^{20}Ne states see (1983AJ01, 1986AJ04, 1987AJ02), and for excitation functions see (1986AJ04).

15. (a) $^{12}\text{C}(^{14}\text{N}, ^{10}\text{B})^{16}\text{O}$ $Q_{\text{m}} = -4.4503$
 (b) $^{12}\text{C}(^{17}\text{O}, ^{13}\text{C})^{16}\text{O}$ $Q_{\text{m}} = 0.8027$

Angular distributions are reported at $E(^{14}\text{N}) = 53$ MeV involving $^{16}\text{O}^*(0, 6.05, 6.13, 6.92)$ and various states of ^{10}B , and at 78.8 MeV involving $^{16}\text{O}_{\text{g.s.}}$: see (1982AJ01). Angular distributions have been measured for the g.s. in reaction (b) for $E(^{17}\text{O}) = 40$ to 70 MeV (1986AJ04). See also (1986AR04, 1989WUZZ, 1990HO1Q), the two-center shell model basis calculations of (1991TH04) and the review of Landau-Zener effect investigations in (1990TH1D).

16. $^{12}\text{C}(^{20}\text{Ne}, ^{16}\text{O})^{16}\text{O}$ $Q_{\text{m}} = 2.428$

Angular distributions have been measured to $E(^{20}\text{Ne}) = 147$ MeV: see (1977AJ02). For yield measurements see (1986AJ04). Studies of projectile-breakup and transfer re-emission in the $^{12}\text{C} + ^{20}\text{Ne}$ system at an incident ^{20}Ne energy of 157 MeV are described in (1987SI06). See also (1990HO1Q).

17. (a) $^{13}\text{C}(^3\text{He}, \gamma)^{16}\text{O}$ $Q_{\text{m}} = 22.79338$
 (b) $^{13}\text{C}(^3\text{He}, \text{n})^{15}\text{O}$ $Q_{\text{m}} = 7.1295$ $E_{\text{b}} = 22.79338$
 (c) $^{13}\text{C}(^3\text{He}, \text{p})^{15}\text{N}$ $Q_{\text{m}} = 10.6658$
 (d) $^{13}\text{C}(^3\text{He}, \text{d})^{14}\text{N}$ $Q_{\text{m}} = 2.5071$
 (e) $^{13}\text{C}(^3\text{He}, ^3\text{He})^{13}\text{C}$
 (f) $^{13}\text{C}(^3\text{He}, \alpha)^{12}\text{C}$ $Q_{\text{m}} = 15.6314$
 (g) $^{13}\text{C}(^3\text{He}, ^8\text{Be})^8\text{Be}$ $Q_{\text{m}} = 8.1729$

The yield of capture γ -rays (reaction a) has been studied for $E(^3\text{He})$ up to 16 MeV [see (1977AJ02)], as have angular distributions. Observed resonances are displayed in Table 16.18. It is suggested that the structures at $E_x \approx 26\text{--}29$ MeV are related to the giant resonances built on the first few excited states of ^{16}O (1979VE02). See also (1986AJ04).

The excitation functions (reaction b) up to $E(^3\text{He}) = 11$ MeV are marked at low energies by complex structures and possibly by two resonances at $E(^3\text{He}) = 1.55$ and 2.0 MeV: see Table 16.18. See also (1977AJ02) for polarization measurements. Excitation functions (reaction c) for $E(^3\text{He}) = 3.6$ to 6.6 MeV have been measured for p_0, p_{1+2}, p_3 : a resonance is reported at $E(^3\text{He}) = 4.6$ MeV. A resonance at 6 MeV has also been observed: see Table 16.18. A comparison of polarization measured in this reaction and of analyzing powers measured in $^{15}\text{N}(p, ^3\text{He})$ has been made [see (1986AJ04)]. Analyzing powers have been measured at $E(^3\text{He}) = 33$ MeV for the elastic scattering (reaction d) and the deuteron groups to $^{14}\text{N}^*(0, 2.31, 3.95, 9.51)$ (1986DR03).

Yields of $\alpha_0, \alpha_1, \alpha_2$, and γ -rays from the decay of $^{12}\text{C}^*(12.71, 15.11)$ (reaction f) have been studied up to $E(^3\text{He}) = 12$ MeV. Observed resonances are displayed in Table 16.18. Those seen in the yield of $\gamma_{15.1}$ are assumed to correspond to ^{16}O states which have primarily a $T = 1$ character. Analyzing power measurements are reported at $E(^3\text{He}) = 33$ MeV to $^{12}\text{C}^*(4.4)$. Excitation functions for α_0 and α_1 are also reported for $E(^3\text{He}) = 16$ to 23 MeV (1986AJ04). DWBA analyses for data at $E(^3\text{He}) = 50, 60$ MeV are described in (1990ADZU). See also (1986ZE1B). The excitation function for $^8\text{Be}(\text{g.s.})$ (reaction g) has been studied for $E(^3\text{He}) = 2$ to 6 MeV. It shows a strong resonance at $E(^3\text{He}) = 5.6$ MeV corresponding to a state in ^{16}O at $E_x = 27.3$ MeV. J^π appears to be 2^+ from angular distribution measurements. A search for anomalous deuterons at 10.8 GeV has been reported (1986AJ04).

$$18. \ ^{13}\text{C}(\alpha, n)^{16}\text{O} \qquad Q_m = 2.2156$$

Angular distributions for the n_0 group have been measured for $E_\alpha = 12.8$ to 22.5 MeV: see (1971AJ02). Polarization measurements for n_0 at $\theta = 0\text{--}70^\circ$ at $E_\alpha = 2.406$ and 3.308 MeV are reported in (1990WE10). The energy of the γ -ray from the decay of $^{16}\text{O}^*(6.13)$ is 6129.266 ± 0.054 keV (1986AJ04) [based on the ^{198}Au standard $E_\gamma = 411804.4 \pm 1.1$ eV]. See also (1982AJ01). Analytical expressions for reaction rates for $^{13}\text{C}(\alpha, n)^{16}\text{O}$ and other astrophysically important low-mass reactions are given in (1988CA26). See also the related work of (1986SM1A, 1987HA1E, 1989KA24, 1990HO1I).

$$19. \ ^{13}\text{C}(^6\text{Li}, t)^{16}\text{O} \qquad Q_m = 6.9977$$

See Table 16.19. See also (1982AJ01) and ^{19}F in (1983AJ01).

$$20. \ ^{13}\text{C}(^9\text{Be}, ^6\text{He})^{16}\text{O} \qquad Q_m = 1.617$$

Table 16.18: Resonances in $^{13}\text{C} + ^3\text{He}$ ^a

E (^3He) (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles	$^{16}\text{O}^*$ (MeV)	$J^\pi; T$
1.55	≈ 80	n_0, n_3	24.05	
1.55 ± 100	450	γ_0	24.1	
2.0	≈ 250	n_0	24.4	
2.6 ± 100		$\alpha\gamma_{15.1}$	24.9	($T = 1$)
2.87 ± 50	600	γ_0	25.12	1^-
≈ 3.1		α_0, α_2	≈ 25.3	
≈ 3.5	≈ 300	α_0	≈ 25.6	(3^-)
≈ 4	≈ 300	$\alpha_0, \alpha_1, \alpha_2$	≈ 26	(3^-)
4.0 ± 100	^b	$\gamma_0, \gamma_{1+2}, \alpha\gamma_{15.1}$	26.0	$1^-; (1)$
4.6 ± 100 ^c	720 ± 160 ^c	γ_2, p_0	26.5	$2^+, 4^+$
5.2 ± 100	^b	$\alpha\gamma_{15.1}$	27.0	($T = 1$)
5.6 ± 100	≈ 600	$\gamma_0, \gamma_{1+2}, \alpha\gamma_{15.1}, ^8\text{Be}$	27.3	(1^-)
≈ 5.8	≈ 2500	γ_{3+4}	27.5	
6.0 ± 100	≈ 500	$p_0, p_{1+2}, ^3\text{He}, \alpha_1, \alpha_2$	27.7	($3^-; 0$)
≈ 6		γ_0	28	
6.5 ± 100	^b	$\alpha\gamma_{15.1}$	28.1	($T = 1$)
6.8 ± 100		$\alpha_0, \alpha_1, \alpha_2$	28.3	($T = 0$)
7.1 ± 200		γ_{1+2}	28.6	
7.5 ± 100	^b	$\alpha\gamma_{15.1}$	28.9	($T = 1$)
8.6 ± 100	^b	$\alpha\gamma_{15.1}$	29.8	($T = 1$)
9.4 ± 100	^b	$\alpha\gamma_{15.1}$	30.4	($T = 1$)
10.1 ± 100	^b	$\alpha\gamma_{15.1}$	31.0	($T = 1$)

^a For references see Tables 16.15 in (1971AJ02), 16.13 in (1977AJ02), and 16.15 in (1982AJ01).

^b Lab widths 0.5 – 1 MeV.

^c Based on $\Gamma_{\text{c.m.}} = 530 \pm 80$ keV [from $^{15}\text{N}(p, \gamma)$, see Table 16.22], $\Gamma_{p_0} = 150 \pm 45$ keV [$J^\pi = 2^+$], 110 ± 35 keV [4^+]; $\Gamma_{p_0}/\Gamma = 0.29 \pm 0.10$ [2^+], 0.21 ± 0.07 [4^+]; $\Gamma_{\gamma_2} = 740 \pm 240$ eV [2^+], 410 ± 140 eV [4^+]. See (1977CH16, 1978CH19, 1986AJ04).

See (1986AJ04).

$$21. \text{}^{13}\text{C}(\text{}^{12}\text{C}, \text{}^9\text{Be})\text{}^{16}\text{O} \quad Q_m = -3.4856$$

At $E(^{13}\text{C}) = 105$ MeV, $^{16}\text{O}^*(6.05, 6.13, 10.35, 16.3, 20.7)$ are strongly populated: see (1977AJ02, 1982AJ01, 1986AJ04). Excitation functions ($E_{\text{c.m.}} = 13.4\text{--}16.8$ MeV) and angular distributions ($E_{\text{c.m.}} = 13.4, 16.38$ MeV) have been measured (1988JA1B).

$$22. \text{}^{13}\text{C}(\text{}^{17}\text{O}, \text{}^{14}\text{C})\text{}^{16}\text{O} \quad Q_m = 4.0328$$

See (1982AJ01).

$$23. \text{}^{14}\text{C}(\text{}^3\text{He}, \text{n})\text{}^{16}\text{O} \quad Q_m = 14.6169$$

At $E(^3\text{He}) = 11$ to 16 MeV, neutron groups are observed to $T = 2$ states at $E_x = 22.717 \pm 0.008$ and 24.522 ± 0.011 MeV ($\Gamma < 30$ keV and < 50 keV, respectively). These two states are presumably the first two $T = 2$ states in ^{16}O , the analog states to $^{16}\text{C}^*(0, 1.75)$. J^π for $^{16}\text{O}^*(24.52)$ is found to be 2^+ from angular distribution measurements (1970AD01). At $E(^3\text{He}) = 25.4$ MeV forward angle differential cross sections have been determined to the 0^+ states of $^{16}\text{O}^*(0, 6.05, 12.05)$ (1986AJ04).

$$24. \text{}^{14}\text{N}(\text{d}, \gamma)\text{}^{16}\text{O} \quad Q_m = 20.7363$$

The γ_0 yield has been studied for $E_d = 0.5$ to 5.5 MeV. Observed resonances are displayed in Table 16.20. Radiative capture in the region of the GDR [$E_d = 1.5$ to 4.8 MeV] has been measured with polarized deuterons. See (1986AJ04).

$$25. \text{}^{14}\text{N}(\text{d}, \text{n})\text{}^{15}\text{O} \quad Q_m = 5.0724 \quad E_b = 20.7363$$

For $E_d = 0.66$ to 5.62 MeV, there is a great deal of resonance structure in the excitation curves with the anomalies appearing at different energies at different angles: the more prominent structures in the yield curves are displayed in Table 16.20. For polarization measurements see (1977AJ02) and (1981LI23) in ^{15}O (1986AJ01).

Table 16.19: States of ^{16}O from $^{13}\text{C}(^6\text{Li}, t)^{16}\text{O}$

E_x (MeV \pm keV) ^a	$\Gamma_{\text{c.m.}}$ (keV) ^c	Comments ^d
0 ^b		
6.13 ^b		
7.0 [u] ^b		
8.87 ^{b, c}		c.n.
9.84 ^{b, c}		c.n.
10.36 ^{b, c}		c.n.
11.10 [u] ^{b, c}		4 ⁺ probably dominates; m.s.
11.52 ^c		
12.05 ^c		consistent with $L = 1 \rightarrow 0^+$
12.53 ^c		consistent with $L = 2 \rightarrow 2^-$
12.97 ^c		consistent with $L = 2 \rightarrow 2^-$
13.10 [u] ^c		$L = 2$, but which state is involved?
14.3 ^c		$L = 4 \rightarrow 4^{(-)}$
14.40 ^c		anomalous shape
14.82 ^c		$L = 5$; probably $J^\pi = 6^+$
15.79 ^c		consistent with $L = 3 \rightarrow 3^+$
16.812 \pm 15 ^c	28 \pm 7	consistent with $L = 3 \rightarrow 3^+$
17.764 \pm 15 ^{c, e}	45 \pm 7	$L = 4$ or $L = 5$
18.032 \pm 15 [u] ^{c, f}	40 \pm 7	$L = 3$; both states are probably populated
18.640 \pm 15 ^c	22 \pm 7	$L = 4$ or 5; probably 5 ⁺
18.976 \pm 15 ^c	25 \pm 7	probably 4 ⁻
19.814 \pm 15 ^c	23 \pm 7	
20.5 [u]		very strongly excited

[u] = unresolved.

c.n. = formation appears to be by a compound nuclear process.

m.s. = multistep process.

^a E_x without uncertainties are from Table 16.13.

^b Angular distributions have been reported at $E(^6\text{Li}) = 25$ MeV to the first seven groups shown here and at 28 MeV: see (1986AJ04) for references. See also (1982AJ01).

^c Angular distribution at $E(^6\text{Li}) = 34$ MeV (see 1983KE06, 1986AJ04).

^d For abbreviations see above. When an L value is shown, stripping patterns are evident (1983KE06).

^e There is some evidence for a state at $E_x = 17.90$ MeV (1983KE06, 1986AJ04).

^f There is some evidence for a state at $E_x = 18.46$ MeV with $\Gamma \approx 60$ keV (1983KE06, 1986AJ04).

Table 16.20: Structure in $^{14}\text{N} + \text{d}$ ^a

E_d (MeV)	Resonant channel	$\Gamma_{\text{c.m.}}$ (keV)	$J^\pi; T$	E_x (MeV)
1.4	n_0, α_0	300 ^e	0^+ ^e	22.0
1.7 ± 0.1	$\gamma_0, \text{p}_0, \text{p}_1, \alpha_0, \alpha_1, \alpha_2, \alpha_3$	400 ^e	1^- ^e	22.2
1.85	n_0, α_0	175	2^+ ^e	22.35
2.0 ± 0.1	$\text{p}_0, \text{p}_1, \alpha_0, \alpha_3$	350 ^e	3^- ^e	22.5
2.272 ± 0.005 ^b	$\text{p}_0, \text{p}_{1+2}, (\text{p}_3), \text{p}_4, \text{p}_5, \alpha_0, \alpha_2$			22.722
2.40 ± 0.05 ^c	γ_0 ^d , p_0, p_1	500 ^e	$1^-; 1$	22.83
2.5	α_0			22.9
2.6	$(\text{n}_0), \alpha_0, \alpha_1$	200 ^e	4^+ ^e	23.0
2.8	$(\text{n}_0), \text{p}_0, \text{p}_1, \text{d}_0$	350 ^e	2^+ ^e	23.2
3.24	$\text{p}_0, \text{p}_{1+2}, \text{p}_4, \text{p}_5, \text{p}_6, \text{d}_0, \alpha_3$			23.57
4.2	$\gamma_0, (\text{p}_0), \text{d}_0, \gamma_{15.1}$			24.4
4.58	$(\text{p}_0), \text{d}_0, \gamma_{15.1}$			24.74
4.9	n_0, p_0			25.0
5.95	$\text{d}_1, \gamma_{15.1}$			25.9
7.1	$\gamma_{15.1}$			26.9
7.4	d_2			27.2
7.7	d_1			27.5
(8.5)	$(\gamma_{15.1})$			(28.2)
10.2	d_2			29.7

^a For earlier references see Table 16.14 in (1977AJ02) and 16.16 in (1982AJ01, 1986AJ04).

^b $(\Gamma_{\text{d}_0} \Gamma_i / \Gamma^2) \times 10^{-3}$ are greater than 1.6 ± 0.4 , 0.27 ± 0.13 , 0.41 ± 0.15 and 0.07 ± 0.05 for the α_2 , p_0 , p_{1+2} , and p_3 groups.

^c If this resonance is fitted with a single-level Breit-Wigner shape, penetrability effects could lower the resonance energy by as much as 50 keV, assuming $l = 1$.

^d The angular distribution of γ_0 is consistent with E1.

^e See references in (1986AJ04).

26. $^{14}\text{N}(\text{d}, \text{p})^{15}\text{N}$ $Q_{\text{m}} = 8.6087$ $E_{\text{b}} = 20.7363$

The yield of various proton groups for $E_{\text{d}} < 5.0$ MeV shows some fluctuations and two resonances: see Table 16.20 and (1982AJ01). For polarization measurements see (1982AJ01, 1986AJ04). Analyzing power measurements at $E_{\text{d}} = 70$ MeV are reported in (1986MO27).

27. $^{14}\text{N}(\text{d}, \text{d})^{14}\text{N}$ $E_{\text{b}} = 20.7363$ Table 16.21: ^{16}O states from $^{14}\text{N}(^3\text{He}, \text{p})^{16}\text{O}$ ^a

E_{x} (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	L	J^{π}
0		0 + 2	
6.052 \pm 5		(0) ^b	
6.131 \pm 4		1 + 3	
6.916 \pm 3		(0)	
7.115 \pm 3		1 + 3	
8.870 \pm 3	< 20	3 + 1	
9.614 \pm 30	510 \pm 60		
9.847 \pm 3	< 20	0(+ 2)	
10.356 \pm 3	25 \pm 5	^b	
10.957 \pm 1	< 12	1	
11.080 \pm 3	< 12	2 + 4 ^c	
11.098 \pm 2	< 12		
11.520 \pm 4	64 \pm 5	^b	
12.049 \pm 2	< 12	0	
12.438 \pm 3	70 \pm 10	1	
12.530 \pm 2 ^d	< 12	1 + 3	
12.797 \pm 4	40 \pm 10	1	0 ⁻ ; $T = 1$ ^f
12.970 \pm 1	< 12	1 + 3	2 ⁻ ; $T = 1$ ^f
13.105 \pm 15	160 \pm 30	0 + 3 ^c	
13.257 \pm 2	20 \pm 5	(1 + 3)	3 ⁻ ; $T = 1$ ^f
13.663 \pm 4	63 \pm 7	0	
13.869 \pm 2	85 \pm 20	(4) ^b	
13.979 \pm 2 ^d	14 \pm 5	1(+ 3)	

Table 16.21: ^{16}O states from $^{14}\text{N}(^3\text{He}, \text{p})^{16}\text{O}$ ^a (continued)

E_x (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	L	J^π
14.302 \pm 3	< 20	b	
14.399 \pm 2 ^d	27 \pm 5	(4)	
14.818 \pm 3		2	(0 \rightarrow 4) ⁺
14.927 \pm 2 ^d	60 \pm 10	0(+ 2)	(0, 1, 2) ⁺ ^g
15.103 \pm 5			
15.196 \pm 3		(0 + 2)	
15.409 \pm 6		b	
15.785 \pm 5 ^d	40 \pm 10	2(+ 4)	(2, 3, 4) ⁺ ^g
16.114 \pm 4 ^e			
16.209 \pm 2 ^d	40 \pm 10	0 + 2	
16.350 \pm 13			
16.440 \pm 13	\approx 30	0 + 2	
16.817 \pm 2	70 \pm 10		
h			

^a For references see Table 16.17 in (1982AJ01).

^b Mostly compound nucleus.

^c Unresolved.

^d Also reported in $\text{p}\gamma_{4.4}$ coincidences.

^e Very weak proton group. See (1986AJ04).

^f (1978FO27) have compared the cross section ratios of these three $T = 1$ states with their analogs in ^{16}N populated in the (t, p) reaction: only the 2^- states have the expected cross section ratio of 0.5 for $(^3\text{He}, \text{p})/(\text{t}, \text{p})$. The populations of the 0^- and 3^- states in ^{16}O are lower by a factor of two.

^g (1978FO19) suggest that these two states [$^{16}\text{O}^*(14.93, 15.79)$] are 1^+ and 3^+ 2p-2h states with $T_p = T_h = 0$.

^h States at 17.82 and 18.04 (± 0.04) MeV are also reported in $\text{p}\gamma_{4.4}$ coincidences.

The yield of elastically scattered deuterons has been studied for $E_d = 0.65$ to 5.5 MeV and for 14.0 to 15.5 MeV: see (1971AJ02, 1977AJ02). There is indication of broad structure at $E_d = 5.9$ MeV and of sharp structure at $E_d = 7.7$ MeV in the total cross section of the d_1 group to the $T = 1$ (isospin-forbidden), $J^\pi = 0^+$ state at $E_d = 2.31$ MeV in ^{14}N . The yield of deuterons (d_2) to $^{14}\text{N}^*(3.95)$ [$J^\pi = 1^+$, $T = 0$] shows gross structures at $E_d = 7.4$ and 10.2 MeV (1970DU04):

see Table 16.20 The yield of d_1 has also been studied for $E_d = 10.0$ to 17.9 MeV: see (1982AJ01). For polarization measurements see (1982AJ01, 1986AJ04).

28. (a) $^{14}\text{N}(d, t)^{13}\text{N}$	$Q_m = -4.2962$	$E_b = 20.7363$
(b) $^{14}\text{N}(d, ^3\text{He})^{13}\text{C}$	$Q_m = -2.0571$	

See (1982AJ01).

29. $^{14}\text{N}(d, \alpha)^{12}\text{C}$	$Q_m = 13.5743$	$E_b = 20.7363$
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There is a great deal of structure in the yields of various α -particle groups for $E_d = 0.5$ to 12 MeV. Broad oscillations ($\Gamma \sim 0.5$ MeV) are reported in the α_0 and α_1 yields for $E_d = 2.0$ to 5.0 MeV. In addition, $^{16}\text{O}^*(23.54)$ is reflected in the α_3 yield (see Table 16.20). The yield of 15.11 MeV γ -rays, [from the decay of $^{12}\text{C}^*(15.11)$, $J^\pi = 1^+$, $T = 1$] which is isospin-forbidden, has been studied for $E_d = 2.8$ to 12 MeV. Pronounced resonances are observed at $E_d = 4.2, 4.58$ and 5.95 MeV and broader peaks occur at $E_d = 7.1$ and, possibly, at 8.5 MeV: see (1982AJ01). For polarization measurements see (1982AJ01, 1986AJ04).

30. (a) $^{14}\text{N}(^3\text{He}, p)^{16}\text{O}$	$Q_m = 15.24276$
(b) $^{14}\text{N}(^3\text{He}, p\alpha)^{12}\text{C}$	$Q_m = 8.08081$

Observed proton groups are displayed in Table 16.21. Angular distributions have been measured at $E(^3\text{He}) = 2.5$ to 24.7 MeV: see (1982AJ01). Branching ratios and τ_m measurements are shown in Tables 16.13 and 16.14.

31. $^{14}\text{N}(\alpha, d)^{16}\text{O}$	$Q_m = -3.1104$
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Angular distributions to states of ^{16}O have been reported at many energies to $E_\alpha = 48$ MeV: see (1971AJ02, 1977AJ02). Among the states which have been reported [see Table 16.7 in (1977AJ02)] are $^{16}\text{O}^*(11.094 \pm 3, 13.98 \pm 50, 14.32 \pm 20, 14.400 \pm 3, 14.815 \pm 2, 15.17 \pm 50, 15.44 \pm 50, 15.78 \pm 50, 16.214 \pm 15, 17.18 \pm 50)$ [MeV \pm keV]: the results are consistent with $J^\pi = 5^+, 6^+, 4^+$ for $^{16}\text{O}^*(14.40, 14.82, 16.29)$ [2p-2h] and with 6^+ for $^{16}\text{O}^*(16.30)$ [4p-4h]. [See refs. in (1977AJ02).] Work reported in (1979CL10) and reviewed in (1982AJ01) determined $\Gamma_{\text{c.m.}} = 34 \pm 12, 27 \pm 5$ and 70 ± 8 keV, respectively for $^{16}\text{O}^*(14.31 \pm 10, 14.40 \pm 10, 14.81)$.

Table 16.22: Levels of ^{16}O from $^{15}\text{N}(p, \gamma)$, $^{15}\text{N}(p, p)$ and $^{15}\text{N}(p, \alpha)$

E_p (keV)	Γ_{γ_0} (eV)	Γ_{γ_1} (eV)	Γ_p (keV)	$\Gamma_p \Gamma_\gamma / \Gamma$ (eV)	Γ_{α_0} (keV)	Γ_{α_1} (keV)	Γ_{lab} (keV)	$J^\pi; T$	E_x (MeV \pm keV)
335 \pm 4 ^a	12 \pm 2	0.12 \pm 0.04	0.9 \pm 0.1		102 \pm 4	0.025	110 \pm 4	1 ⁻ ; 0	12.442
429.57 \pm 0.09 ^b	(33 \pm 5) \times 10 ⁻³ ^c	2.1 \pm 0.2	0.016 \pm 0.003 ^c		nr	0.092 \pm 0.010 ^c	0.103 \pm 0.011	2 ⁻ ; 0	12.530
710 \pm 7			40		nr		40 \pm 40	0 ⁻ ; 1	12.793
897.37 \pm 0.29	(34 \pm 9) \times 10 ⁻³ ^c		1.04 \pm 0.07 ^c		nr	0.30 \pm 0.06 ^c	1.47 \pm 0.04	2 ⁻ ; 1	12.9686
1028 \pm 10	32 \pm 5		100		40	r	140 \pm 10	1 ⁻ ; 1	13.091
1050 \pm 150					$\Gamma_p \Gamma_{\alpha_0} =$ 500 keV ²			2 ⁺	13.1
1210 \pm 3			4.1		r	8.2 \pm 1.1	22.5 \pm 1	3 ⁻ ; 1	13.262
1640 \pm 3	< 1 ^d		10		nr	59 \pm 6	68 \pm 3	1 ⁺ ; 0	13.664
1890 \pm 20			0.5		r	(r)	90 \pm 2		13.90
1979 \pm 3			r		nr	r	23 \pm 2	2 ⁻	13.982
2982 \pm 6 ^e			20 \pm 3 ^f		1.5	30 ^g	55 \pm 5 ^e	2 ⁺	14.921 ¹
3170 ^h			12 ⁱ		152	163	330 \pm 100	0 ⁺	15.10 ¹
3264 \pm 11 ^e			j		nr	7 ^k	67 \pm 4 ^e	2 ⁻	15.186 ¹
3340 ^{h,m}			15 ⁱ		12	182	315 \pm 100	2 ⁺ ; (0)	15.26 ¹
3499 \pm 8 ^{e,m}			15 \pm 5 ^f		103	1	131 \pm 18 ^e	3 ⁻	15.406 ¹
4350 \pm 90 ^f			210 \pm 38 ^f				620 \pm 60 ^f	1 ⁻ ; 0	16.20
4357 \pm 5 ^e	3.7 \pm 0.5 ⁿ	0.44 \pm 0.06 ⁿ	7 \pm 3 ^f	2.70 \pm 0.25 ^d			20 \pm 3 ^e	1 ⁺ ; 1	16.210
4505 \pm 12 ^f			53 \pm 12 ^f				65 \pm 8 ^f	0 ⁺ ; 0	16.349
4612 \pm 9 ^d			r	1.11 \pm 0.24 ^o	r	r	26 \pm 8 ^d	1 - 4; 1 ^d	16.449
5001 \pm 5 ^{e,m}			7 \pm 2 ^f	p	nr	r	28 \pm 4 ^e	3 ⁺ ; 0 + 1 ^d	16.813
5300 \pm 40 ^f	r		q				405 \pm 43 ^e	1 ⁻ ; 1	17.09
5329 \pm 5 ^e	6.7 \pm 1.0	1.00 \pm 0.17 ⁿ	22 ^d	3.90 \pm 0.50 ^d			33 \pm 4 ^e	1 ⁺ ; 1	17.120
5487 \pm 9 ^e	67		45	r			80 \pm 8 ^e	1 ⁻ ; 1	17.268
5848 \pm 8 ^f			37 \pm 8 ^f				117 \pm 15 ^f	2 ⁺ ; (1)	17.607
6100 \pm 100 ^f			500 \pm 100 ^f				875 \pm 110 ^f	2 ⁻	17.84
6137 \pm 6 ^e			6 ^d	(r)		r	26 \pm 3 ^e	1 ⁻ ; 2 ⁻ ; 1	17.877
6297 \pm 6 ^e	nr	4.8 \pm 1.9 ^t	13 \pm 3 ^{f,u}			8.9 \pm 3.2 ^d	28 \pm 6	3 ⁻ ; 1 ^y	18.027
6490 \pm 15 ^f			33 \pm 12 ^f				150 \pm 26	2 ⁺	18.208
6727 \pm 15 ^f			11 \pm 6				97 \pm 41	2 ⁺	18.430
6785 \pm 6 ^f			17 \pm 3				37 \pm 6	1 ⁻	18.484
7100 \pm 100 ^d	\geq 3.6 ⁿ		v					1 ⁺ ; 1	18.78
7313 \pm 9 ^d		7.1 \pm 3.1 ^w	x	x		0.57 \pm 0.49 ^d	8.7 \pm 4.1 ^d	4 ⁻ ; 1 ^y	18.979
7330 \pm 30	38		\leq 130	\geq 1.8 \pm 0.3			\approx 260	1 ⁺	18.99
7420	r		\approx 30				\approx 130	2 ⁺ ; (1)	19.08

Table 16.22: Levels of ^{16}O from $^{15}\text{N}(p, \gamma)$, $^{15}\text{N}(p, p)$ and $^{15}\text{N}(p, \alpha)$ (continued)

E_p (keV)	Γ_{γ_0} (eV)	Γ_{γ_1} (eV)	Γ_p (keV)	$\Gamma_p \Gamma_\gamma / \Gamma$ (eV)	Γ_{α_0} (keV)	Γ_{α_1} (keV)	Γ_{lab} (keV)	$J^\pi; T$	E_x (MeV \pm keV)
7600 \pm 30 ^z	nr	1.5 ^{aa}					100	(2, 3; 1)	19.25
7840 \pm 30 ^z			(r)				350	1 ⁻ ; 1	19.47
8289 \pm 7 ^d	nr	17 \pm 6 ^{bb}	25 \pm 10 ^{cc}	dd		r	45 \pm 10	3; 1 ^d	19.893
8843 \pm 17 ^d	nr	38 ^{ee}		ee			200 \pm 20	1 - 4; 1	20.412
8990				ff			160		20.55
9410 ^h	170			ff	21 \pm 1		320 \pm 10	1 ⁻ ; 1	20.945 \pm 20
10000 ^h				hh			130	1 \rightarrow 4	21.50
10180 ^h				ii		r	< 45	$T = 0$	21.66
10700 ^{h,gg}	r			hh	488 \pm 20		730 \pm 10	1 ⁻ ; 1	22.150 \pm 10
11490 ^h	120	27 ^{aa}		hh	69 \pm 5		320 \pm 10	1 ⁻ ; 1	22.89 \pm 10
12740 ^h	r				130 \pm 13		590 \pm 40	1 ⁻ ; 1	24.07 \pm 30
13490 \pm 60		230 \pm 90, or 130 \pm 50 ^{jj}	85 ^{cc}				360 \pm 60	(2, 4) ⁺ ; 1	24.76
13870 ^h	r				651 \pm 117	kk	3150 \pm 320	1 ⁻ ; 1	25.12 \pm 60
15250 \pm 80		740 \pm 240, or 410 \pm 140 ^{jj}	122 ^{cc}			kk	565 \pm 85 ^{ll}	(2, 4) ⁺ ; 1	26.41
16250 \pm 100		1070 \pm 380, or 590 \pm 10 ^{jj}	206 ^{cc}			kk	880 \pm 125	(2, 4) ⁺ ; 1	27.35

nr = non-resonant; r = resonant.

For earlier references see Tables 16.21 in (1971AJ02), 16.19 in (1977AJ02), 16.18 in (1982AJ01) and 16.18 in (1986AJ04).

^a (1982RE06).

^b (1987OS01). See also the result $E_p = 429.88 \pm 0.14$ from the $^1\text{H}(^{15}\text{N}, \alpha\gamma)$ reaction.

^c (1986ZI08).

^d See (1983SN03).

^e Weighted mean of values obtained by (1983SN03, 1984DA18) and in earlier work [see (1982AJ01)].

^f (1984DA18). See also for calculated Γ_n .

^g $\Gamma_p\Gamma_{\alpha_1}/\Gamma = 16.4$ keV (1983SN03).

^h Nominal E_p calculated from E_x .

ⁱ Not observed in p_0 channel.

^j 35 ± 3 keV ($s = 1$), 15 ± 2 keV ($s = 0$); $\Gamma_p/\Gamma = 0.78$ (1984DA18).

^k $\Gamma_p\Gamma_{\alpha_1}/\Gamma = 10.9$ keV (1983SN03).

^l See also footnote ^c) in Table 16.18 (1982AJ01).

^m Broad structures have also been observed at $E_p \approx 3.5$ MeV in $(\alpha_1\gamma)$ and at 5.7 MeV in $(\alpha_1\gamma)$ and (γ_{1+2}) (1983SN03).

ⁿ Γ_γ uncertainties neglect the error in Γ_p/Γ (1983SN03).

^o $\Gamma_p\Gamma_{\gamma_2}/\Gamma$; also $\Gamma_{\gamma_2} \approx 11$ eV (1983SN03).

^p $\Gamma_p\Gamma_{\gamma_2}/\Gamma = 0.48 \pm 0.09$ eV, $\Gamma_p\Gamma_{\gamma_{3+4}}/\Gamma = 0.62 \pm 0.13$ eV, $\Gamma_p\Gamma_{\alpha_1}/\Gamma = 6.8$ eV; $\Gamma_{\gamma_2} = 1.0$ eV, $\Gamma_{\gamma_3} = 1.2$ eV, $\Gamma_p/\Gamma = 0.5$ [see, however, values shown for Γ_p and Γ] (1983SN03).

^q $\Gamma_p = 24 \pm 6$ ($l = 0$), 246 ± 24 keV ($l = 2$) (1984DA18).

^r $\Gamma_{\gamma_3} = 8$ eV, $\Gamma_p\Gamma_{\gamma_3}/\Gamma = 3.27 \pm 0.41$ eV (1983SN03).

^s $\Gamma_{\gamma_4} = 2$ eV, $\Gamma_p\Gamma_{\gamma_4}/\Gamma = 0.69 \pm 0.10$ eV, $\Gamma_p\Gamma_{\alpha_1}/\Gamma = 1.48$ keV (1983SN03).

^t Γ_{γ_2} ; $\Gamma_{\gamma_3} = 0.76 \pm 0.39$ eV: see (1983SN03).

^u $\Gamma_{p_0} = 7.8 \pm 2.8$ keV, $\Gamma_{p_{1+2}} = 2.7 \pm 1.2$ keV; $\Gamma_p\Gamma_{\gamma_2}/\Gamma = 1.96 \pm 0.27$ eV, $\Gamma_p\Gamma_{\gamma_{3+4}}/\Gamma = 0.31 \pm 0.11$ eV, $\Gamma_p\Gamma_{p_{1+2}}/\Gamma = 1.11 \pm 0.26$ keV, $\Gamma_p\Gamma_{\alpha_1}/\Gamma = 4.25 \pm 1.00$ keV: see (1983SN03).

^v $\Gamma_p/\Gamma \leq 0.5$, $\Gamma_p\Gamma_{\gamma_0}/\Gamma \geq 1.8 \pm 0.3$ eV (1983SN03).

^w $\Gamma_p\Gamma_{\gamma_2}$; $\Gamma_p\Gamma_{\gamma_3} < 0.3$ eV: see (1983SN03).

^x $\Gamma_{p_0} = 0.98 \pm 0.19$ keV, $\Gamma_{p_{1+2}} = 5.2 \pm 2.3$ keV; $\Gamma_p\Gamma_{\gamma_2}/\Gamma = 0.85 \pm 0.01$ eV, $\Gamma_p\Gamma_{\gamma_{3+4}}/\Gamma < 0.03$ eV, $\Gamma_p\Gamma_{p_{1+2}}/\Gamma = 0.62 \pm 0.09$, $\Gamma_p\Gamma_{\alpha_0}/\Gamma < 0.09$ keV: see (1983SN03).

^y See also Table IV in (1983SN03).

^z See also (1983SN03).

aa $\gamma_1 + \gamma_2$.

bb Γ_{γ_0} (1977CH19). See also (1983SN03).

cc Γ_{p_0} based on $\Gamma_{c.m.}$ and values of Γ_{p_0}/Γ assumed by (1977CH19).

dd $\Gamma_p\Gamma_{\gamma_2}/\Gamma = 3.9 \pm 0.56$ eV, $\Gamma_p\Gamma_{p_{1+2}}/\Gamma = 4.48$ keV, $\Gamma_p\Gamma_{p_3}/\Gamma = 0.52$ keV, $\Gamma_p\Gamma_{\alpha_1}/\Gamma = 1.07$ keV (1983SN03).

ee $\Gamma_{\gamma_2} = 38$ eV; $\Gamma_p\Gamma_{\gamma_2}/\Gamma = 18.8 \pm 3.9$ eV, $\Gamma_p\Gamma_{p_{1+2}}/\Gamma = 15.8$ keV, $\Gamma_p\Gamma_{p_3}/\Gamma = 5.8$ keV, $\Gamma_p\Gamma_{n_0}/\Gamma = 22$ keV; the state is probably 4^+ ; $T = 1$: see (1983SN03).

ff Resonant in p_2 .

gg $\sigma = 12.9$ mb at peak of GDR (1978OC01).

hh Resonant in p_1 .

ii Resonant in p_0, p_1, p_6 .

jj Γ_{γ_2} (eV).

kk Apparent resonance in yield of ($\alpha\gamma_{15.1}$) (1978OC01).

ll Average of values obtained in this experiment and in $^{12}\text{C}(\alpha, \gamma_2)$.

$$32. \text{}^{14}\text{N}(\text{}^6\text{Li}, \alpha)\text{}^{16}\text{O} \quad Q_m = 19.2611$$

See (1977AJ02).

$$\begin{aligned} 33. \text{(a)} \text{}^{14}\text{N}(\text{}^{11}\text{B}, \text{}^9\text{Be})\text{}^{16}\text{O} & \quad Q_m = 4.9208 \\ \text{(b)} \text{}^{14}\text{N}(\text{}^{12}\text{C}, \text{}^{10}\text{B})\text{}^{16}\text{O} & \quad Q_m = -4.4503 \\ \text{(c)} \text{}^{14}\text{N}(\text{}^{13}\text{C}, \text{}^{11}\text{B})\text{}^{16}\text{O} & \quad Q_m = 2.0575 \\ \text{(d)} \text{}^{14}\text{N}(\text{}^{14}\text{N}, \text{}^{12}\text{C})\text{}^{16}\text{O} & \quad Q_m = 10.46390 \end{aligned}$$

For reactions (a) and (c) see (1982AJ01). For reactions (b), (c), and (d) see (1986AJ04).

$$34. \text{}^{15}\text{N}(\text{p}, \gamma)\text{}^{16}\text{O} \quad Q_m = 12.12776$$

The yield of γ -rays has been measured for $E_p = 0.15$ to 27.4 MeV [see (1986AJ04)] and for $E_p = 6.25$ – 13.75 MeV (1988WI16), 20 – 100 MeV (1988HA04), 20 – 90 MeV (1989KA02), and 10 – 17 MeV (1987BA71): observed resonances are displayed in Table 16.22. The γ_0 cross section shows a great deal of structure up to $E_p = 17$ MeV. Above that energy the γ_0 yield decreases monotonically. Besides the GDR which peaks at $^{16}\text{O}^*(22.15)$ there is evidence for the emergence of a giant structure (E2) with $E_x = 24$ – 29 MeV in the $\gamma_{1+2+3+4}$ yield (1978OC01). Measurements for (p, γ_0) cross sections and analyzing powers for $E_p = 6.25$ – 13.75 MeV indicated a clear enhancement of the E2 cross section above $E_x = 22$ MeV. Differential cross sections for γ_0 and several other (unresolved) γ -rays at $E_p \approx 28$ to 48 MeV generally show a broad bump at $E_x \approx 34 \pm 2$ MeV. The angular distributions show a dominant E1 character (1986AJ04). See also (1988HA04, 1988KIIC, 1989BOYV) and the review of (1988HA12). For comparisons with measurements of the inverse reaction see (1991FI08).

Measurements of (p, γ_1) yields (1987BA71) indicated a pronounced concentration of dipole strength which was interpreted as an E1 giant resonance built on the ^{16}O first excited state. Other measurements of proton capture to excited states for $E_p = 20$ – 90 MeV are reported in (1989KA02).

Cross sections and analyzing powers for capture into the 3^- state at $E_x = 6.13$ MeV were studied by (1988RA15). Studies of quadrupole and octupole radiation from ^{16}O at $E_x = 39$ MeV determine $\sigma_{E2}/\sigma_{E1} = 0.124 \pm 0.015$, and $\sigma_{E3}/\sigma_{E1} = 0.0051 \pm 0.0026$ (1989KO29).

A study of the M1 decays of $^{16}\text{O}^*(16.21, 17.14)$ [both $J^\pi; T = 1^+; 1$] to $^{16}\text{O}^*(6.05)$ finds $B(\text{M1}, 1^+ \rightarrow 0_2^+)/B(\text{M1}, 1^+ \rightarrow 0_1^+) = 0.48 \pm 0.03$ and 0.55 ± 0.04 , respectively. $^{16}\text{O}^*(18.03)$ is a $3^-; 1$ state with a strength $\Gamma_p \Gamma_{\gamma_2}/\Gamma = 1.96 \pm 0.27$ eV and $^{16}\text{O}^*(18.98)$ is the $4^-; 1$ stretched particle-hole state with a strength of (0.85 ± 0.10) eV (1983SN03). See also (1983SN03) for the identification of analog states in ^{16}N and in ^{16}O , and for a discussion of Gamow-Teller matrix elements in $A = 14$ – 18 nuclei. See also the review of (1987BE1G). A study of the strong M2 transitions $E_x = 12.53 \rightarrow 0$ MeV and $E_x = 12.97 \rightarrow 0$ MeV is reported in (1986ZI08).

For astrophysical considerations see (1986AJ04) and (1985CA41, 1988CA26, 1989BA2P). See also Table 16.14 here. An application of this reaction for thin film analysis is described in (1992EN02).

Calculations of the decay of the GDR and GQR by (1990BU27) have included 1p-1h and 2p-2h configurations, but the fine structure of the GDR remains unexplained. RPA calculations overestimate p_0 decay but the use of a non-local mean field partially corrects this. The ISGQR is misplaced by RPA calculations, but is lowered by coupling to α - ^{12}C channels. Data from (e, e' α) experiments are needed. RPA spectra have been examined (1988BL10) using a relativistic Hartree-Fock model for the ground state. Hartree-Fock based calculations appear to be insensitive to short-range repulsion. 1^- and $T = 1$ strength distributions for ^{16}O have been calculated using Hartree and Hartree-Fock methods. Shell-model plus R -matrix and continuum shell-model results for 1p shell nuclei have been considered (1987KI1C), but underestimate ground state (γ , N_0) decay branches. Ground state shell-model plus R -matrix calculations describe the GDR region reasonably well.

$$35. \ ^{15}\text{N}(p, n)^{15}\text{O} \qquad Q_m = -3.5363 \qquad E_b = 12.12776$$

Excitation functions and cross sections have been measured for $E_p = 3.8$ to 19.0 MeV: see (1982AJ01). For a listing of observed resonances see Table 16.23. (1983BY03) have measured the polarization and analyzing power for the n_0 group for $E_p = 4.5$ to 11.3 MeV and have deduced integrated cross sections. Differential cross sections and analyzing powers at $E_p = 200$ and 494 MeV have been measured (1988CIZZ). See also (1986AJ04).

The theoretical work of (1987BE1D) has shown the sensitivity of the (p, n) reaction to spin dynamics and pionic fields for $E_p = 150$ –500 MeV and isovector density below 50 MeV. The importance of configuration mixing in Gamow-Teller quenching is also considered. The authors of (1989RA15) discuss the failure of the DWIA to explain the analyzing power for (p, n) at 500 MeV, focusing on transverse and longitudinal spin-flip cross sections and projectile no-spin-flip cross sections as the sensitive terms primarily responsible for the inadequacies of this method.

$$36. \text{ (a) } ^{15}\text{N}(p, p)^{15}\text{N} \qquad E_b = 12.12776$$

$$\text{ (b) } ^{15}\text{N}(p, \alpha)^{12}\text{C} \qquad Q_m = 4.9656$$

$$\text{ (c) } ^{15}\text{N}(p, ^3\text{He})^{13}\text{C} \qquad Q_m = -10.6658$$

Elastic scattering studies have been reported for $E_p = 0.6$ to 15 MeV and angular distributions and excitation functions have been measured for $E_p = 2.5$ to 9.5 MeV for the ($p_{1+2}\gamma$) and ($p_3\gamma$) transitions [see (1986AJ04)]. Measurements of the depolarization parameter $K_{y,y'}$ at $E_p = 65$ MeV are reported in (1990NA15). Excitation functions for α_0 and α_1 particles [corresponding to $^{12}\text{C}^*(0, 4.43)$] and of 4.43 MeV γ -rays have been measured for $E_p = 93$ keV to 45 MeV [see (1982AJ01)] and at $E_p = 77.6$ keV to 9.5 MeV (1986AJ04). The yield of 15.1 MeV γ -rays has been measured for $E_p = 12.5$ to 17.7 MeV (1978OC01). Measurements of the 430 keV

Table 16.23: Resonances in $^{15}\text{N}(p, n)^{15}\text{O}$ ^a

E_p (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	$J^\pi; T$ ^b	E_x (MeV)
4.37 ± 15	19 ± 6	$1^{(+)}; 1$	16.22
4.45 ± 30	240 ± 30	$0^{(-)}$	16.30
5.35 ± 15	33 ± 5	$1^{(-)}; 1$	17.14
5.52 ± 15	90 ± 10	$1^-; 1$	17.30
5.88 ± 15	59 ± 10	$\geq 1; 1$	17.64
6.12 ± 15	101 ± 10	$\geq 1; 1$	17.86
6.23 ± 15 ^c	≤ 50	$T = 1$	17.96
6.33 ± 15	26 ± 5	$\geq 1; 1$	18.06
6.43 ± 30	$\simeq 300$		18.15
6.76 ± 25	$\simeq 160$		18.46
7.03 ± 30	260 ± 30		18.71
7.59 ± 25	90 ± 10	$2^-; 1$	19.24
7.86 ± 30	300 ± 80		19.49
8.30 ± 25	120 ± 40		19.90
8.88 ± 40 ^d	200 ± 50	2	20.45
9.08 ± 40	130 ± 50		20.63
9.42 ± 100	235 ± 45		20.95
10.73 ± 100	800 ± 95	1	22.18
11.01 ± 100	300 ± 100		22.44
11.92 ± 100	520 ± 200		23.29
13.03 ± 100	520 ± 100		24.33
13.63 ± 100	≈ 280	2, 4	24.89
15.12 ± 100	610 ± 140	2, 4	26.29
18.4 ± 200	470 ± 150		29.4

^a For references see Table 16.19 in (1982AJ01).

^b Assignments are from (p, n) and (p, γ) results. The T -assignments are made on the basis of energy and width comparisons with states of ^{16}N .

^c Probably a doublet.

^d Values of $(2J + 1)\Gamma_{p_0}\Gamma_{n_0}/\Gamma^2$ are derived for this resonance and the ones below: see (1978CH09).

resonance in $^{15}\text{N}(p, \alpha\gamma)^{12}\text{C}$ were carried out by (1987OS01, 1987EV01). Observed anomalies and resonances are displayed in Table 16.22. The resonance at $E(^{15}\text{N}) = 6.4$ MeV observed in the reaction $^1\text{H}(^{15}\text{N}, \alpha\gamma)^{12}\text{C}$ has been used extensively to determine hydrogen concentration in thin films. See (1987EV01, 1987OS01, 1990FU06, 1990HJ02, 1992FA04).

A phase shift analysis of angular distributions of cross section and analyzing power for elastic scattering has yielded information on many ^{16}O states in the range $E_x = 14.8$ to 18.6 MeV. In particular a broad $J^\pi = 2^-, T = 1$ state at 17.8 MeV appears to be the analog of the 1p-1h ($d_{3/2}, p_{1/2}^{-1}$) ^{16}N state at $E_x \approx 5.0$ MeV (1986AJ04). The isospin mixing of the 2^- states $^{16}\text{O}^*(12.53, 12.97)$ has been studied by (1983LE25): the charge-dependent matrix element responsible for the mixing is deduced to be 181 ± 10 keV. The α_0 yield and angular distribution study by (1982RE06) leads to a zero-energy intercept of the astrophysical $S(E)$ factor, $S(0) = 65 \pm 4$ MeV·b. See (1982AJ01, 1986AJ04) for the earlier work. See also (1987RO25), and see the tables of thermonuclear reaction rates in (1985CA41).

Among recent theoretical developments related to these reactions, electron screening effects for $^{15}\text{N}(p, \alpha)^{12}\text{C}$ at very low energies (< 50 keV) have been evaluated (1987AS05). Expressions for longitudinal and irregular transverse PNC analyzing powers in cases of parity-mixed resonances such as $^{15}\text{N}(\vec{p}, p)^{15}\text{N}$ and $^{15}\text{N}(\vec{p}, \alpha)^{12}\text{C}$ are derived in (1989CA1L). Recent theoretical studies of the parity- and isospin-forbidden α -decay of the 12.97 MeV state to the ^{12}C ground state are reported in (1991DU04, 1991KN03). See also the theoretical study of single particle resonances in (1991TE03).

An investigation into the separation of the strength of the giant resonance for underlying levels neglecting statistical assumptions (1986KL06) has shown deviations from statistical behavior at the tops of resonances, leading to missing spectroscopic strength. A calibration method for heavy-ion accelerators has been described by (1987EV01), who have also determined the energy of the $E_p = 430$ keV resonance in the $^{15}\text{N}(p, \alpha\gamma)^{12}\text{C}$ reaction. Quantum fluctuations are shown to cause structures having collective properties (1986RO26). These new collective states are dissipative. $^{15}\text{N}(p, p)^{15}\text{N}$ is considered for $25 < E_p < 40$ MeV. (1988RO09) consider the transition from resonance to direct reactions as well as the significance of quantum fluctuations.

$$37. \ ^{15}\text{N}(d, n)^{16}\text{O} \qquad Q_m = 9.9030$$

Observed neutron groups, l -values and spectroscopic factors are displayed in Table 16.24. See also (1986AJ04).

$$38. \ ^{15}\text{N}(^3\text{He}, d)^{16}\text{O} \qquad Q_m = 6.6340$$

See Table 16.24.

$$39. \ ^{16}\text{N}(\beta^-)^{16}\text{O} \qquad Q_m = 10.419$$

Table 16.24: States in ^{16}O from $^{15}\text{N}(\text{d}, \text{n})$ and $^{15}\text{N}(^3\text{He}, \text{d})$

$^{16}\text{O}^*$ (MeV \pm keV)	$J^\pi; T$	l^a	l^b	S^c
0	$0^+; 0$	1	1	3.1
6.05	$0^+; 0$		1	^d
6.13	$3^-; 0$	2	2	
6.92	$2^+; 0$	not direct	1 + 3	^d
7.12	$1^-; 0$	0	0 + 2	
8.87	$2^-; 0$	2	2	0.72
9.59	$1^-; 0$		0	^d
9.84	$2^+; 0$	1	not direct	^d
10.36	$4^+; 0$		3	^d
10.96	$0^-; 0$	0	0	0.76
11.08	$3^+; 0$	3	3	0.18
11.26	$0^+; 0$		broad	
12.44	$1^-; 0$	0	0	0.40
12.53	$2^-; 0$	2	2	0.72
12.80	$0^-; 1$	0	0	0.44
12.97	$2^-; 1$	2	2	0.40
13.09	$1^-; 1$	(0)		0.58
			2(+ 0)	
13.13 ^e	$3^-; 0$	(2)		0.32
13.26	$3^-; 1$	2	2	0.46
17.14			obs.	
17.20	2^+		obs.	

^a $^{15}\text{N}(\text{d}, \text{n})$; $E_{\text{d}} = 4.8$ to 6 MeV; see (1977AJ02) for references.

^b $^{15}\text{N}(^3\text{He}, \text{d})$; $E(^3\text{He}) = 11, 16.0$ and 24.0 MeV; see (1977AJ02).

^c “Best” values from (d, n) and ($^3\text{He}, \text{d}$) data. See Table 16.22 in (1977AJ02) for a more complete display.

^d Very small value of S : see (1977AJ02).

^e $\Gamma = 128$ keV.

Table 16.25: Beta decay of the ground state of ^{16}N

Final State		Branch (%)	$\log ft$
$^{16}\text{O}^*$ (MeV)	J^π		
0	0^+	28.0 ± 0.5^a	$9.077 \pm 0.005^{d, e}$
6.05	0^+	$(1.2 \pm 0.4) \times 10^{-2}$	9.96 ± 0.15^d
6.13	3^-	66.2 ± 0.6^b	4.48 ± 0.04
7.12	1^-	4.8 ± 0.4	5.11 ± 0.04
8.87	2^-	1.06 ± 0.07^c	4.41 ± 0.03^c
9.59	1^-	$(1.20 \pm 0.05) \times 10^{-3}$	6.12 ± 0.05^f
9.84	2^+	$(6.5 \pm 2.0) \times 10^{-7}$	9.07 ± 0.13^d

^a Adopted value average of (1984WA07, 1985HE08).

^b Recalculated so that the sum of the branches is 100%.

^c See (1986AJ04).

^d $\log f_1 t$.

^e E.K. Warburton, private communication. We are indebted to Dr. Warburton for his very useful comments.

^f See also (1993CH06).

The ground state of ^{16}N decays to seven states of ^{16}O : reported branching ratios are listed in Table 16.25. The ground state transition has the unique first-forbidden shape corresponding to $\Delta J = 2$, fixing J^π of ^{16}N as 2^- : see (1959AJ76). The unique first-forbidden decay rates to the 0^+ ground state and 6.06-MeV level are well reproduced by a large-basis $(0 + 2 + 4)\hbar\omega$ shell-model calculation (1992WA25). The decays to odd-parity states (see Table 16.25) are well reproduced by recent calculations of Gamow-Teller matrix elements (1993CH06). For the β -decay of $^{16}\text{N}^*(0.12)$, see Reaction 1 in ^{16}N .

The β -delayed α -decays of $^{16}\text{O}^*(8.87, 9.59, 9.84)$ have been observed: see (1971AJ02). The parity-forbidden α -decay from the 2^- state $^{16}\text{O}^*(8.87)$ has been reported: $\Gamma_\alpha = (1.03 \pm 0.28) \times 10^{-10}$ eV [$E_\alpha = 1282 \pm 5$ keV]: see (1977AJ02).

Transition energies derived from γ -ray measurements are: $E_x = 6130.40 \pm 0.04$ keV [$E_\gamma = 6129.142 \pm 0.032$ keV (1982SH23)], $E_x = 6130.379 \pm 0.04$ [$E_\gamma = 6129.119 \pm 0.04$ keV (1986KE15)] and $E_x = 7116.85 \pm 0.14$ keV [$E_\gamma = 7115.15 \pm 0.14$ keV]. See (1977AJ02). See also p. 16 in (1982OL01).

See (1990JI02) for an R-matrix analysis for the 9.59-MeV level and discussion of its astrophysical significance and see astrophysical related work of (1991BA1K, 1991HU10).

40. (a) $^{16}\text{O}(\gamma, n)^{15}\text{O}$

$$Q_m = -15.6639$$

(b) $^{16}\text{O}(\gamma, 2n)^{14}\text{O}$	$Q_m = -8.8863$
(c) $^{16}\text{O}(\gamma, pn)^{14}\text{N}$	$Q_m = -22.9609$
(d) $^{16}\text{O}(\gamma, 2p)^{14}\text{C}$	$Q_m = -22.178$
(e) $^{16}\text{O}(\gamma, 2d)^{12}\text{C}$	$Q_m = -31.0087$

The absorption cross section and the (γ, n) cross section are marked by a number of resonances. On the basis of monoenergetic photon data, excited states of ^{16}O are observed at $E_x = 17.3$ [u], 19.3 [u] and 21.0 MeV [u=unresolved], followed by the giant resonance with its principal structures at 22.1 and 24.1 MeV, and with additional structures at 23 and 25 MeV: see (1986AJ04, 1988DI02). The integrated nuclear absorption cross section for $E_\gamma = 10$ to 30 MeV is 182 ± 16 MeV·mb (1986AJ04). See also Reaction 42. The (γ, n) cross section has been measured for $E_\gamma = 17$ to 33 MeV: in that energy interval the $(\gamma, 2n)$ cross section is negligible. The cross section for formation of the GDR at 22.1 MeV is 10.0 ± 0.4 mb and the integrated cross section to 30 MeV is 54.8 ± 5 MeV·mb. There is apparently significant single particle-hole excitation of ^{16}O near 28 MeV and significant collectivity of the GDR. A sharp rise is observed in the average E_n above 26 MeV. The cross section for (γ, n_0) decreases monotonically for $E_x = 25.5$ to 43.8 MeV. In the range 30–35 MeV the E2 cross section exhausts about 4% of the isovector E2 EWSR. Over the range 25.5 to 43.8 MeV it exhausts $\sim 68\%$ of the isovector E2 EWSR [see (1986AJ04) and references cited there]. M1, E1, and E2 strengths were studied by recent polarization and cross section measurements for $E_\gamma = 17$ to 25 MeV (1991FI08). An atlas of photoneutron cross sections obtained with monoenergetic photons is presented in (1988DI02).

The absorption cross section has been measured with bremsstrahlung photons of energies from $E_{\text{bs}} = 10$ MeV to above the meson threshold: see (1982AJ01). The (γ, n) , $(\gamma, 2n)$ and (γ, Tn) cross sections have been studied with monoenergetic photons for $E_\gamma = 24$ to 133 MeV. Above 60 MeV, the main reaction mechanisms appear to be absorption of the photons by a correlated n-p pair in the nucleus: the integrated cross section from threshold to 140 MeV is 161 ± 16 MeV·mb (1986AJ04). Differential cross sections for (γ, n_0) have been measured at $E_\gamma = 150, 200,$ and 250 MeV at $\theta_{\text{lab}} = 49^\circ, 59^\circ,$ and 88° (1988BE20, 1989BE14). See also ^{15}O in (1991AJ01). For reaction (b) and pion production see (1986AJ04). For reaction (c) measurements have been carried out with bremsstrahlung photons with $E_\gamma \leq 150$ MeV (1989VO19), and with tagged photons in the $\Delta(1232)$ resonance region (1987KA13). See also (1991VA1F). Measurements of reactions (d) and (e) were made with tagged photons of energies 80–131 MeV (1991MA39). Measurements of the total cross section at $E_\gamma = 90$ –400 MeV are described in (1988AH04). Calculations which indicate that molecular effects are important in screening corrections to the cross section in the Δ resonance region are discussed. The hadron production cross section has been studied over the range 0.25 to 2.7 GeV see (1986AJ04).

Sum rules and transition densities for isoscalar dipole resonances are discussed in (1990AM06). For a calculation of monopole giant resonances see (1990AS06). Calculations relating to polarization effects are discussed in (1990BO31, 1990LO20). The contribution of six-quark configurations to the E1 sum rule has been considered (1989AR02), and upper bounds for the production probabilities of 6q-clusters have been derived. The continuum self-consistent RPA-SK3 theory predicts

charge transition densities in ^{16}O for excitation of GDR (1988CA07). Neutron and proton decay is also indicated. See also (1991LI28, 1991LI29). A continuum shell model description of (γ, n) and (γ, p) data at medium energies is reported in (1990BRZY). Radial dependence of charge densities depends on whether r -values correspond to the interior of the nucleus or to the surface (1988CA07). In (1985GO1A) (γ, n) and (γ, p) experimental results are compared with those of large-basis shell model calculations. Good results were obtained, but a new source of spreading is warranted. Ratios of (γ, n) -to- (γ, p) cross sections have been computed using R-matrix theory including configuration splitting, isospin splitting, and kinematics effects (1986IS09). Computations of the partial photonuclear cross sections have been performed (1987KI1C) using the continuum shell model. GDR and other giant multipole resonances are also considered. The authors of (1988RO1R) use the continuum shell model as a basis for their study of “self-organization”. The role of the velocity-dependent part of the N-N interaction is also examined. A method for solving the RPA equations, and an examination of the long-wavelength approximation is discussed in (1988RY03). Levinger’s modified quasi-deuteron model is applied for $7 \leq A \leq 238$ and $E_\gamma = 35\text{--}140$ MeV (1989TE06). The quantities $L = 6.1 \pm 2.2$ and $D = 0.72 A$ are also deduced. The role of distortion in (γ, np) reactions is explored in (1991BO29).

41. (a) $^{16}\text{O}(\gamma, p)^{15}\text{N}$	$Q_m = -12.12776$
(b) $^{16}\text{O}(\gamma, d)^{14}\text{N}$	$Q_m = -20.7363$
(c) $^{16}\text{O}(\gamma, \alpha)^{12}\text{C}$	$Q_m = -7.16195$
(d) $^{16}\text{O}(\gamma, \pi^0)^{16}\text{O}$	$Q_m = -134.964$
(e) $^{16}\text{O}(\gamma, \pi^+)^{16}\text{N}$	$Q_m = -149.986$
(f) $^{16}\text{O}(\gamma, \pi^-)^{16}\text{F}$	$Q_m = -154.984$
(g) $^{16}\text{O}(\gamma, \pi^- p)^{15}\text{O}$	$Q_m = -154.4485$

The (γ, p_0) cross section derived from the inverse capture reaction (reaction 34) confirms the giant resonance structure indicated above in Reaction 40, as do the direct (γ, p_0) measurements. For the earlier work see (1982AJ01). For results of measurements with linear polarized photons at $E_{\text{bs}} = 22$ and 30 MeV and for differential cross sections at $E_\gamma = 101.5\text{--}382$ MeV and proton spectra at $E_\gamma \approx 360$ MeV, see (1986AJ04). See also the reviews (1987BE1G, 1988KO1S), and see (1987MA1K). Angular distributions for (γ, p) reactions populating low-lying states of ^{15}N were measured (1988AD07) with bremsstrahlung photons with $E_\gamma = 196\text{--}361$ MeV. Differential cross sections measurements with $E_\gamma \approx 300$ MeV tagged photons (1990VA07) were used to study the interaction mechanism. Proton spectra measured at 90° (1990VA07) showed evidence for an absorption process in which the photon interacts with a $T = 1$ np pair. See also the comment (1992SI01) and reply on the interpretation of these data. A related calculation concerning quasideuteron behavior of np pairs is described in (1992RY02). See also (1987OL1A).

For reaction (b) see (1982AJ01). A study of the $^{16}\text{O}(\gamma, \alpha_0)$ reaction (c) at $\theta = 45^\circ$ and 90° shows a 2^+ resonance at $E_x = 18.2$ MeV with an E2 strength which is spread out over

a wide energy interval. A strong resonance corresponding to an isospin-forbidden 1^- state at $E_x \approx 21.1$ MeV is also observed (1986AJ04). The systematics of cross sections for reaction (d) are discussed in (1991BO26). For pion production reactions (e), pion angular distributions were measured for a mixed flux of real and virtual photons at $E_\gamma = 320$ MeV (1987YA02). Double differential cross sections with tagged photons with $E_\gamma = 220$ –450 MeV are reported in (1991AR06). See also ^{16}N and (1986AJ04). Exclusive cross sections for reaction (g) in the Δ resonance region are reported by (1992PH01).

Recent theoretical work includes calculations of sum rules and transition densities (1990AM06), monopole giant resonances (1990AS06), and polarization effects (1990BO31, 1990LO20). A scheme using fractional-parentage coefficients to separate the wavefunction into three fragments in arbitrary internal states has been proposed, and examples include $^7\text{Li}(\gamma, t)^4\text{He}$, $^{16}\text{O}(\gamma, dd)^{12}\text{C}$ and $^{12}\text{C}(\gamma, pd)^9\text{Be}$ (1988BU06). A formula for cross sections for $A(\gamma, d\gamma')A - 2$ reactions with $E_\gamma = 2.23$ MeV has been derived (1988DU04). In a study of Dirac negative energy bound states, a relativistic shell model predicts $\gamma + ^{16}\text{O} \rightarrow ^{15}_p\text{N} + p$ has a threshold at 1.2 GeV and rises to about $5 \mu\text{b}$ by 1.6 GeV (1988YA08). (1988LO07) calculate $^{16}\text{O}(\gamma, p)^{15}\text{N}$ using Dirac phenomenology. Dirac spinors are used to describe the proton dynamics in a DWBA calculation, and results are compared to data. $^{16}\text{O}(\gamma, p)^{15}\text{N}$ for $E_\gamma = 50$ –400 MeV has been calculated (1986LU1A) using a coupled-channels continuum shell-model technique. A single particle direct knock-out model is used by (1987RY03) to calculate (γ, π) cross sections for $E_\gamma = 40$ –400 MeV. See also (1990BRZY, 1991IS1D). $^{16}\text{O}(\gamma, p)$ at intermediate energies has been calculated using both a single particle and a pion-exchange-current mechanism in a relativistic form of the nucleon current operator and four-component nucleon wave functions (1988MC03). See also the study of the effects of current conservation in these reactions (1991MA39) and of scaling (1991OW01). An expression for the (γ, N) cross section with incident circularly polarized photons and outgoing nucleon polarization being detected is given in (1986PO14). A direct-semidirect model calculation for $^{16}\text{O}(\gamma, N_0)$ at 60 MeV is given as an example. A model, based on basic interactions between photons, pions, nucleons and isobars, providing an adequate description of the $\gamma N \rightarrow \pi N$ reaction is described in (1992CA04).

42. $^{16}\text{O}(\gamma, \gamma)^{16}\text{O}$

Resonances have been reported (1970AH02) at $E_\gamma = 22.5 \pm 0.3$, 25.2 ± 0.3 , 31.8 ± 0.6 and 50 ± 3 MeV: the dipole sum up to 80 MeV exceeds the classical value by a factor 1.4. Elastic photon scattering cross sections for $E_\gamma = 25$ to 39 MeV have been measured. The E2 strength is $1.25^{+1.3}_{-0.9}$ times the total EWSR strength over that interval. The widths of $^{16}\text{O}^*(6.92, 7.12)$ are, respectively, 94 ± 4 and 54 ± 4 meV (1985MO10, 1986AJ04). Differential cross sections at angles of 135° and 45° for elastic scattering of tagged photons between 21.7 and 27.5 MeV in the giant dipole resonance region have been measured by (1987LE12). Differential cross sections for tagged photons with $E_\gamma = 27$ –68 MeV have been reported by (1990MEZV). Polarizabilities of nucleons imbedded in ^{16}O were measured via Compton scattering of 61 and 77 MeV photons by (1992LU01). See also Table 16.14.

A non-perturbative study of damping of dipole and quadrupole motion in ^{16}O is discussed in (1992DE06). (1987VE03) have used an extended isobar doorway model including open-shell configurations in both ground and excited states to calculate elastic and inelastic photon scattering in the Δ -region, and for linearly polarized photons.

Table 16.26: Excited states observed in $^{16}\text{O}(e, e')^{16}\text{O}$ ^a

E_x (MeV \pm keV)	$J^\pi; T$	Mult.	$\Gamma_{\text{c.m.}}$ (keV)	Γ_{γ_0} (eV)
6.05	0^+	E0		3.55 ± 0.21 ^c
6.13	3^-	E3		$(2.60 \pm 0.13) \times 10^{-5}$
6.92	2^+	E2		0.105 ± 0.007
7.12	1^-	E1		$(4.6 \pm 2.3) \times 10^{-2}$
8.87 ^b	2^-	M2		
9.84	2^+	E2		$(8.8 \pm 1.7) \times 10^{-3}$
10.36	4^+	E4		$(5.6 \pm 2.0) \times 10^{-8}$
11.52	2^+	E2		0.61 ± 0.02
12.05	0^+	E0		4.03 ± 0.09 ^c
12.44 ^b	1^-	E1		
12.53 ^b	2^-	M2		0.021 ± 0.006
12.97 ^b	2^-	M2		0.071 ± 0.002
13.02	2^+	E2		0.89
13.10 ± 250	$1^-; 1$	E1		$\leq 49 \pm 13$
13.26 ^b	3^-	E3		
13.87 ^b	4^+	E4		
14.00 ± 50 ^b	0^+	E0	170 ± 50	3.3 ± 0.7 ^c
≈ 14.7 ^b			≈ 600	
14.93 ^b	2^+	E2		
15.15 ± 150	2^+	E2	500 ± 200	1.0 ± 0.5
15.20 ^b	2^-	M2		
15.41 ^b	3^-	E3		
≈ 15.85			≈ 600	
16.22 ± 10 ^{b,d}	$1^+; 1$	M1	18 ± 3	3.2 ± 0.3
16.45 ± 10 ^{b,d}	2^+	E2	32 ± 4	0.18 ± 0.01
16.82 ± 10 ^{b,d}	2^-	M2	30 ± 5	0.05 ± 0.01
17.14 ± 10 ^{b,d}	$1^+; 1$	M1	< 25	6.1 ± 0.5

Table 16.26: Excited states observed in $^{16}\text{O}(e, e')^{16}\text{O}$ ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	Mult.	$\Gamma_{\text{c.m.}}$ (keV)	Γ_{γ_0} (eV)
17.30 ± 10 ^{b,d}	1^-	E1	70 ± 10	3.4 ± 2.3
17.774 ± 17 ^b	$4^-; 0$	M4		
17.78 ± 10 ^{d,e}	2^-	M2		0.07 ± 0.01
17.880 ± 15 ^f	$(4^+; 1)$	E4	20 ± 20	
18.021 ± 23 ^b	$3^-; 1$			
18.20 ± 10 ^d	2^+	E2	280 ± 20	1.68 ± 0.22
≈ 18.3 ^f			≈ 430	
18.50 ± 10 ^{b,d}	2^-	M2	70 ± 5	0.38 ± 0.07
18.635 ± 20 ^f	$(4^-; 1)$		35 ± 30	
18.79 ± 10 ^d	$1^+; 1$	M1	120 ± 20	5.3 ± 0.3
18.968 ± 17 ^{b,g}	$4^-; 1$	M4		
19.02 ± 40 ^{d,h}	$2^-; 1$	M2	420 ± 50	2.52 ± 0.38
19.206 ± 12 ^b	$3^-; 1$	E3		
19.430 ± 20 ^f			150 ± 15	
20.185 ± 40 ^f			400 ± 100	
20.335 ± 25 ^f			≈ 200	
20.510 ± 25 ^f	$(4^-; 1)$		50 ± 30	
20.88 ^b			≈ 90	
20.95 ± 50	$1^-; 1$	E1	270 ± 70	180 ± 50
≈ 21.46 ^b			≈ 300	
22.60 ± 20 ^b			90 ± 40	
23.0				
23.7 ± 250	$(2^-; 1)$			
24.2				
25.5 ± 250	$1^-; 1$	E1		
26.7 ± 250	1^+	M1		
44.5	$(1^-; 1)$		2000 – 3000	5300
49	$(1^-; 1)$		2000 – 3000	19000

- ^a See also Table 16.26 in (1971AJ02). For references see Table 16.24 in (1977AJ02). See also the text.
- ^b (1985HY1A: momentum transfer range 0.8 to 2.5 fm⁻¹). See (1986AJ04).
- ^c Monopole matrix element in fm².
- ^d (1983KU14).
- ^e An unresolved complex of M1 strength has a centroid at $E_x \approx 17.7$ MeV: the total Γ_{γ_0} is 7.4 ± 1.9 eV (1983KU14).
- ^f (1987HY01).
- ^g See also (1986AJ04).
- ^h The total cross section ($E_x = 18.7-19.4$ MeV) is 12% M1 and 88% M2, leading to $B(M1) \uparrow = 0.13 \pm 0.03 \mu_N^2$ and $B(M2) \uparrow = 341 \pm 51 \mu_N^2 \cdot \text{fm}^2$: see (1986AJ04).

43. (a) $^{16}\text{O}(e, e)^{16}\text{O}$
 (b) $^{16}\text{O}(e, e'p)^{15}\text{N}$ $Q_m = -12.12776$
 (c) $^{16}\text{O}(e, e'\alpha)^{12}\text{C}$ $Q_m = -7.161$

The ^{16}O charge radius = 2.710 ± 0.015 fm (1978KI01). Form factors for transitions to the ground and to excited states of ^{16}O have been reported in many earlier studies [see (1982AJ01, 1986AJ04)], and by (1987HY01); see Table 16.26. Table 16.26 lists the excited states observed from (e, e'). The form factor for $^{16}\text{O}^*(9.84)$ indicates a transition density peaked in the interior (1986BU02). The energy-weighted M2 strength is nearly exhausted by the M2 states which have been observed. The isospin-forbidden (E1) excitation of $^{16}\text{O}^*(7.12)$ is reported: the isovector contribution interferes destructively with the isoscalar part and has a strength $\sim 1\%$ of the $T = 0$ amplitude. The 0^+ states of $^{16}\text{O}^*(6.05, 12.05, 14.00)$ saturate $\sim 19\%$ of an isoscalar monopole sum rule. In a recent measurement, the magnetic monopole $0^+ \rightarrow 0^-$ transition to $^{16}\text{O}^*(10.957)$ was observed (1991VO02). The E2 strength is distributed over a wide energy region: see Table 16.26, and (1982AJ01, 1986AJ04) for references. See also the compilation of nuclear charge density distribution parameters (1987DEZV), and the reviews of (1989DR1C, 1987HO1F).

A study of reaction (b) at 500 MeV shows separation energies of 12.2 and 18.5 MeV, corresponding to $^{15}\text{N}^*(0, 6.32)$. The momentum distribution of the recoiling nucleus has been measured. High precision data with ~ 100 keV resolution in the missing mass are reviewed in (1990DE16). The excitation of $^{16}\text{O}^*(11.52, 12.05, 22.3)$ and some other states is reported at $E_e = 112-130$ MeV in (e, e'). The (e, e'p) and (e, e α) processes lead to the excitation of $^{15}\text{N}^*(0, 6.32)$ and of $^{12}\text{C}^*(0, 4.44)$. (See (1982AJ01, 1986AJ04) for the references). In a recent measurement the nuclear response function R_{LT} for $^{15}\text{N}^*(0, 6.32)$ was determined in (e, e'p) by (1991CH39). See also (1990MO1K). Coincidence experiments at $E_e = 130$ MeV are reported by (1987DM01). See also (1987RI1A). Non-spherical components in the ^{16}O ground state are indicated by the (e, e'p) data of (1988LEZW). The inelastic cross section for 537 and 730 MeV electrons has been measured by (1987OC01), and the electromagnetic excitation of the Δ resonance was studied.

Angular correlation measurements for reaction (c) to determine isoscalar E2 strengths in ^{16}O are reported in (1992FR05).

Inelastic electron-nucleus interactions for ^{16}O at 5 GeV are reported in (1990DE1M).

In theoretical work on reactions (a) and (b), models for relativistic Coulomb sum rules are developed in (1989DO05). See also (1991LE14). A shell-model study of giant resonances and spectroscopic factors in ^{16}O is described in (1988HO10). See also (1990BO31). (1988AM03) studied an isoscalar dipole excitation in ^{16}O (7.12 MeV state). Core polarization was used in their limited shell model treatment. Exchange amplitudes proved crucial in fitting (p, p') data. A relativistic Dirac-Hartree-Fock approach is shown to give a reasonably good account of binding energies, single-particle energies and charge, as well as proton and neutron densities of ^{16}O and other closed shell nuclei (1988BL11). The application of Monte Carlo methods in light nuclei including ^{16}O is reviewed in (1991CA35). Non-locality of the nucleon-nucleus optical potential has been used (1987BO54) to evaluate the missing single particle strength observed in (e, e'p) data. (1988BO40) have studied the charge form factor by taking the one- and two-body isoscalar charge operands into account in the topological soliton model. Nuclear responses were calculated (1987CA16) using self-consistent HF and RPA theory with a SK3 interaction. Decay properties in (e, e'p) and (e, e'n) for semidirect and knockout processes are also discussed. A self-consistent RPA with the SK3 interaction has been used by (1988CA10) to calculate (\vec{e} , e'x) reactions. Polarization structure functions are also discussed. (1989CA13) use self-consistent RPA with SK3 interactions to calculate monopole excitations in (e, e') and (\vec{e} , e'x) reactions. Evidence has been presented by (1989FR02) for a violation of Siegert's theorem, based on cross section measurements of the electro-excitation of the first 1^- level in ^{16}O . Previous Hartree-Fock calculations were used by (1990CA34) to study Siegert's Theorem in E1 decay in ^{16}O . Their results show that the previously claimed violation cannot be definitely asserted. A pole graph method is used by (1987CH10) to calculate production of hypernuclei in the continuum. Radial wave functions obtained from realistic nuclear potentials have been used to calculate electron scattering form factors for stretched configurations, which are compared to data (1988CL03). (1987CO24) exhibit and discuss DWBA structure functions for (\vec{e} , e'x) cross sections. A numerical study of the decay of giant resonances of ^{16}O was also conducted. The ratio of transverse-to-longitudinal electromagnetic response in (e, e'p) reactions has been examined in terms of relativistic dynamics and medium modifications (1987CO26). Electron scattering form factors have been calculated (1990DA14) using relativistic self-consistent RPA descriptions of discrete excitations. (1986GU05) derived an expression for the transition charge density in the Helm model, and (1988GU03) calculated charge density distributions using harmonic oscillator wave functions. Experimental values have been compared with calculated transition charge densities from various models in (1988GU14). (1988KU18) calculated binding energy, excitation spectra to ~ 12 MeV, and e-scattering form factors using the mean-field approximation and the BZM boson image of the shell model Hamiltonian. Results appear superior to the standard shell model. The two-body pion exchange current contributions to the form factor of inelastic electron scattering has been calculated by (1986LA15) using the effective pion propagator approximation. Effects due to meson exchange currents and unbound wavefunctions for the valence nucleon were included in calculations of electron scattering form factors (1987LI30). Special attention was paid to $1\hbar\omega$ stretched states. A Sum Rule formalism was used by (1989LI1G) to investigate giant resonances. Surface effects, non-Hermitian operators, and magnetic excitations were considered.

Normalized correlated wavefunctions were used by (1988MA29) to simplify a previously derived expression for the charge form factor in the non-unitary model operator approach, and compared to data. (1989MA06, 1990MA63) derived an approximate formula for the two-body term in the cluster expansion of the charge form factor, and discussed the correlation parameter. (1989MC05) used the Gelerkin approach to calculate a finite nucleus Dirac mean field spectrum, and then applied it to Dirac RPA response and the present results for 1^- and 3^- longitudinal form factors. A comprehensive study of a full set of 18 response functions relevant to the $(\bar{e}, e'p)$ reaction is presented by (1989PI07). (1988PR05) have studied the linear response of ^{16}O to external electroweak current in a relativistic model. Hartree-Fock-RPA quasi-elastic cross sections for $^{16}\text{O}(e, e'p)$ are calculated by (1989RY01), who also discuss final state interactions. Electromagnetic quasi-free proton knockout in a one-photon exchange approximation is studied in (1991BO10, 1991PA06). (1989RY06) performed self-consistent HF-RPA model calculations for $(e, e'p)$ and $(e, e'n)$ using Skyrme interactions in parallel and perpendicular kinematics. A consistent extension of the QHD1 mean-field RPA theory including correlations induced by isoscalar σ and ω mesons of QHD1 is used by (1989SH27) to calculate (e, τ') form factors and transition charge and current densities. See also (1991ZH17). (1986TK01) calculated M1 resonances taking $1p-1h \times$ phonon excitations into account. Comparisons were made with data. (1987YO04) studied $1\hbar\omega$ stretched excitations in configuration mixing calculations based on first-order perturbation theory.

44. $^{16}\text{O}(\pi^\pm, \pi^\pm)^{16}\text{O}$

Angular distributions of elastically scattered pions have been studied at $E_{\pi^-} = 20$ to 240 MeV and at 1 GeV/c as well as at $E_{\pi^\pm} = 20$ to 315 MeV [see (1982AJ01, 1986AJ04)] and recently at $E_{\pi^\pm} = 100$ –250 MeV at 175° (lab) (1987DH01), and at $E_{\pi^-} = 30, 50$ MeV (1990SE04). At $E_{\pi^\pm} = 164$ MeV, $^{16}\text{O}^*(0, 6.1, 6.9, 7.1, 11.5, 17.8, 19.0, 19.8)$ are relatively strongly populated. The π^+ and π^- cross sections to $^{16}\text{O}^*(17.8, 19.8)$ [$J^\pi = 4^-; T = 0$] are substantially different while those to $^{16}\text{O}^*(19.0)[4^-; 1]$ are equal. Isospin mixing is suggested with off-diagonal charge-dependent mixing matrix elements of -147 ± 25 and -99 ± 17 keV (1980HO13). [See also Reaction 67, $^{17}\text{O}(d, t)$]. The inelastic pion scattering is dominated by a single quasi-free pion-nucleon interaction mechanism at $E_{\pi^+} = 240$ MeV (1983IN02): this is not the case at energies below the Δ -resonance (114 and 163 MeV). For recent inelastic measurements see (1987BLZZ).

For a study of $(\pi^+, 2p)$ and (π^\pm, pn) at $T_{\pi^+} = 165$ MeV see (1986AL22), at $T_{\pi^+} = 115$ MeV see (1992MA09). See also (1986KY1A, 1986KY1B). Pion absorption at $T_{\pi^+} = 65$ MeV followed by multinucleon emission is reported by (1992BA31). For $(\pi^+, \pi^0 p)$ at $T_{\pi^+} = 165$ and 245 MeV see (1986GI15, 1988HO1L, 1991HO03). For (π^+, π^-) and (π^-, π^+) at $T_{\pi^+} = 180, 240$ MeV see (1989GR06). For $(\pi^+, \pi^+\pi^-)$ at $T_{\pi^+} = 280$ MeV see (1989GR05). See also (1987ME12, 1989ME10, 1990KO36).

A calculation of differential elastic cross sections in a local approximation to the delta-hole model is described in (1991GA07).

Optical-model calculations for pion scattering on ^{16}O are discussed in (1990CA09, 1990LI10).

Table 16.27: Excited states of ^{16}O from $^{16}\text{O}(\text{p}, \text{p}')$, (d, d') , $(^3\text{He}, ^3\text{He}')$ and (α, α') ^a

No.	E_x^b (MeV \pm keV)	L^b	E_x^c (MeV)	E_x^d (MeV \pm keV)	E_x^e (MeV \pm keV)	L^e	Γ^b (keV)	$J^\pi; T^b$
1			6.05					
2	6.13 ^f	3	6.13	6.13 ⁱ	6.13	3		3 ⁻ ; 0
3	6.92 ^f	2	6.92	6.92 ^d	6.92	2		2 ⁺ ; 0 ^f
4	7.12 ^f	1	7.12		7.12	1		1 ⁻ ; 0
5	8.87 ^g		8.87	8.87 \pm 30 ^d	8.87	3 ^a		2 ⁻ ; 0 ^g
6	9.84 ^f	2	9.85	9.84 \pm 30	9.85	2		2 ⁺ ; 0 ^{d,f}
7	10.35 \pm 20 ^f	4	10.34	10.35 \pm 30	10.35 \pm 30	4		4 ⁺ ; 0
8	10.95 \pm 30 ^h	1	10.95					0 ⁻ ; 0
9	11.10 \pm 20 ^f	4	11.1 ⁱ	11.09 \pm 30 ⁱ	11.10 \pm 30	4		4 ⁺ ; 0
10	11.52 \pm 20 ^f	2	11.52	11.52 \pm 30 ^d	11.52 \pm 30	2	74 \pm 4	2 ⁺ ; 0
11	12.05 \pm 20 ^f		12.05	12.04 \pm 30	12.05 \pm 30	(0)		0 ⁺ ; 0 ⁻
12			12.44		12.44	1		1 ⁻ ; 0
13	12.53 \pm 20 ^g	1	12.53		12.51 \pm 30			2 ⁻ ; 0 ^g
14	12.80 ^h							0 ⁻ ; 1
15	12.97 ^g							2 ⁻ ; 1
16	13.02 \pm 20	2	13.1 ⁱ	13.11 \pm 30	13.07 \pm 20 ⁱ	2		2 ⁺ ; 0
17	13.26 \pm 30	3						3 ⁻ ; 1
18			13.66					
19	13.95 \pm 50	(0 + 4)		13.97 \pm 30	13.95 \pm 50 ⁱ	4		4 ⁺ ; 0
20	14.0 ^{g,i}							(1 ⁺ ; 1)
21				14.94 \pm 30	14.87 \pm 100	6		6 ⁺
22	15.26 \pm 50	(3)		15.4				
23	15.50 \pm 30 ^f	3			15.50 \pm 50	3	200 \pm 60	3 ⁻ ; 0
24	16.22 \pm 10 ^g							1 ⁺ ; 1
25	16.52 \pm 50	2		16.46 \pm 30	16.40 \pm 100		< 100	2 ⁺
26	16.93 \pm 50	(3)						
27	17.14 \pm 10 ^g							1 ⁺ ; 1
28	17.25 \pm 50 ^f			17.19 \pm 30	17.25 \pm 80	(2)	160 \pm 60	1 ⁺ ; 0 ^f
29	17.79 \pm 40	(3)		17.8	17.83 \pm 100		150 \pm 60	4 ⁻ ; 0
30	18.15 \pm 50	(2)			18.0 \pm 100	2	300 \pm 50	(2 ⁺); 0
31	18.40 \pm 100	2		18.52 \pm 30	18.5 \pm 100	2	250 \pm 50	2 ⁺ ; 0
32	18.60 \pm 100				18.70 \pm 100	(3)	280 \pm 80 ⁱ	
33	18.77 \pm 10 ^g							1 ⁺ ; 1
34	18.98 \pm 40	(3)		19.09 \pm 30			< 100	4 ⁻ ; 1
35	19.35 \pm 80	(1)						
36	19.56 \pm 50 ^f				19.50 \pm 100	(2,3)	300 \pm 50	3 ⁻ ; 0

Table 16.27: Excited states of ^{16}O from $^{16}\text{O}(\text{p}, \text{p}')$, (d, d') , $(^3\text{He}, ^3\text{He}')$ and (α, α') ^a
(continued)

No.	E_x^b (MeV \pm keV)	L^b	E_x^c (MeV)	E_x^d (MeV \pm keV)	E_x^e (MeV \pm keV)	L^e	Γ^b (keV)	$J^\pi; T^b$
37	19.80 \pm 40	3					< 100	4 ⁻ ; 0
38				20.2 \pm 200 ⁱ	20.15 \pm 100	2	350 \pm 50	2 ⁺ ; 0
39	20.40 ^{g,i}							2 ⁻ ; 1
40	20.56 \pm 80	(1, 2)					370 \pm 100	
41	20.90 ^{g,i}							2 ⁻ ; 1
42	21.05 \pm 50	1			21.0 \pm 100	2	320 \pm 50	(2 ⁺ ; 0)
43				21.6 \pm 200			1000 \pm 300	2 ⁺
44	21.80 \pm 80	1			21.85 \pm 100	2	400 \pm 50	(2 ⁺ ; 0)
45	22.40 \pm 80	(1, 2)					420 \pm 100	1 ⁻ ; 1
46					22.5 \pm 100		400 \pm 50	(2 ⁺ , 3 ⁻); 0
47	23.20 \pm 80	1					600 \pm 200	1 ⁻ ; 1
48				23.50 \pm 150	23.25 \pm 100	2	400 \pm 50	2 ⁺ ; 0
49					23.85 \pm 100	(0)	400 \pm 50	(2 ⁺ , 0 ⁺); 0
50	24.00 \pm 100	(1, 2)					1200 \pm 300	1 ⁻ ; 1
51					24.4 \pm 100		400 \pm 50	(2 ⁺ , 3 ⁻); 0
52					25.15 \pm 300		2800 \pm 600	2 ⁺
53	25.50 \pm 150	(1)					1300 \pm 300	1 ⁻ ; 1

^a For references see Table 16.24 in (1982AJ01).

^b (p, p').

^c (d, d'). Energies are nominal (± 100 to ± 260 keV); angular distributions reported to all but last state.

^d (^3He , $^3\text{He}'$).

^e (α , α').

^f (1984AM04): $E_p = 135$ MeV.

^g (1987DJ01).

^h (1984HO17); $E_p = 65$ MeV.

ⁱ Unresolved states.

45. $^{16}\text{O}(\text{n}, \text{n}')^{16}\text{O}$

Angular distributions have been measured at E_n to 24 MeV [see (1982AJ01, 1986AJ04)] and recently at $E_n = 18$ to 26 MeV (1987IS04, 1988MEZX); n's were observed leading to $^{16}\text{O}^*(6.05, 6.13, 6.92, 7.12, 9.85, 10.35, 11.0, 11.52)$. For small-angle measurements at $E_n = 14.8$ MeV, see (1992QI02). Differential cross sections for (n, n) and (n, n') at $E_n = 21.6$ MeV are reported by

(1990OL01). Polarization of gamma rays from (n, n') with polarized neutrons to $^{16}\text{O}^*(6.05, 6.13)$ was studied by (1988LI34) [see also (1987PO11)]. See also the evaluation of $E_n = 10^{-5}$ eV–20 MeV neutron data for ^{16}O in (1990SH1D).

The folding model has been used to calculate the nucleon– ^{16}O interaction potential, and the effect of different nucleon-nucleon forces has been discussed (1989HA24). See also the analysis with nonlocal potentials based on RGM formulations by (1992KA21) and the optical model study of (1992BO04). See also (1991KA19, 1991KA22, 1991SH08).

46. (a) $^{16}\text{O}(p, p')^{16}\text{O}$
 (b) $^{16}\text{O}(p, 2p)^{15}\text{O}$ $Q_m = -12.12776$
 (c) $^{16}\text{O}(p, pd)^{14}\text{N}$ $Q_m = -20.7363$
 (d) $^{16}\text{O}(p, pt)^{13}\text{N}$ $Q_m = -25.0325$
 (e) $^{16}\text{O}(p, p\alpha)^{12}\text{C}$ $Q_m = -7.16195$
 (f) $^{16}\text{O}(p, p)^{16}\text{O}$

Angular distributions of elastically and inelastically scattered protons have been measured at many energies up to $E_p = 1000$ MeV [see (1982AJ01, 1986AJ04)] and recently at $E_p = 7.58$ MeV (1987KR19; p to $^{16}\text{O}^*(6.05)$), 8.9–50 MeV, (1988LE08; p to $^{16}\text{O}^*(6.129)$), 35 MeV, (1990OH04; p to $^{16}\text{O}^*(E_x \leq 12.97)$), 40–85 MeV, (1987LA11; p to $^{16}\text{O}^*(6.1299, 8.8719)$), 22, 35, 42 MeV, (1988SA1B; p to $^{16}\text{O}^*(6.129)$), 135 MeV, (1986GA31; p to $^{16}\text{O}^*(6.044, 7.117, 12.043)$), (1989KE03; p to $^{16}\text{O}^*(6.049, 6.130, 6.917, 7.117, 9.847, 10.353, 11.09)$), 180 MeV, (1990KE03; p to $^{16}\text{O}^*(E_x \leq 12.1)$), 200 MeV, (1986KIZW; p to $^{16}\text{O}^*(10.957)$), (1989SAZZ; p to $^{16}\text{O}^*(10.957, 12.797)$), 201 MeV. (1987DJ01; p to many states [see Table 16.27]), 320–800 MeV (1988BL07), 318 and 500 MeV, (1988FEZX, 1989FEZV, 1991FL01, 1991KE02), 100 and 200 MeV (1988SEZU, 1990GL09), 200, 318 MeV, (1990FEZY), 400 MeV (1991KI08), and 1000 MeV (1988BE2B). Parameters of the observed groups are displayed in Table 16.27. See also (1990OP01) and the analysis of (1990ER09).

For reaction (b) see (1991CO13; 151 MeV), (1986MC10; 505 MeV) and the review of (1987VD1A). For reaction (c) see (1986BO1A; 50 MeV), (1986SA24; 76.1, 101.3 MeV). For reaction (p, p α) see (1986VD04; 50 MeV). See also the study with antiproton beams of (1986KO22).

(1987CO25) have performed calculations using the Dirac equation for p and n distortions for the $^{16}\text{O}(\vec{p}, n\pi^+)^{16}\text{O}$ reaction. A coupled-channels calculation using Dirac phenomenology for inelastic scattering of 800 MeV protons from ^{16}O is presented in (1988DE35). (1988DE31) have studied the importance of a deformed spin-orbit potential in the calculations of (1988DE35). Approximate treatment of the nucleon-nucleus interaction in the resonating group method is discussed in (1991KA19). First order Kerman-McManus-Thaler optical potentials have been constructed from realistic meson-exchange models of N-N interaction including off-shell effects, and are found to be important for spin observables at 200–500 MeV (1989EL02). Optical phase shifts have been calculated to fifth order by (1988FR06), taking into account cm correlations. The significance of higher-order corrections is assessed. (1989GU06) consider breakup reactions in high temperature

plasmas, including production of 6.129 MeV γ 's from ^{16}O : mainly from $p + ^{16}\text{O} \rightarrow p' + ^{16}\text{O}^*$, $\gamma + ^{16}\text{O} \rightarrow \gamma' + ^{16}\text{O}^*$, and $p + ^{20}\text{Ne} \rightarrow X + ^{16}\text{O}^*$. (1988HA08) found Dirac optical potentials constrained by relativistic Hartree theory to give good agreement with elastic scattering data. See also (1990TJ01, 1991SH08). Spin observables have been calculated by (1988HO1K) for proton quasi-elastic scattering in the relativistic plane wave-impulse approximation, and compared to (p, p') data at 490 MeV. Isoscalar spin response functions are studied in (1990SH10). (1987KE1A) constructed a parametrization of medium modifications of the 2N effective interaction to reproduce nuclear matter theory, and adjusted it to reproduce proton inelastic scattering data. They obtained good fits to cross section and analyzing power for nine states simultaneously. (1989KE05) performed similar calculations, and fitted 135 MeV proton cross section and analyzing power data with the effective interactions. (1986KU15) performed a DWIA calculation of $\sigma(\theta)$ and $A_y(\theta)$ for $^{16}\text{O}(\vec{p}, 2p)$ at 200 MeV including spin-orbit and off-shell effects. (1987LU02) performed a semi-relativistic multiple scattering model calculation of intermediate energy proton elastic scattering, and investigated target nucleon correlation contributions. Multiple diffraction scattering theory was used to calculate cross sections and polarization observables in (1988BE57, 1991BE1E, 1991BE45, 1992BE03). See also (1991CH28, 1991CR04, 1992CR05). A Skyrme force approach was explored in (1988CH08). A scalar-vector form of a second-order relativistic impulse approximation optical model including dispersion effects was used by (1988LU03) to calculate elastic proton scattering at 500 and 800 MeV. Evidence for a small imaginary potential or actual flux emission was presented (1988MA05) for nucleon scattering from ^{16}O at 30 MeV. As an alternate explanation of the (1988MA05) findings, (1988MA31) discuss the “ ψ -potentials”, related to projectile current. (1988MA1X) contains a review of relativistic theory of nuclear matter and finite nuclei. A relativistic microscopic optical potential derived from the relativistic Brueckner-Bethe-Goldstone equation is discussed in (1992CH1E). Polarization transfer measurements in (p, p') reactions have been examined by (1986OR03) with regard to correlations of tensor character. (1986OS08) used the T-matrix approximation with distorted waves to analyze knock-off nucleon (p, pN) and cluster (p, pX) proton induced reactions from 30 to 100 MeV. The scattering of 500 MeV protons has been calculated by (1987OT02) using the Dirac equation with and without recoil corrections. Both cross section and spin observables are examined and compared to data. See also (1991KA22). (1988OT04) present systematics of Dirac impulse approximation for cross sections and spin observables in elastic p scattering at 200, 500, and 800 MeV. Results are compared to data. A mixed-density expansion of the off-diagonal density matrix is used by (1988PE09) to study the non-local knockout exchange amplitude for nucleon-nucleus scattering. (1987PI02) studied $0^+ \rightarrow 0^-$ transitions by medium energy protons using the relativistic impulse approximation. (1989PI01) considered corrections arising from the energy dependence of the NN interaction, especially for $0^+(\vec{p}, \vec{p}')0^-$ reactions. Relativistic and non-relativistic dynamical scattering models have been used by (1988RA02) to predict elastic scattering observables in the forward angle for $p + ^{16}\text{O}$ at 500 and 800 MeV. See also (1990CO19, 1990RA12). (1989RA02) have obtained the leading three-body anti-symmetrization correction to nucleon-nucleus elastic scattering calculations using multiple scattering theory. Small effects are found at intermediate energies. Folding model potentials are used by (1986YA16) to perform a systematic analysis of proton elastic scattering from 65–200 MeV. See also (1990AR11, 1990CR02, 1990EL01, 1991AR11, 1991AR1K).

Effects of short-range correlations on the self energy in the optical model of ^{16}O are studied in (1992BO04). See also (1992LI1D).

47. (a) $^{16}\text{O}(\text{d}, \text{d}')^{16}\text{O}$
 (b) $^{16}\text{O}(\text{d}, \text{n})^{17}\text{F}$ $Q_m = 1.623$

Angular distribution studies have been carried out for E_d up to 700 MeV [see (1986AJ04)] and recently angular distributions and analyzing powers with polarized deuterons were measured at 19–24 MeV (1991ER03) and at 200, 400, 700 MeV (1987NG01). Observed deuteron groups are displayed in Table 16.27. See also ^{18}F in (1987AJ02), and see the analysis of (1990ER09).

Reaction (b) has been used for analysis of oxygen in Fluoride glasses (1990BA1M).

Coupled-channels variational formalism is discussed and applied to $^{16}\text{O}(\text{d}, \text{d})^{16}\text{O}$ (1986KA1A). Coupling to the proton channel is significant at 11 MeV, but can be ignored at ≥ 40 MeV. Coupling to d-breakup channels decreases as E increases, but is still significant at 60 MeV. (1988IS02) use folding interactions to investigate polarized d-scattering at $E_d = 56$ MeV. Breakup channels are important, as is the D-state admixture in the deuteron ground state — especially for tensor analyzing powers. (1988IS02) employed the continuum-discretized coupled-channels (CDCC) method, and obtained good agreement with data. (1987GR16) studied d-scattering at 400 MeV using the folding model, but failed to describe A_{yy} at relatively low momentum transfers. They attribute this failure to inadequacies in off-shell properties of N-N potentials. (1986MA32) analyzed elastic data at 56 MeV using an optical model potential containing a complex tensor term. The OM potential was compared with folding-model results. (1987MA09) evaluate the Pauli-blocking correction of the three-body Schrödinger equation for d-nucleus reactions.

48. $^{16}\text{O}(\text{t}, \text{t})^{16}\text{O}$

Angular distributions are reported for E_t to 20.01 MeV: see (1977AJ02) and recently at 36 MeV (1986PE13, 1987EN06). See also ^{19}F in (1987AJ02), and see the analysis of (1990ER09).

(1989WA26) studied the spin-orbit potential for triton scattering to explain previous discrepancies with folding model predictions.

49. (a) $^{16}\text{O}({}^3\text{He}, {}^3\text{He})^{16}\text{O}$
 (b) $^{16}\text{O}({}^3\text{He}, \alpha)$ $Q_m = 4.915$

Angular distributions have been measured to $E({}^3\text{He}) = 132$ MeV [see (1982AJ01, 1986AJ04)] and at $E({}^3\text{He}) = 60$ MeV (1990ADZU). The matter radius $\langle r^2 \rangle^{1/2} = 2.46 \pm 0.12$ fm (1982VE13). Inelastic groups are shown in Table 16.27. See also the analysis of (1990ER09). Differential cross

sections for reaction (b) have been measured at $E(^3\text{He}) = 60$ MeV (1990ADZT). The reaction has also been used in thin film analysis (1990AB1G).

(1986WA1U) studied the spin-orbit potential for ^3He scattering to explain previous discrepancies with folding model predictions. The M3Y double folding model is used (1987CO07) to fit data at 33 MeV. No change in the spin-orbit strength is necessary. The three-parameter strong absorption model of Trahn and Venter is applied to data at 25 and 41 MeV. (1987RA36) obtain radii, diffusivities and quadrupole deformation parameters. (1987TR01) perform a simple optical model analysis of elastic ^3He scattering from 10 to 220 MeV.

50. (a) $^{16}\text{O}(\alpha, \alpha')^{16}\text{O}$
 (b) $^{16}\text{O}(\alpha, \alpha p)^{15}\text{N}$ $Q_m = -12.127$
 (c) $^{16}\text{O}(\alpha, 2\alpha)^{12}\text{C}$ $Q_m = -7.16195$

Angular distributions and/or differential cross sections of α -particles have been measured up to $E_\alpha = 146$ MeV [see (1982AJ01, 1986AJ04)] and recently at $E_\alpha = 48.7, 54.1$ MeV (1987AB03; α_0): see ^{20}Ne in (1983AJ01, 1987AJ02). See also the work on (α, α_0) resonances at $E_\alpha = 2.0 - 3.6$ MeV (1985JA17, 1988BL1H). A search at $E_\alpha = 10.2-18$ MeV for continuum levels in ^{20}Ne with a large [$^{16}\text{O}^*(0_2^+) + \alpha$] parentage is described in (1992LA01). Reaction (a) has also been observed in astrophysical measurements (1989LA1G). Observed excited states are displayed in Table 16.27. See also the analysis of (1990ER09), and see (1990DA1Q, 1990IR01).

Reaction (b) has been studied at $E_\alpha = 13.92$ MeV in a quasifree geometry (1987SA01). Angular correlations (reaction (c)) have been studied to $^{12}\text{C}_{\text{g.s.}}$ at $E_\alpha = 23.0$ to 27.5 MeV to try to determine if a 3^- state exists near the 2^+ state $^{16}\text{O}^*(9.84)$: the evidence is strong that this is not the case (1986AJ04). The isoscalar (E2, $T = 0$) giant resonance decays predominantly via the α_1 channel which contains $\sim 40\%$ of the E2 EWSR, rather than via the α_0 and p_0 channels. For the $(\alpha, \alpha d)$, $(\alpha, \alpha t)$ and $(\alpha, \alpha^3\text{He})$ reactions see references in (1986AJ04).

In a theoretical study of nucleus-nucleus potentials, (1987BA35) determine shallow potentials that are phase equivalent to deep ones. This method eliminates non-physical bound states encountered in some microscopically founded potentials. (1987BU06) calculate the probability of direct alpha-decay of the giant quadrupole resonance in ^{16}O . They find direct and statistical mechanisms to be commensurate, and obtain good agreement with the data. The construction of a cranked cluster wave function for molecular-like states is discussed by (1986HO33). (1986MA35) study the radial shape and the energy dependence of the dispersive contribution to the real potential and apply it to alpha-particle scattering from ^{16}O . (1989MI06) show that alpha-particle scattering from ^{16}O near the Coulomb barrier can be described if the interaction is angular momentum dependent and has a less diffuse surface than that used to describe scattering at higher energies. The potential separable expansion method based on Coulomb-Sturmian functions is presented (1988PA21) and the $l = 3$ phase shift is calculated for $\alpha + ^{16}\text{O}$ at $E = 12$ MeV. (1987SA55) show the one-channel orthogonality condition model provides results which agree with experiment for $E_\alpha \leq 7.5$ MeV. (1987WA1B) compare a microscopic potential obtained from RGM calculations with the optical

model potential. They conclude that internucleus antisymmetrization is responsible for a large part of the energy dependence of the real part of OM potential. (1989YA15, 1991YA08) use the many body theory which takes the Pauli principle into account to calculate the α - ^{16}O complex potential from a realistic effective two-nucleon interaction. The role of the Pauli principle is also examined in (1991OM03). Internucleus potentials in $\alpha + ^{16}\text{O}$ systems are calculated with Skyrme-type forces in (1990WA01). Nuclear molecular resonances are discussed in the analyses of (1990AB10, 1992SA26). See also (1990KR16). A peripheral 3-body coupling model is applied to reaction (c) in (1992JA04).

51. (a) $^{16}\text{O}(^6\text{Li}, ^6\text{Li})^{16}\text{O}$
 (b) $^{16}\text{O}(^7\text{Li}, ^7\text{Li})^{16}\text{O}$

Elastic angular distributions for reaction (a) have been measured at $E(^6\text{Li}) = 4.5$ to 75.4 MeV and $E(^{16}\text{O}) = 36$ to 94.2 MeV [see (1986AJ04) and Tables 16.25 in (1977AJ02) and 16.23 in (1982AJ01)] and recently at $E(^6\text{Li}) = 50$ MeV (1988TRZY). See also (1987GO1C). Vector analyzing power has been measured with polarized ^6Li beams at $E(^6\text{Li}) = 25.7$ MeV (1987VAZY, 1989VA04). See also ^6Li in (1988AJ01). For studies of d- α angular correlations see ^{20}Ne in (1983AJ01, 1987AJ02). For a fusion cross section study see (1986MA19). Inelastic scattering to states in ^{16}O are reported at $E(^6\text{Li}) = 50$ MeV by (1990TR02).

Elastic distributions for reaction (b) have been studied at $E(^7\text{Li}) = 9.0$ to 68 MeV [see (1986AJ04) and Tables 16.25 in (1977AJ02) and 16.23 in (1982AJ01)] as well as at $E(^7\text{Li}) = 10.3$ – 22.40 MeV (1988MA07). For fusion cross section studies see (1988SC14) and references in (1986AJ04). See also (1988KE07).

A generalized optical model within the method of orthogonal conditions (MOC) has been formulated by (1988GR32). Taking account of antisymmetrization improves the description of angular distribution data. See also (1990SA10).

52. $^{16}\text{O}(^9\text{Be}, ^9\text{Be})^{16}\text{O}$

Elastic angular distributions have been reported at $E(^9\text{Be}) = 20$ to 43 MeV and $E(^{16}\text{O}) = 15$ to 29.5 MeV [see (1986AJ04) and Table 16.23 in (1982AJ01)] and recently at $E_{\text{c.m.}} = 7.2, 8.4, 9.0, 9.6, 10.2$ MeV (1989WE11). Projectile decomposition measurements were reported at $E(^{16}\text{O}) = 32$ MeV/nucleon. For fusion cross sections see (1982AJ01, 1986AJ04, 1988HAZS). See also (1985BE1A).

53. (a) $^{16}\text{O}(^{10}\text{B}, ^{10}\text{B})^{16}\text{O}$
 (b) $^{16}\text{O}(^{11}\text{B}, ^{11}\text{B})^{16}\text{O}$

Angular distributions have been reported at $E(^{10}\text{B}) = 33.7$ to 100 MeV and at $E(^{11}\text{B}) = 41.6$, 49.5 and 115 MeV [see (1986AJ04) and Table 16.23 in (1982AJ01)] and recently at $E_{\text{c.m.}} = 14.17$, 16.15 , and 18.65 MeV (1989KO10). See also (1989KO2A). For fusion cross section measurements (reaction (a)) see (1982AJ01, 1986AJ04).

54. (a) $^{16}\text{O}(^{12}\text{C}, ^{12}\text{C})^{16}\text{O}$
 (b) $^{16}\text{O}(^{12}\text{C}, \alpha^{12}\text{C})^{12}\text{C}$ $Q_{\text{m}} = -7.16195$

Angular distributions have been reported at many energies to $E(^{16}\text{O}) = 1503$ MeV [see (1982AJ01, 1986AJ04)] and recently at $E(^{16}\text{O}) = 49.14$, 48.14 , 48.06 MeV (1986BA80). A peak in the excitation function at $E_{\text{c.m.}} = 33.5$ MeV was observed by (1990KO1X). See also the review of (1986BA1D) and analyses of (1988BR04, 1988RO01, 1989VI09). Many of the studies of this reaction have involved yield and cross section measurements, as they apply to compound structures in ^{28}Si , fusion cross sections and evaporation residues. See (1990SN1A). Some involve multinucleon transfer. Others involve fragmentation of the incident particle. See (1982AJ01, 1986AJ04) and (1986GA13, 1986IK03, 1986SU1G, 1987SU03, 1988KO17, 1988SZ02, 1990BO1X). See also (1986CH41, 1986DE40, 1986SN1B, 1986WU03, 1987HO1C, 1987NA1C, 1987YO1A, 1988BR1N, 1988CAZV, 1988KR11, 1988ME1H, 1989BEZC, 1989KRZX, 1989SU1I, 1989WE1E, 1990BA1Z).

At $E(^{16}\text{O}) = 100$ MeV members of the $K^{\pi} = 0^{+}$ [$^{16}\text{O}^*(6.05, 6.92, 10.35, 16.3)$] and $K^{\pi} = 0^{-}$ bands [$^{16}\text{O}^*(9.63, 11.60, 14.67)$] are reported to be preferentially populated. In reaction (b), as well as in the scattering of 140 MeV ^{16}O on ^{13}C and ^{28}Si , $^{16}\text{O}^*$ states (9.83, 10.33, 11.04, 11.47, 11.98, 12.38, 13.81, 14.75, 15.33, 17.76), with $J^{\pi} = 2^{+}, 4^{+}, 4^{+}, 2^{+}, 0^{+}, 1^{-}, 2^{+}, 4^{+}, 6^{+}, 3^{-}$, respectively, for the first ten states, are populated: the state at 11.5 MeV is preferentially populated [see references in (1982AJ01, 1986AJ04)]. For pion emission see (1986AJ04, 1988SA31, 1989LE12).

(1987BA50) have investigated the two-proton correlation function using the BUU (semiclassical transport equations) model with conserved total momentum. Experimental features of the correlation function are reproduced. (1988BA43) study the energy dependence of the real part of the nucleus-nucleus potential using a modified Seyler-Blanchard two-body effective interaction containing density and momentum dependence. (1987BRZW) perform an optical model analysis of $^{12}\text{C}-^{12}\text{C}$ and $^{16}\text{O}-^{12}\text{C}$ elastic scattering from $10-94$ MeV; real part: double folding of a density dependent M3Y interaction — imaginary part: phenomenological.

(1988BR20) examine dips in the far-side cross sections which reduce or eliminate potential ambiguities from analyses as in (1987BRZW). (1988BR29) analyzed elastic data at 9 to 120 MeV per nucleon using a folded potential based on the density and energy-dependent DDM3Y interaction. (1987DA02) present a solution to the inversion problem (i.e., obtaining potentials from data) and apply it to $^{16}\text{O} + ^{12}\text{C}$ at 1503 MeV with good results. A microscopic calculation of pion-production in heavy-ion collisions is applied (1986DE15) to coherent pion-production in $^{16}\text{O} + ^{12}\text{C}$ collisions. Effects of Pauli blocking and a surface contribution to the optical potential are investigated by (1989EL01). Data require that a collective surface contribution be added to the volume part.

(1988FR14) resolve optical potential model ambiguities by using dips in far side cross section data along with other special features of the angular distributions of elastic scattering data.

(1986HA13) performed a barrier penetration calculation of heavy-ion fusion cross sections, valid both above and below the Coulomb barrier. (1986KA1B) survey projectile breakup processes using the method of coupled discretized continuum channels. An optical model potential containing a parity dependence which accounts for elastic α -particle transfer can explain the oscillations seen in the total fusion excitation function of ^{16}O on ^{12}C (1988KA13). (1988KO27) perform an optical model analysis of ^{16}O scattering data at $E/A = 94$ MeV. They explored potential shapes more general than folded or Woods-Saxon; no improvement in agreement with data. (1989LE23) analyzed reaction data using an eikonal approach. They input only the densities and transition densities of the nuclei and elementary nucleon-nucleon scattering amplitudes. Good agreement with data was obtained. The $^{12}\text{C} + ^{16}\text{O}$ internucleus potential is calculated with the use of Skyrme type forces by (1990WA01).

(1989MI1K) calculate zero-degree and transverse energy for relativistic collisions. Results fit data very well. Low energy optical potentials are derived (1987PA24) from effective interactions using double-folding. Only the effective interaction of Satchler and Love give good results over a wide energy range. (1988RA1G) explores the relationship between clustering and shell effects, and find that this relationship is a close one. (1986SA1D) perform a microscopic coupled-channels calculation. Breakup and virtual breakup effects are found to be important. (1987SC34) present an expression for the real part of the nucleus-nucleus potential (energy dependent) which arises in the framework of the elastic model for heavy-ion fusion. This model is applied to sub-barrier fusion. (1988WU1A) propose a non-compact group model to describe quasi-molecular nuclei.

55. (a) $^{16}\text{O}(^{13}\text{C}, ^{13}\text{C})^{16}\text{O}$
 (b) $^{16}\text{O}(^{14}\text{C}, ^{14}\text{C})^{16}\text{O}$

For elastic scattering studies see Table 16.23 in (1982AJ01), and see the more recent work at $E_{\text{c.m.}} = 48.06, 48.48, 49.14$ MeV (1986BA80), and $E_{\text{c.m.}} = 19\text{--}30$ MeV (1989FR04). For fusion cross sections see (1986AJ04) and recent work at $E_{\text{c.m.}} = 7.8\text{--}14.6$ MeV (1986PA10). See also the review of (1986ST1A). For the excitation of a number of states in ^{16}O in reaction (a) see (1986AJ04). Cross sections for different exit channels of $^{16}\text{O} + ^{13}\text{C}$ at $E_{\text{c.m.}} = 4.8\text{--}9.8$ MeV were measured by (1991DA05). Emission ratios for pn to d and α pn to α d were studied in (1986GA13). Competition between p2n, dn, and t emission was studied at $E_{\text{c.m.}} = 10\text{--}16$ MeV (1990XE01). For reaction (b) a search for resonances in elastic scattering at $E_{\text{lab}} = 38\text{--}54$ MeV is reported in (1990AB07).

(1987DA34) performed a six-parameter optical model analysis of $^{13}\text{C}(^{16}\text{O}, ^{16}\text{O})^{13}\text{C}$. A two-center shell model is applied (1987NU02) to the $^{13}\text{C} + ^{16}\text{O}$ system. Parity dependence of collisions between p- and sd-shell nuclei is studied (1986BA69) microscopically in the two-center harmonic oscillator model.

56. (a) $^{16}\text{O}(^{14}\text{N}, ^{14}\text{N})^{16}\text{O}$
 (b) $^{16}\text{O}(^{15}\text{N}, ^{15}\text{N})^{16}\text{O}$

For elastic scattering studies see (1986AJ04) and Table 16.23 in (1982AJ01) and (1977AJ02). Recent measurements on reaction (b) at $E_{\text{lab}} = 30\text{--}70$ MeV were reported in (1986HA1F). For yield and total fusion cross-section measurements see (1982AJ01, 1986AJ04). See also (1986BA69).

57. $^{16}\text{O}(^{16}\text{O}, ^{16}\text{O})^{16}\text{O}$

The angular distributions for elastic scattering have been measured with $E(^{16}\text{O})$ up to 140.4 MeV [see (1982AJ01, 1986AJ04)] and recently at $E_{\text{c.m.}} = 17$ MeV (1987TI01), $E(^{16}\text{O}) = 350$ MeV (1989ST08) and $E(^{16}\text{O}) = 38$ MeV/nucleon (1986BR25). Inelastic scattering studies involving $^{16}\text{O}^*(6.05) [J^\pi = 0^+]$ (1989ZUZZ) are reported at $E(^{16}\text{O}) = 51.0$ to 76.0 MeV, and similar studies involving $^{16}\text{O}^*(6.13) [J^\pi = 3^-]$ (1988PAZZ) are reported at $E_{\text{c.m.}} = 26.5\text{--}43.0$ MeV. Coupled channels effects are important at energies a few times the Coulomb barrier (1977AJ02, 1986AJ04). Intermediate and compound structure studies are described in (1986GA10, 1986GA24).

For yield and fusion cross sections see (1982AJ01, 1986AJ04) and more recent work (1986IK03, 1986TH1A, 1987GO30, 1987KU02, 1988AU03). At $E(^{16}\text{O}) = 72$ MeV, (1988AU1A) see no evidence for a low- ℓ fusion window. At $E(^{16}\text{O}) = 70\text{--}130$ MeV measurements of evaporation residues by (1986IK03) find no evidence for a low- ℓ cutoff. For a study of α -transfer at near-barrier energies see (1986CA24). Light-particle emission at $E(^{16}\text{O}) = 25$ MeV/nucleon was studied by (1986CH27). Related work includes an investigation of the role of isospin in the statistical decay of the GDR by (1986HA30) and the review of hot nuclear matter (1989SU11). See also (1989FE1F, 1989SC11).

(1988AS03) evaluate the influence of the Uehling potential on subbarrier fusion. (1987GO19) report a calculation of the fusion cross section using a classical microscopic equations of motion approach. (1987LO01) study the effect of elastic transfer process on sub-barrier fusion reactions between similar nuclei. (1987OH08) show that internal and barrier waves based on a semiclassical picture can account for the oscillations seen in fusion excitation functions. (1987RA28) use statistical theory to study the behavior of high spin states formed in fusion reactions. (1987SP11) calculate the fusion excitation function using the one-body wall friction.

(1987TO10) investigate the influence of nucleon-nucleon collisions in the low angular momentum limit for fusion predicted by TDHF. A relativistic mean-field model consisting of nucleons coupled to scalar and vector mesons is used to solve the time-dependent mean-field equations. A relativistic Vlasov equation derived from mean field theory is applied in (1990JI1C). An extended TDHF theory has been used (1989GO1F) to study mass fluctuations in deep-inelastic collisions. Results show differences from conventional TDHF calculations (1987BA10). (1988RE1A) performed TDHF calculations of $^{16}\text{O} + ^{16}\text{O}$ using various Skyrme forces. (1986TO14) calculate subthreshold pion-production using the TDHF formalism, and compare their findings with data. (1986UM02) study fusion of $^{16}\text{O} + ^{16}\text{O}$ using TDHF and Skyrme forces. See also the study of (1990SL01).

(1986CH44) perform an optical model analysis of elastic scattering data using a calculated real part of the potential. The potentials are constructed in the energy density formalism with nuclear density distributions obtained in the framework of the method of hyperspherical functions.

(1989DA1C) develop a simple theory of a heavy-ion optical model potential. Colliding ions are described as two slabs of nuclear matter, with energy densities from properties of nuclear matter. (1986FA1A) extend and refine the calculation of the real and imaginary parts of the optical model potential in the 20–100 MeV/nucleon range. Techniques for choosing a unique potential are discussed in (1990KO18). See also (1990RE1E). (1988NA10) calculate microscopic nucleus-nucleus potentials using the energy-density formalism. See also (1991MA29). (1987PA24) derive real parts of the low-energy optical potential using the double-folding model. Pauli exchange effects within this model are studied in (1991KH08). A semiclassical method for calculating elastic scattering cross sections was used in (1991SA20).

(1989HU1C) combine the concepts from a partition temperature model and the wounded nucleon model to describe high-energy nucleus-nucleus collisions. (1988IT03) have applied coupled equations which treat the relative motion and internal excitation simultaneously to the case of $^{16}\text{O} + ^{16}\text{O}$ at intermediate energies. (1987KA04) study subthreshold pion production mechanisms for $^{16}\text{O} + ^{16}\text{O}$ at 40 and 80 MeV/nucleon. A quantum transport equation with two-body collisions included via a relaxation-time method is applied to $^{16}\text{O}-^{16}\text{O}$ collisions between 40 and 200 MeV/nucleon (1988KO02). (1988KO09) compare predictions of momentum dependence of nucleus-nucleus interactions deduced from various models. (1989KO23) describe resonant phenomena in $^{16}\text{O} + ^{16}\text{O}$ in terms of an ion-ion potential. (1988MA10) solve the inverse scattering problem for fixed angular momentum using E -dependent phases and a Povzner-Levian representation of the wave function. Adiabatic bound and Gamow states have been calculated (1986MI22) in a realistic two-center potential. Specific results for a neutron in a $^{16}\text{O} + ^{16}\text{O}$ potential are presented. (1985SH1A) develop a microscopic approach to describe elastic and inelastic cross sections. They employ the quasiparticle phonon model for heavy ions and resolve the “fusion-window-anomaly”. The resonating group method is used by (1988WA31) to investigate constituent components of the $^{16}\text{O}-^{16}\text{O}$ exchange potential. A two-center shell model description is discussed in (1990KH04).

58. (a) $^{16}\text{O}(^{17}\text{O}, ^{17}\text{O})^{16}\text{O}$
 (b) $^{16}\text{O}(^{18}\text{O}, ^{18}\text{O})^{16}\text{O}$

Angular distributions of elastically scattered ions have been studied at $E(^{16}\text{O}) = 24, 28$ and 32 MeV and $E(^{17}\text{O}) = 53.0$ to 66 MeV, $E(^{17}\text{O}) = 22$ MeV (reaction (a)) and at $E(^{16}\text{O}) = 24$ to 54.8 MeV and $E(^{18}\text{O}) = 35$ to 89.3 MeV (reaction (b)) [see (1982AJ01, 1986AJ04)]. Yields and fusion cross sections are reported in (1982AJ01, 1986AJ04). See also the studies on light-particle emission ratios in these reactions (1986GA13, 1990XE01).

(1987IMZZ) have studied the effects of rotational couplings by using the rotating molecular orbitals model. (1987IM1C) develop and use a formalism for dynamical treatment of the molecular orbitals of valence nucleons in nucleus-nucleus collisions. (1988IM02) consider the role of rotational coupling interactions in the transition between nucleon molecular orbitals. (1987MA22) use the semiclassical approach including both one- and two-step contributions to calculate the two-particle elastic transfer reaction, while (1988KA39) calculate differential cross sections for transfer

of two neutrons taking Coulomb effects into account in a four-body model. (1986MI22) use a realistic two-center potential to show that a substantial fraction of the particle emission comes from sequential decay of the excited fragments after separation, and (1986VI08) consider two-particle exchange reactions using a parity-dependent optical potential.

59. (a) $^{16}\text{O}(^{19}\text{F}, ^{19}\text{F})^{16}\text{O}$
 (b) $^{16}\text{O}(^{20}\text{Ne}, ^{20}\text{Ne})^{16}\text{O}$

Elastic scattering angular distributions have been studied at $E(^{16}\text{O}) = 21.4$ and 25.8 MeV and at $E(^{19}\text{F}) = 33$ and 36 MeV: see (1977AJ02). Angular distributions in reaction (b) have been measured at $E(^{16}\text{O}) = 40.7$ to 94.8 MeV, 25.6 to 44.5 MeV, 44.1 to 63.9 MeV [see (1986AJ04)], 60 – 80 MeV (1986FUZV), and at $E(^{20}\text{Ne}) = 50$ MeV (1986AJ04). Recent excitation functions were measured for reaction (b) at $E_{\text{c.m.}} = 21.5$ – 31.2 MeV (1988HE06). See also (1989SA14). For yield and fusion cross section measurements see (1986AJ04). Projectile breakup studies are reported at 3.6 GeV/nucleon. See also (1987AN1C). Hyperon production is investigated in (1986FUZV, 1988BO46). See also (1986HE1A, 1988BE2A).

(1986FU1C) discuss ways of accounting for the phase anomaly between elastic and inelastic scattering of $^{19}\text{F} + ^{16}\text{O}$. (1989GA05) derive a parity-dependent potential for $^{16}\text{O} + ^{20}\text{Ne}$.

60. (a) $^{16}\text{O}(^{23}\text{Na}, ^{23}\text{Na})^{16}\text{O}$
 (b) $^{16}\text{O}(^{24}\text{Mg}, ^{24}\text{Mg})^{16}\text{O}$
 (c) $^{16}\text{O}(^{25}\text{Mg}, ^{25}\text{Mg})^{16}\text{O}$
 (d) $^{16}\text{O}(^{26}\text{Mg}, ^{26}\text{Mg})^{16}\text{O}$

Elastic angular distributions are reported at $E(^{16}\text{O}) = 35$ to 60.7 MeV (reaction (b)) and 27.4 to 50 MeV (reaction (d)) [see (1982AJ01)] and $E(^{16}\text{O}) = 150$ MeV (1986AJ04; reaction (b); elastic). More recent work on reaction (b) includes elastic scattering excitation function measurements at $E_{\text{c.m.}} = 31.6$ – 45.2 MeV (1986DR11, 1986DR1B) and inelastic measurements at $E_{\text{c.m.}} = 33.6$ – 49.2 MeV (1986NU01, 1986NU1A) and at $E_{\text{c.m.}} = 64$ – 88 MeV (1986PE1G). Orbiting cross sections for reaction (b) are reported in (1989BLZZ). For yield, evaporation residue and fusion measurements, see references in (1982AJ01, 1986AJ04).

(1988AL06) show that algebraic scattering theory provides a simple yet detailed description of the complex coupled channels problem ($^{16}\text{O} + ^{24}\text{Mg}$). (1989FI03) calculate the effect of the dynamic α -transfer potential on several channels of the $^{24}\text{Mg} + ^{16}\text{O}$ systems. (1987NA13) obtain an energy and angular momentum-dependent polarization potential from a compound nucleus level density dependent imaginary potential. They find that the elastic and fusion cross sections of $^{16}\text{O} + ^{24}\text{Mg}$ are hardly affected by this potential.

61. $^{16}\text{O}(^{27}\text{Al}, ^{27}\text{Al})^{16}\text{O}$

An elastic angular distribution has been measured at $E(^{16}\text{O}) = 46.5$ MeV: see (1982AJ01). For yield, fusion and evaporation residue studies see (1982AJ01, 1986AJ04) and (1987IK01, 1988KO01, 1989CA14, 1989DE02, 1990KR1D). See also (1986BR26, 1987DEZV). For fragmentation studies see (1986AJ04) and (1986SH1F, 1987SH1C, 1987SH23, 1988AI1C, 1988BR1N, 1988SH1H, 1989CA14, 1989YI1A, 1990PAZW). For work on deeply inelastic collisions see (1986AJ04) and (1987SH21). For pion production see (1986AJ04) and (1987HU1C, 1988BA21, 1988JU02, 1989FO07). For total reaction cross sections see (1987KO12). Angular correlations have been studied at $E(^{16}\text{O}) = 65\text{--}65.6$ MeV (1986AJ04) and at $E(^{16}\text{O}) = 82.7$ MeV (1988SH1H), at 215 MeV (1990KR14), at $E_{\text{c.m.}} = 80\text{--}250$ MeV (1988DE1A, 1989DE02), and at $E(^{16}\text{O}) = 4\text{--}5$ MeV/nucleon (1987CA1E). The sequential decay of $^{16}\text{O}^*(10, 11.6, 13.2, 15.2, 16.2, 21)$ is reported via α_0 [see (1986AJ04)].

(1987BA01) evaluate the energy dependence of the real part of the nucleus-nucleus potential using two-body effective interactions, calculate $^{16}\text{O} + ^{27}\text{Al}$, and compare to data. (1989CA11) introduce “pre-equilibrium” temperature to describe the thermodynamics of nuclear systems prior to equilibrium. (1988DA11) modify the coalescence model for complex-particle emission by correcting for the Coulomb barrier and the ejectile’s binding energy.

62. (a) $^{16}\text{O}(^{28}\text{Si}, ^{28}\text{Si})^{16}\text{O}$

(b) $^{16}\text{O}(^{29}\text{Si}, ^{29}\text{Si})^{16}\text{O}$

(c) $^{16}\text{O}(^{30}\text{Si}, ^{30}\text{Si})^{16}\text{O}$

(d) $^{16}\text{O}(^{31}\text{P}, ^{31}\text{P})^{16}\text{O}$

Angular distributions for reaction (a) have been reported at $E(^{16}\text{O}) = 29.3$ to 215.2 MeV [see (1982AJ01, 1986AJ04)], and recently at $E(^{16}\text{O}) = 94$ MeV/nucleon (1987RO04). Elastic angular distributions for reactions (b) and (c) are reported at $E(^{16}\text{O}) = 60$ MeV (1986AJ04). For yield, fusion cross section and evaporation residue measurements see (1982AJ01, 1986AJ04). See also (1986BL08). For a crystal-blocking measurement of time delays in reaction (a) see (1989MA23). For pion production see (1986AJ04).

(1988AL08) obtain expressions for the elastic S -matrix which include effects of the coupling to α -transfer channels to all orders. They study $^{16}\text{O} + ^{28}\text{Si}$ at 180° . (1988AS03) evaluate the influences of the Uehling potential on sub-barrier fusion and obtain noticeable modifications of the barrier penetrability. (1986BR11) study the E -dependence of an optical potential which fits all $^{16}\text{O} + ^{28}\text{Si}$ elastic data for $E = 54.7\text{--}215.2$ MeV. (1986HO18) employ a fixed energy potential inversion method to generate an optical model potential which fits $^{16}\text{O} + ^{28}\text{Si}$ elastic scattering data at 34.8 MeV. (1986BR19) create a deformed optical potential consistent with calculations based on nuclear structure information which fits $^{16}\text{O} + ^{28}\text{Si}$ scattering and fusion data. (1986BR23) use an optical model with repulsive core and coupled channels method to describe $^{16}\text{O} + ^{28}\text{Si}$ scattering data at large angles for $E = 29\text{--}35$ MeV. (1988CH28) use a Monte Carlo simulation to calculate the

nucleon transfer part of the imaginary optical-model potential. (1987HU11) find good agreement with back angle elastic data in $^{16}\text{O} + ^{28}\text{Si}$ by including a derived α -transfer polarization potential. (1990DE35) employ a multistep α -transfer treatment to study back angle scattering of $^{16}\text{O} + ^{28}\text{Si}$. (1985KH10) use a conventional optical model potential for $E_{\text{lab}} = 33.16\text{--}55$ MeV. They parameterize the S -matrix in terms of Regge poles and look at semiclassical features. (1985KR1A) show that existing data do not allow one to draw conclusions about the relevance of Regge poles in $^{16}\text{O} + ^{28}\text{Si}$. (1989MA08) use elastic phase shifts obtained by the algebraic approach to scattering theory in a fixed energy inversion procedure. Results point to an underlying nonlocal interaction. (1987NA13) show that the elastic and fusion cross sections are hardly affected by a strongly attractive real-polarization-potential. (1987VA03) have applied a fast algorithm-based method for performing unconstrained phase-shift analyses to $^{16}\text{O} + ^{28}\text{Si}$ at 21.1 MeV ($E_{\text{c.m.}}$). (1987XI01) formulate a molecular orbit theory for the 3α -transfer process and apply it to $^{16}\text{O} + ^{28}\text{Si}$ for $E = 18.67\text{--}34.80$ MeV, and compare it to data.

63. (a) $^{16}\text{O}(^{40}\text{Ca}, ^{40}\text{Ca})^{16}\text{O}$
 (b) $^{16}\text{O}(^{42}\text{Ca}, ^{42}\text{Ca})^{16}\text{O}$
 (c) $^{16}\text{O}(^{44}\text{Ca}, ^{44}\text{Ca})^{16}\text{O}$
 (d) $^{16}\text{O}(^{48}\text{Ca}, ^{48}\text{Ca})^{16}\text{O}$
 (e) $^{16}\text{O}(^{48}\text{Ti}, ^{48}\text{Ti})^{16}\text{O}$

Elastic angular distributions are reported on ^{40}Ca at $E(^{16}\text{O}) = 50$ to 214.1 MeV [see (1982AJ01, 1986AJ04) and recently at $E(^{16}\text{O}) = 94$ MeV/nucleon (1988RO01)]. Elastic angular distributions were reported at $E(^{16}\text{O}) = 60$ MeV ($^{42,44}\text{Ca}$; also inelastic distributions) and 150 MeV [see (1986AJ04)]. Similar measurements have been reported for ^{48}Ca at $E(^{16}\text{O}) = 60$ MeV [see (1982AJ01)] and at 56 MeV (1986AJ04; also $^{48}\text{Ca}^*$) and 158.2 MeV (1986AJ04; also $^{48}\text{Ca}^*$). Yield, fusion cross section and evaporation residue measurements are reported in (1982AJ01, 1986AJ04) and by (1986SA25, 1987BEZY, 1987BR20, 1987HI10, 1988KO1U, 1989BE17). See also (1986GU1C). For a measurement of the total non-fusion reaction cross section at $E(^{16}\text{O}) = 158.2$ MeV (reaction (d)) see (1986AJ04). For a study of deep inelastic collisions at 142 MeV (reaction (d)) and for reaction (e) see (1986AJ04).

A microscopic study of the $^{16}\text{O} + ^{40}\text{Ca}$ potential is discussed in (1986WAZM). (1986AN18) calculate angular distributions for elastic scattering using a simple prescription for the part of the imaginary potential arising from inelastic processes and a folding expression for the real part of the potential, and fit it to the data. (1986CH20) perform a microscopic optical model analysis using folding and realistic NN interactions (direct and exchange terms). They compare their results to data. (1986CH38) calculate the real part of the optical model potential in a folding approximation using the density dependent M3Y interaction in factorized form. They also compare their results to data. (1989DA1C) describe colliding nuclei as two slabs of nuclear matter. Energy density is derived from properties of nuclear matter. (1989ES07) obtain good agreement with elastic and inelastic data using a coupled-channels treatment. (1987GR04) study peripheral reactions. Neutrons

and protons behave separately in an effective mean field. They find a transition between incomplete deep inelastic processes and fragmentation reactions near 35 MeV/nucleon. (1986HA13) calculate barrier penetrations with Coulomb included. They obtain good agreement with data in the above and sub-barrier fusion regions. (1989HO10) calculated heavy-ion fusion reactions with a macroscopic model proposed by Bertsch. They give a good account of the fusion cross section up to very high energies. (1987DA23) develop a semi-microscopic model of elastic and inelastic scattering with a full finite range NN interaction. They also study the role of NN exchange correlations. The real and imaginary potentials have been derived (1987VI04) in a model which includes a large set of non-elastic channels. (1988PA20) calculate the particle transfer flux between two scattering nuclei from the time-dependent single-particle wave functions in the field of two moving potential pockets. They deduce the absorptive potentials which compare well with phenomenological ones. (1989SU05) study the excitation of the GDR within the framework of the Landau-Vlasov equation. They analyze the GDR excited in peripheral $^{16}\text{O} + ^{40}\text{Ca}$ reactions at $E = 5$ MeV/nucleon.



The beta-delayed proton emission in the ^{17}Ne decay has been studied by (1988BO39). See Tables 17.16 and 17.27. The half life is measured to be $T_{1/2} = 109.3 \pm 0.6$ ms.



See (1986AJ04, 1989OR07, 1990MC06) and ^{17}O .



Angular distributions for the ground state deuteron group have been studied at $E_{\text{p}} = 8.62$ to 11.44 MeV. At $E_{\text{p}} = 31$ MeV, angular distributions are reported for the deuterons corresponding to $^{16}\text{O}^*(0, 6.05 + 6.13, 7.12, 8.87, 10.36, 12.97, 13.26)$. States at $E_{\text{x}} = 15.22$ and 15.42 MeV were also observed. Spectroscopic factors were obtained from a DWBA analysis: see (1977AJ02, 1986AJ04). See also (1989DE1P, 1989OB1B).



Differential cross sections and analyzing powers for the reaction were measured at $E_{\text{d}} = 89$ MeV by (1990SA27) and summarized in Table 16.28. Earlier information obtained at $E_{\text{d}} = 52$ MeV is displayed in Table 16.20 of (1986AJ04). As discussed there, comparison of the (d, t)

and (d, ^3He) reactions leads to assignments of analog states in ^{16}N and in ^{16}O [see Table 16.10 in (1982AJ01)]. A study of this reaction, the (d, ^3He) reaction, and reaction 67 [$^{17}\text{O}(^3\text{He}, \alpha)^{16}\text{O}$] below, suggests that there is more than 17% isospin mixing of the 2^- states in $^{16}\text{O}^*(12.97, 12.53)$: the corresponding mixing matrix element is $\geq 155 \pm 30$ keV. An isospin mixing matrix element of 110 ± 10 keV for the 4^- states of $^{16}\text{O}^*(17.79, 18.98, 19.80)$ is compatible with the results from this reaction and with pion scattering (1986AJ04). See also reaction 44 [$^{16}\text{O}(\pi^\pm, \pi^\pm)^{16}\text{O}$].

$$68. \ ^{17}\text{O}(^3\text{He}, \alpha)^{16}\text{O} \quad Q_m = 16.4341$$

Angular distributions have been reported at $E(^3\text{He}) = 11$ MeV [see (1977AJ02)], at $E(^3\text{He}) = 14$ MeV (α_0) and at $E(^3\text{He}) = 33$ MeV (to many states of ^{16}O) [see (1986AJ04)]. Table 16.28 displays some of the information derived from this reaction. For polarization measurements see (1986AJ04) and ^{20}Ne in (1983AJ01, 1987AJ02). See also (1982AJ01).

$$69. \ ^{18}\text{O}(\pi^+, \text{d})^{16}\text{O} \quad Q_m = 130.3863$$

See (1986AJ04).

$$70. \ ^{18}\text{O}(\text{p}, \text{t})^{16}\text{O} \quad Q_m = -3.7061$$

Angular distributions of tritons have been measured for $E_p = 43.7$ MeV [see (1982AJ01)] and at $E_p = 90$ MeV (1986VO10) (to $^{16}\text{O}^*(6.1, 6.92, 7.12, 9.84, 13.26, 16.35)$): see also (1985BLZY). It is noted in (1986VO10) that the 16.35 MeV state may be the (0^+ , 1^- , 2^+) multiplet at $E_x = 16.35$ and 16.144 MeV (1982AJ01). The population of $^{16}\text{O}^*(22.7, 24.5)$ is consistent with $L = 0$ and 2, respectively, and with assignments of $T = 2$, $J^\pi = 0^+$ and 2^+ . The decay of $^{16}\text{O}^*(22.7)$, J^π ; $T = 0^+$; 2, is via α_0 , α_1 and α_2 [$^{12}\text{C}^*(0, 4.4, 7.7)$] with (1.6 ± 0.7) , (1.9 ± 0.7) and $(14 \pm 2)\%$ branches and Γ_i (eV) = 190 ± 100 , 230 ± 110 and 1680 ± 550 eV, respectively; via p_0 , p_{1+2} , p_3 with (7 ± 2) , (11 ± 2) and $(5 \pm 2)\%$ branches and Γ_i (eV) = 840 ± 343 , 1320 ± 454 and 600 ± 300 eV; and via n_{1+2} with a $(23 \pm 15)\%$ branch [$\Gamma_n = 2760 \pm 1970$ eV] (the n_0 branch is $< 15\%$) [Γ_i are based on a total width of 12 ± 3.5 keV]. See (1986AJ04). See also (1982AJ01) and ^{19}F in (1987AJ02).

$$71. \ ^{18}\text{O}(\alpha, ^6\text{He})^{16}\text{O} \quad Q_m = -11.213$$

Angular distributions have been measured at $E_\alpha = 58$ MeV to $^{16}\text{O}^*(0, 6.1, 6.92, 7.12)$. Groups at $E_x = 10.4$, 13.3 ± 0.1 and 16.3 ± 0.1 MeV were also observed: see (1977AJ02, 1986AJ04).

Table 16.28: States in ^{16}O from $^{17}\text{O}(\text{d}, \text{t})$ and $^{17}\text{O}({}^3\text{He}, \alpha)$

E_x^a (MeV \pm keV)	$J^\pi; T$	l^a	j^a	C^2S^a	$(d\sigma/d\Omega)_{\text{max}}^a$ $\mu\text{b/sr}$	l^c	S^c
0.000	$0^+; 0$	2	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	1.034 ± 0.084	1736 ± 21.9	2	0.88
6.045 ± 8	$0^+; 0$	2	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.016 ± 0.004	17.9 ± 2.2	2	0.009
6.131 ± 3	$3^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.578 ± 0.137	527 ± 21.9	1^d	0.37
6.913 ± 4	$2^+; 0$	(2)	$\left(\frac{1}{2}\right)$	(0.030 ± 0.004)	78.9 ± 11.9	$(2+0)$	0.022
7.115 ± 3	$1^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.055 ± 0.006	39.2 ± 3.2	$(3+1)$	0.007
8.870 ± 3	$2^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.335 ± 0.086	289 ± 24.0	1^d	0.26
9.841 ± 6	$2^+; 0$	2	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.137 ± 0.048	12.9 ± 2.7	2	0.025
10.354 ± 3	$4^+; 0$	(2)	$\left(\frac{1}{2}\right)$	(0.016 ± 0.004)	19.9 ± 3.5	2	0.025
10.955 ± 9	$0^-; 0$				6.7 ± 3.4	$(3+1)$	0.008
11.08^b	$3^+; 0$					2	0.044 or 0.086
11.095 ± 6	$4^+; 0$				26.1 ± 5.3		
11.525 ± 9	$2^+; 0$				20.0 ± 18.5		
12.528 ± 6	$2^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.234 ± 0.046	53.5 ± 22.3		
12.782 ± 23	$0^-; 1$			0.036 ± 0.015	29.8 ± 5.0		
12.971 ± 3	$2^-; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.396 ± 0.101	356 ± 22.2	1^d	0.38
13.09^b	$1^-; 1$					1	0.1
13.148 ± 14	$3^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.058 ± 0.019	62.1 ± 17.0		
13.256 ± 3	$3^-; 1^b$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.019 ± 0.012	335 ± 21.9	1^d	0.34
13.857 ± 30	$4^+; 0$	(2)	$\left(\frac{1}{2}\right)$	(0.015 ± 0.003)	10.3 ± 4.6		
13.979 ± 17	2^-	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.016 ± 0.004	11.9 ± 4.7		
14.313 ± 18	$4^{(-)}$				24.1 ± 9.2		
14.409 ± 11	5^+				7.8 ± 6.2		
15.195 ± 32	$2^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.106 ± 0.030	38.4 ± 16.8	d	
15.414 ± 6	$3^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.242 ± 0.038	76.3 ± 16.7	d	
16.808 ± 11	$3^+; 1$	(2)	$\left(\frac{1}{2}\right)$	(0.015 ± 0.005)	72 ± 4.3		
17.776 ± 11	$4^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.089 ± 0.045	48.3 ± 13.2	d	$(\Gamma < 50 \text{ keV})^b$
18.027 ± 7	$3^{(-)}; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.102 ± 0.023	76.1 ± 20.8		
18.483 ± 17	$1^-; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.129 ± 0.028	94.6 ± 26.0	d	
18.978 ± 7	$4^-; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.706 ± 0.065	502 ± 11.2	d	
19.210 ± 14	$3^-; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.338 ± 0.036	227 ± 9.9	d	$\Gamma = 68 \pm 10 \text{ keV}^b$
19.806 ± 11	$4^-; 0$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.423 ± 0.116	281 ± 127	d	$\Gamma = 36 \pm 5 \text{ keV}^b$
20.481 ± 8	$2^-; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.015 ± 0.018	65.3 ± 10.0	d	
				0.144 ± 0.029			
20.922 ± 30	$1^-; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.032 ± 0.009	15.6 ± 5.6		
22.857 ± 60	$1^-; 1$	1	$\frac{1}{2} \frac{3}{2} \frac{5}{2} \frac{7}{2} \frac{9}{2}$	0.109 ± 0.023	50.0 ± 12.4		

^a $^{17}\text{O}(\text{d}, \text{t})$; $E_d = 89 \text{ MeV}$ (1990SA27).

^b See Table 16.20 (1986AJ04).

^c $^{17}\text{O}({}^3\text{He}, \alpha)$; $E({}^3\text{He}) = 11 \text{ MeV}$ (1971BO02).

^d $^{17}\text{O}({}^3\text{He}, \alpha)$; $E({}^3\text{He}) = 33 \text{ MeV}$ (1982KA12).

72. $^{18}\text{O}(^{18}\text{O}, ^{20}\text{O})^{16}\text{O}$ $Q_m = -0.624$

Angular distributions involving $^{16}\text{O}_{\text{g.s.}}$ and ^{20}O states are reported at $E(^{18}\text{O}) = 24$ to 36 MeV and at 52 MeV: see (1982AJ01, 1986AJ04).

73. $^{19}\text{F}(\text{p}, \alpha)^{16}\text{O}$ $Q_m = 8.1137$

Angular distributions have been measured at many energies up to $E_p = 44.5$ MeV [see (1982AJ01)] and $E_p = 1.55$ to 2.03 MeV (α_0, α_1), 1.66 to 1.86 MeV (α_0), 10.0 to 11.4 MeV ($^{16}\text{O}^*(0, 6.05, 6.13, 6.92, 7.13, 8.87, 9.84, 10.36, 10.96, 11.08 + 11.10)$) [see (1986AJ04)]. See also Table 16.31 in (1971AJ02). For a DWBA analysis of data for incident energies below the Coulomb barrier see (1991HE16). A recent measurement of the absolute differential cross section at $E_p = 2$ – 3.4 MeV is reported in (1986OU01). Measurements at $E_p = 1.55$ – 1.64 MeV by (1990AZZY) were used to study resonances corresponding to states in ^{20}Ne . Absolute yields, angular distributions and resonance widths of the 6.13 , 6.92 , and 7.12 MeV photons from the 340.5 keV resonance are reported in (1991CR06). See also (1991MC08) for a study of resonance-yield deconvolution techniques.

The internal conversion to pair production ratio of the E0 transition $^{16}\text{O}^*(6.05 \rightarrow \text{g.s.}) [0^+ \rightarrow 0^+]$ is $(4.00 \pm 0.46) \times 10^{-5}$. The ratio of double γ -emission to pair production $\Gamma_{\text{E1E1}}/\Gamma_{\text{E0}(\pi)} = (2.5 \pm 1.1) \times 10^{-4}$. τ_m for $^{16}\text{O}^*(6.05, 6.13)$ are 96 ± 7 psec and 26.6 ± 0.7 psec, respectively. See (1982AJ01) for references. $|g|$ for $^{16}\text{O}^*(6.13) = 0.556 \pm 0.004$ (1984AS03, 1986AJ04). For γ -ray branching ratios and mixing ratios see Table 16.14 and (1986AJ04).

See also ^{20}Ne in (1983AJ01, 1987AJ02), and see (1986KH1A, 1987KH1A, 1988GN1A, 1988UM1A; applied) and (1988CA26; astrophysics).

74. $^{19}\text{F}(\text{t}, ^6\text{He})^{16}\text{O}$ $Q_m = 0.248$

Differential cross section measurements at $E_t = 38$ MeV are reported in (1992CL04).

75. $^{19}\text{F}(^3\text{He}, ^6\text{Li})^{16}\text{O}$ $Q_m = 4.0954$

See (1977AJ02).

76. $^{19}\text{F}(\alpha, ^7\text{Li})^{16}\text{O}$ $Q_m = -9.233$

See (1988SH1E).

77. (a) $^{20}\text{Ne}(\gamma, \alpha)^{16}\text{O}$ $Q_m = -4.734$
 (b) $^{20}\text{Ne}(p, p\alpha)^{16}\text{O}$ $Q_m = -4.734$

See (1982AJ01, 1986AJ04) and ^{20}Ne in (1983AJ01, 1987AJ02). See also (1989TH1C).

78. $^{20}\text{Ne}(\alpha, 2\alpha)^{16}\text{O}$ $Q_m = -4.734$

See (1988SH05) for a DWBA analysis of differential cross section data at $E_\alpha = 140$ MeV.

79. $^{20}\text{Ne}(d, ^6\text{Li})^{16}\text{O}$ $Q_m = 3.2589$

Angular distributions have been studied at E_d to 80 MeV: see (1982AJ01). At $E_d = 55$ MeV $^{16}\text{O}^*(0, 6.05, 6.13, 6.92, 9.8, 11.10)$ are strongly populated (1986AJ04).

80. $^{23}\text{Na}(d, ^9\text{Be})^{16}\text{O}$ $Q_m = -3.006$

The angular distribution to $^{16}\text{O}_{\text{g.s.}}$ has been measured at $E_d = 13.6$ MeV (1986AJ04).

81. $^{24}\text{Mg}(\alpha, ^{12}\text{C})^{16}\text{O}$ $Q_m = -6.7712$

Angular distributions have been reported at $E_\alpha = 22.8$ to 25.4 MeV and at 90.3 MeV, the latter to $^{16}\text{O}^*(0, 6.1, 7.0, 8.8, 9.8, 10.3)$ [see (1982AJ01)] and at $E_\alpha = 25.1$ to 27.8 MeV (1986AJ04). Excitation functions measured for $E_\alpha = 26 - 37$ MeV at $\theta_{\text{lab}} = 30^\circ, 40^\circ, 60^\circ$ have been reported (1986ESZV, 1989ES06). See also (1987SH1B, 1988SH1F).

82. $^{24}\text{Mg}(^{12}\text{C}, ^{20}\text{Ne})^{16}\text{O}$ $Q_m = -2.150$

The ground state angular distribution has been studied at $E(^{12}\text{C}) = 40$ MeV [see (1986AJ04)]. $^{16}\text{O} + ^8\text{Be}$ breakup of ^{24}Mg following inelastic scattering of ^{24}Mg projectiles on ^{12}C has been reported (1989FU10).

83. $^{28}\text{Si}(^{12}\text{C}, ^{24}\text{Mg})^{16}\text{O}$ $Q_m = -2.822$

Forward-angle yields of ^{16}O measured at $E(^{28}\text{Si}) = 100-170$ MeV have been reported (1986SH25).

84. $^{28}\text{Si}(^{14}\text{N}, ^{16}\text{O})^{26}\text{Al}$ $Q_m = -1.682$

Forward-angle yields of ^{16}O measured at $E(^{28}\text{Si}) = 100-170$ MeV have been reported (1986SH25).

¹⁶F
(Figs. 4 and 5)

GENERAL: See Table 16.29.

- | | |
|--|-------------------------|
| 1. (a) $^{14}\text{N}(^3\text{He}, \text{n})^{16}\text{F}$ | $Q_{\text{m}} = -0.957$ |
| (b) $^{14}\text{N}(^3\text{He}, \text{np})^{15}\text{O}$ | $Q_{\text{m}} = -0.421$ |

Observed neutron groups from reaction (a) and results from reaction (b) are displayed in Table 16.31. A recent measurement of n-p angular correlations from $^{14}\text{N}(^3\text{He}, \text{n})^{16}\text{F}(p)^{15}\text{O}$ is reported in (1986RYZZ).

- | | |
|---|----------------------------|
| 2. $^{15}\text{N}(p, \pi^-)^{16}\text{F}$ | $Q_{\text{m}} = -142.3475$ |
|---|----------------------------|

Measurements of pion spectra with polarized protons at $E_{\text{p}} = 200$ MeV are reported in (1987AZZY). Levels in ^{16}F at 0.39 (2^-), 0.72 (3^-), 5.40, 6.37 (4^-), 7.85, and 11.52 MeV are observed.

- | | |
|--|---------------------------|
| 3. $^{16}\text{O}(\gamma, \pi^-)^{16}\text{F}$ | $Q_{\text{m}} = -154.984$ |
|--|---------------------------|

Angular distributions and photoproduction cross sections vs. energy have been measured for $E_{\text{p}} = 200\text{--}350$ MeV (1987JE02). See also (1986AJ04).

- | | |
|--|--------------------------|
| 4. $^{16}\text{O}(p, \text{n})^{16}\text{F}$ | $Q_{\text{m}} = -16.199$ |
|--|--------------------------|

Observed neutron groups are displayed in Table 16.31. Angular distributions of cross sections and/or polarization observables have been studied at $E_{\text{p}} = 35\text{--}135.2$ MeV (1986AJ04) and recently at $E_{\text{p}} = 35$ and 40 MeV (1987OH04) and at $E_{\text{p}} = 135$ MeV (1989WAZZ). See also (1983WA29). For a comparison of (p, n) cross sections with B(M1) see (1986AJ04). A study of Gamow-Teller strengths is described in (1988MA53). An investigation of $0^+ \rightarrow 0^-$ transitions is discussed in (1986GA31). See also (1989GA26) and the reviews of (1986AN1E, 1986BA78).

- | | |
|--|--------------------------|
| 5. $^{16}\text{O}(^3\text{He}, \text{t})^{16}\text{F}$ | $Q_{\text{m}} = -15.436$ |
|--|--------------------------|

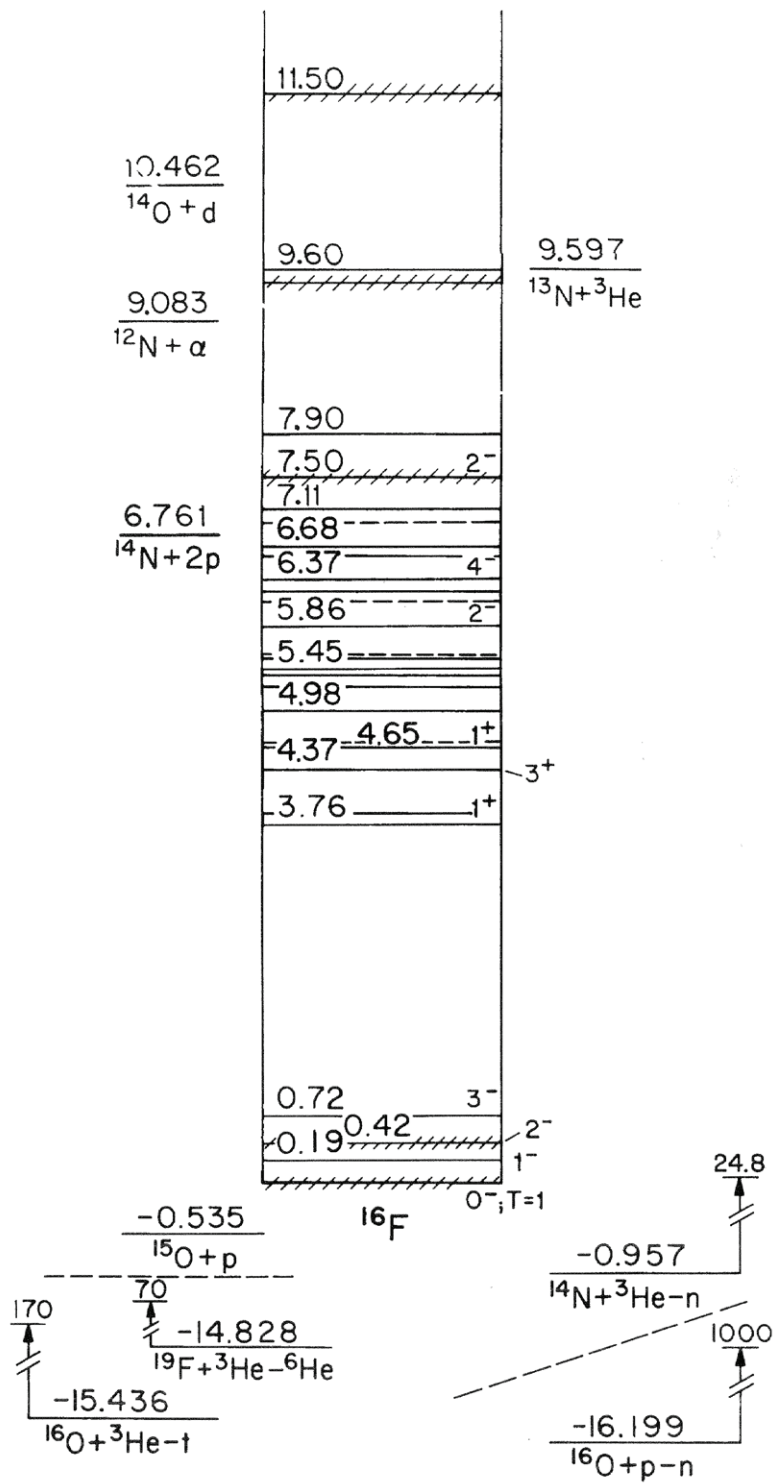


Fig. 4: Energy levels of ^{16}F . For notation see Fig. 2.

Table 16.29: ^{16}F & ^{16}Ne – General

Reference	Description
General	
Reviews:	
1986AN07	Predicted masses & excitation energies in higher isospin multiplets for $9 \leq A \leq 60$
1986BA1C	Pion-nucleus double charge exchange: review of LAMPF workshop
1987GI1C	Pion-nucleus interactions
1988CO15	Thomas-Ehrman shift; charge-symmetric mass relationship calcs. for proton-rich nuclei
Other Articles:	
1986CH39	$\pi\Delta$ interaction mechanism comp. with double charge exchange exp. data on $N = Z$ nuclei
1986GI13	Nuclear-structure aspects of nonanalog pion double charge exchange
1987KA39	Delta-hole approach to pion double charge exchange
1987LE1B	Strong interaction studies via meson-nucleus reactions
1988GO21	Neutron-excessive nuclei & two-proton radioactivity
1988MA27	Non-analog dbl. chrg. exchn. transition: $^{16}\text{O}(\pi^+, \pi^-)^{16}\text{Ne}(\text{g.s.})$ & $^{12}\text{C}(\pi^+, \pi^-)^{12}\text{O}(\text{g.s.})$
1989WI24	Hot proton-proton chains in low-metallicity objects
1990LO11	Self-consistent calculations of light nuclei: binding energies & radii
1990PO04	Determining masses of light nuclides & quantum characteristics of corresponding nucl.

Table 16.30: Energy levels of ^{16}F ^a

E_x (MeV \pm keV)	$J^\pi; T$	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
0	$0^-; 1$	40 ± 20 ^b	p	1, 2, 3, 4, 5, 6, 7
0.193 ± 6	1^-	< 40 ^b	p	1, 4, 5, 7
0.424 ± 5	2^-	40 ± 30	p	1, 4, 5, 7
0.721 ± 4	3^-	< 15	p	1, 4, 5, 7
3.758 ± 6	1^+	< 40	p	1, 4, 5, 7
3.870 ± 6	2^+	< 20	p	1, 4, 5, 7
4.372 ± 6	3^+	50 ± 20	p	1, 4, 5, 7
4.654 ± 6	1^+	60 ± 20	p	1, 4, 5, 7
(4.71 ± 20)				7
4.977 ± 8	(2^+)	60 ± 40	p	1, 5, 7
5.272 ± 8	(1^-)		p	1, 4, 5
5.404 ± 10	4		p	1, 5, 7
5.449 ± 14			p	1
5.524 ± 9	$\pi = +$		p	1, 5, 7
(5.57 ± 20)			p	1
5.856 ± 10	2^-		p	1, 4, 5
(6.05 ± 20)				7
6.224 ± 14				1, 4
6.372 ± 9	4^-			1, 4, 5
6.559 ± 10	$(3^- + 1^-)$	≤ 45	p	4
6.679 ± 8				1, 5, 7
(6.93 ± 20)				7
7.110 ± 20				1
7.50 ± 30	2^-	950 ± 100	p	4, 5
7.90 ± 15		< 100		1, 4, 5
9.50 ± 30	$1^- (+ 2^-)$	1050 ± 100	p	4, 5
9.60 ± 20		250 ± 50		5
11.50 ± 50	$1^- (+ 2^-)$	1900 ± 500	p	4, 5

^a See Table 16.24 in (1986AJ04).

^b (1984ST10) report $\Gamma_{\text{c.m.}} \approx 25$ and ≈ 100 keV for $^{16}\text{F}^*(0, 0.19)$.

Table 16.31: ^{16}F levels from $^{14}\text{N}(^3\text{He}, \text{n})$, $^{16}\text{O}(\text{p}, \text{n})$, $^{16}\text{O}(^3\text{He}, \text{t})$ and $^{19}\text{F}(^3\text{He}, ^6\text{He})$ ^a

$^{16}\text{F}^* \text{ b}$ (MeV \pm keV)	$L \text{ b}$	$^{16}\text{F}^* \text{ c}$ (MeV \pm keV)	$J\pi \text{ d}$	$^{16}\text{F}^* \text{ e}$ (MeV \pm keV)	$\Delta l \text{ f}$	$^{16}\text{F}^* \text{ g}$ (MeV \pm keV)	$^{16}\text{F}^* \text{ h}$ (MeV \pm keV)	$\Gamma_{\text{c.m.}} \text{ i}$ (keV)	$J\pi \text{ j}$
0	1	0	(1 ⁻)	0		0	0	40 \pm 20	0 ⁻
0.192 \pm 15	1	0.190 \pm 20	(0 ⁻)	0.197 \pm 12		0.19 \pm 20	0.192 \pm 10	< 40	1 ⁻
0.425 \pm 15	3	0.425 \pm 10	(≥ 2)	0.424 \pm 5	1	0.425 \pm 20	0.424	40 \pm 30	2 ⁻
0.722 \pm 10	(3)	0.725 \pm 10	(≥ 2)	0.720 \pm 6	3	0.72 \pm 20	0.722 \pm 10	< 15	3 ⁻
3.751 \pm 10	0	3.775 \pm 10 ^k	(1)	3.76	0	3.75 \pm 20	3.740 \pm 15 ⁿ	< 40	1 ⁺
3.861 \pm 10	2	3.880 \pm 10 ^k	≥ 1			3.86 \pm 20	3.873 \pm 15 ⁿ	< 20	2 ⁺
4.370 \pm 10		4.375 \pm 10 ^k	(≥ 2)	4.37	2	4.37 \pm 20	4.372 ⁿ	50 \pm 20	3 ⁺
4.646 \pm 10	0	4.661 \pm 10 ^k	≥ 1	4.65	0	4.66 \pm 20	4.652 \pm 10 ⁿ	60 \pm 20	1 ⁺
						4.71 \pm 20 ^m			
4.973 \pm 10	2	4.97 \pm 20 ^l	≥ 2			4.97 \pm 20	5.007 \pm 20	60 \pm 40	(2 ⁺)
5.264 \pm 20		5.27 \pm 20 ^l		5.27	1		5.274 \pm 10 ⁿ		(1 ⁻)
5.390 \pm 20	2	5.40 \pm 20 ^l				5.39 \pm 20	5.414 \pm 15		4
5.448 \pm 20		5.45 \pm 20 ^l							
5.528 \pm 20	2	5.52 \pm 20 ^l				5.53 \pm 20	5.521 \pm 15		$\pi = +$
		(5.57 \pm 20) ^l							
5.840 \pm 40				5.86	3		5.858 \pm 10 ⁿ		2 ⁻
						6.05 \pm 20 ^m			
6.230 \pm 50				6.22	0		6.224 \pm 15		
6.371 \pm 20				6.37	3		6.372 \pm 10		4 ⁻
							6.559 \pm 10 ⁿ		
6.678 \pm 10		6.68 \pm 20 ^l	≥ 1			6.68 \pm 20		≤ 45	(3 ⁻ + 1 ⁻)
						6.93 \pm 20 ^m			
7.110 \pm 20				≈ 7.5	1		7.50 \pm 30 ^{n,o}	950 \pm 100	2 ⁻
7.730 \pm 40				≈ 9.5	1		7.90 \pm 15	< 100	
				≈ 11.5	1		9.50 \pm 30 ^{n,o}	1050 \pm 100	1 ⁻ + (2 ⁻)
							9.60 \pm 20	250 \pm 50	
							11.50 \pm 50 ^{n,o}	1900 \pm 500	1 ⁻ + (2 ⁻)

^a See also Tables 16.33 in (1971AJ02) and 16.26 in (1982AJ01) for earlier work and for references.

^b $^{14}\text{N}(^3\text{He}, \text{n})^{16}\text{F}$.

^c $^{14}\text{N}(^3\text{He}, \text{np})^{15}\text{O}$.

^d From angular correlation studies.

^e $^{16}\text{O}(\text{p}, \text{n})^{16}\text{F}$. E_x shown without uncertainties are from Table 16.30.

^f (1982FA06; $E_p = 99.1$ and 135.2 MeV).

^g $^{16}\text{O}(^3\text{He}, \text{t})$ and $^{19}\text{F}(^3\text{He}, ^6\text{He})^{16}\text{F}$.

^h $^{16}\text{O}(^3\text{He}, \text{t})$: (1984ST10; $E(^3\text{He}) = 81$ MeV). See (1986AJ04).

ⁱ From (a) and (1984ST10, 1985HA01).

^j From (a) and (1984ST10).

^k See also (1985HA01).

^l (1985HA01).

^m Observed only in $^{19}\text{F}(^3\text{He}, ^6\text{He})$.

ⁿ Decays to $^{15}\text{O}_{\text{g.s.}}$ by proton emission (1984ST10).

^o Decays to $^{15}\text{O}^*(6.18)$ (1984ST10).

Observed triton groups are shown in Table 16.31. Angular distributions at $E(^3\text{He}) = 81$ MeV, analyzed by DWBA, and angular correlation measurements [mainly involving protons to $^{15}\text{O}^*(0, 6.18)$], together with information from reactions 1 and 4, lead to the J^π values shown in the table. The analog of the giant dipole resonance [$E_x \approx 9.5$ MeV] is strongly excited. The magnetic quadrupole strength has two strong components in $^{16}\text{F}^*(0.42, 7.5)$. The 4^- state at 6.4 MeV and the GDR have also been observed at $E(^3\text{He}) = 170$ MeV [see (1982AJ01, 1986AJ04)]. A recent measurement of differential cross sections at $E(^3\text{He}) = 66\text{--}90$ MeV and DWBA analysis is reported in (1989VA09). See also (1985VA1A, 1990VA08).

$$\begin{aligned} 6. \text{ (a) } & ^{16}\text{O}(^6\text{Li}, ^6\text{He})^{16}\text{F} & Q_m &= -8.924 \\ & \text{(b) } & ^{16}\text{O}(^7\text{Li}, ^7\text{He})^{16}\text{F} & Q_m &= -26.62 \end{aligned}$$

Measurements have been reported at $E(^6\text{Li}) = 93$ MeV, $E(^7\text{Li}) = 78$ MeV [see (1986AJ04)]. See also (1989GA26).

$$7. \ ^{19}\text{F}(^3\text{He}, ^6\text{He})^{16}\text{F} \quad Q_m = -4.828$$

See Table 16.31 and (1982AJ01, 1986AJ04).

^{16}Ne (Fig. 5)

GENERAL: See Table 16.29.

Mass of ^{16}Ne : The Q -values of the $^{20}\text{Ne}(\alpha, ^8\text{He})$ and $^{16}\text{O}(\pi^+, \pi^-)$ reactions lead to atomic mass excesses of 23.93 ± 0.08 MeV (1978KE06), 23.978 ± 0.024 MeV (1983WO01) and 24.048 ± 0.045 MeV (1980BU15) [recalculated using the (1985WA02) masses for ^8He , ^{16}O and ^{20}Ne]. The weighted mean is 23.989 ± 0.020 MeV, which is also the (1985WA02) value. ^{16}Ne is then bound with respect to decay into $^{15}\text{F} + \text{p}$ by 0.07 MeV and unbound with respect to $^{14}\text{O} + 2\text{p}$ by 1.40 MeV (1986AJ04).

$$1. \ ^{16}\text{O}(\pi^+, \pi^-)^{16}\text{Ne} \quad Q_m = -24.77$$

For ground state cross sections and analyses for $E_{\pi^+} = 80$ to 292 MeV see (1982AJ01, 1986AJ04). A recent measurement at $\theta_{\text{lab}} = 5^\circ$ for $E_{\pi^+} = 140\text{--}292$ MeV has been reported (1990SE11).

Table 16.32: Energy levels of ^{16}Ne

E_x (MeV \pm keV)	$J^\pi; T$	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
0	$0^+; 2$	122 ± 37	p	1, 2
1.69 ± 0.07	$(2^+); 2$		(p)	2



At $E_\alpha \approx 117.5$ MeV, $^{16}\text{Ne}^*(0, 1.69 \pm 0.07)$ are populated, the former with a differential cross section of 5 ± 3 nb/sr at 8° (lab). The $\Gamma_{\text{c.m.}}$ for the ground state group is 200 ± 100 keV; applying penetrability corrections leads to a total decay width of 5–100 keV. The di-proton branching ratio is 10–90%, with the most probable value being 20%. The cubic term, d , in the IMME (Isobaric Multiplet Mass Equation) is 8 ± 5 keV, 15 ± 6 keV based, respectively, on the masses of $^{16}\text{Ne}^*(0, 1.69)$. The first $T = 2$ states in $^{16}\text{F}[0^+, 2^+]$ are predicted to lie at $E_x = 10.08 \pm 0.02$ and 11.87 ± 0.03 MeV (1978KE06). At $E_\alpha = 129$ MeV (1983WO01) find $\Gamma_{\text{c.m.}}$ for $^{16}\text{Ne}_{\text{g.s.}} = 110 \pm 40$ keV and the d and e coefficients in the IMME are both 4 ± 3 keV.

^{16}Na , ^{16}Mg , ^{16}Al , ^{16}Si
(not observed)

See (1986AN07).

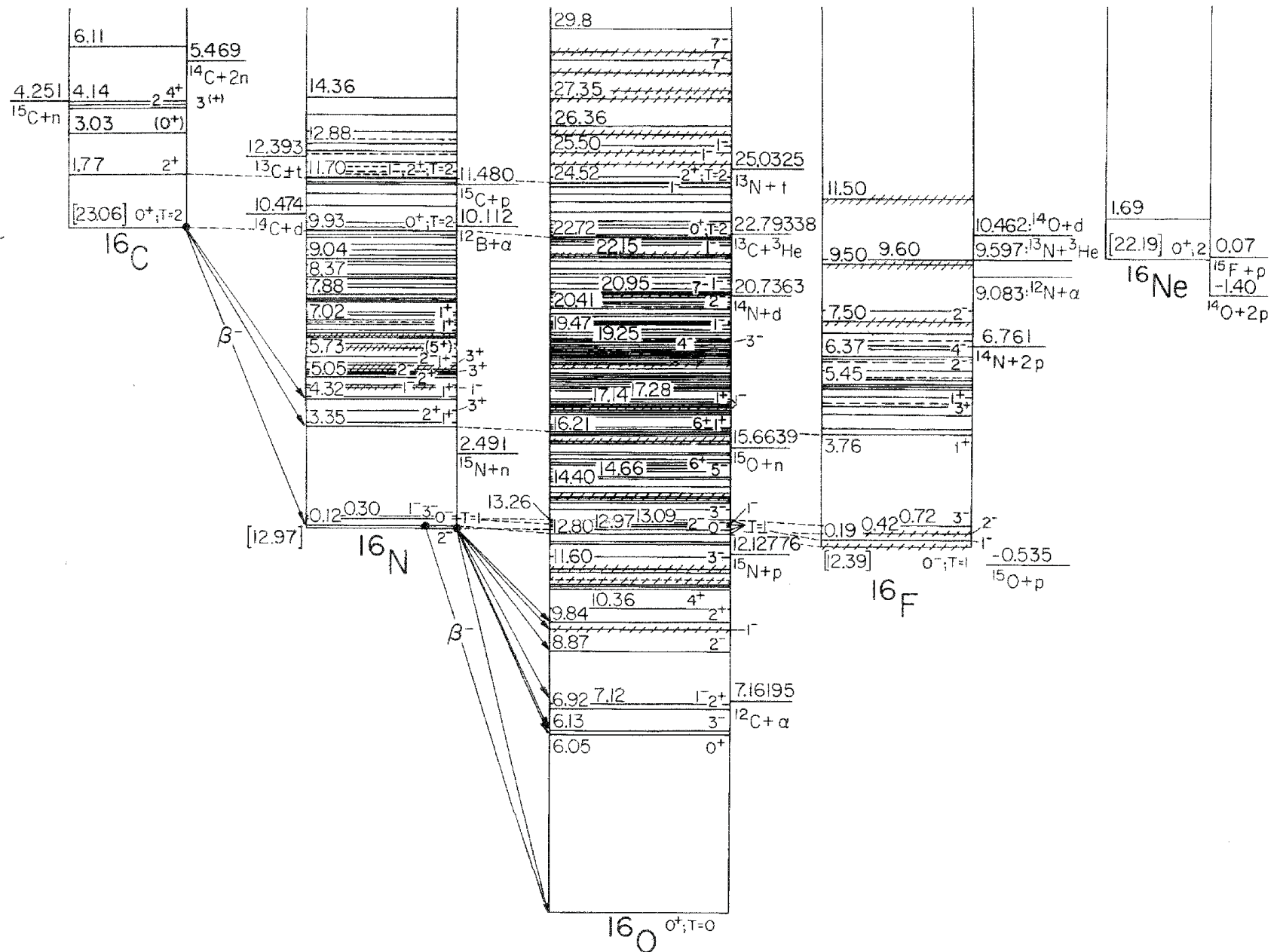


Fig. 5: Isobar diagram, $A = 16$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron-proton mass difference and the Coulomb energy, taken as $E_C = 0.60Z(Z - 1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_N = M(Z, A) - ZM(\text{H}) - NM(\text{n}) - E_C$, minus the corresponding quantity for ^{16}O : here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

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