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Energy Levels of Light Nuclei
$A = 6$

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Abstract: This is a preliminary version of the $A = 6$ evaluation which we plan to submit to Nuclear Physics A later this year. Your comments on this draft will be greatly appreciated.

(References closed 1 January 1998)

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Table 6.1: Astrophysical S-factor summary

^{3}H(t, 2n)^{4}He	(^{6}He reaction 2)	(86BR1K, 85JA16) measured $S(E_t)$ at $E_t = 115$, 105, 90, 75 keV, compared with older data and with R-matrix analysis. The extrapolated value is $S(0) \approx 180$ keV · b.
^{4}He(d, γ)^{6}Li	(^{6}Li reaction 4)	(96CE02) measured $S(E_{cm}) \leq 2 \times 10^{-7}$ MeV · b (90% confidence level) at $E_{cm} = 53$ keV. (95MU21) analyzed data and calculated recommended values of $S(E_{cm})$ for $E_{cm} = 10$–300 keV.
^{9}Be(p, α)^{6}Li	(^{6}Li reaction 35)	(97ZA06) measured excitation functions and angular distributions, deduced $S(E_p)$ at $E_p = 16$–330 keV. They present a parametric fit including resonance and direct processes and the effects of electron screening.
^{3}He(^{3}He, γ)^{6}Be	(^{6}Be reaction 1)	(87KR09) measured $\sigma(E_{cm})$ at $E_{cm} = 17.9$–342.5 keV and deduced best-fit value of $S(0) = 5.57 \pm 0.32$ MeV · b. (89BE08) studied electron screening effects and present a corrected value. See also the corrected value determined by (87AS05). (89VA20) calculated $S(E)$ with a 2-channel approximation to RGM.

A = 6

GENERAL: The $A = 6$ nuclides reviewed in the following pages are of considerable importance to astrophysics. Table 6.1 provides a convenient preliminary summary of the astrophysical S-factor information contained in the more lengthy reaction-by-reaction discussions to follow.

^{6}n

^{6}n has not been observed. See (79AJ01, 88AJ01) and references cited there. More recently (90AL40) reports a search for ^{6}n in a ^{14}C(^{7}Li, ^{6}n) activation experiment at $E(^7\text{Li}) = 82$ MeV. No evidence for ^{6}n was obtained.

The method of angular potential functions was used by (89GO18) in a calculation of the properties of multi-neutron systems which indicated that these systems have no bound states. The ground state energy of a six-neutron drop has been computed with variational and Green's function Monte Carlo methods (97SM07).

^{6}H

^{6}H was reported in the ^{7}Li(^{7}Li, ^{8}B)^{6}H reaction at $E(^7\mathrm{Li}) = 82$ MeV (84AL1F, 85AL1G) [$\sigma(\theta) \approx 60$ nb/sr at $\theta = 10°$] and in the ^{9}Be(^{11}B, ^{14}O)^{6}H reaction at $E(^{11}\mathrm{B}) = 88$ MeV(86BE35) [$\sigma(\theta) \approx 16$ nb/sr at $\theta \approx 8°$]. ^{6}H is unstable with respect to breakup into ^{3}H + 3n by 2.7 ± 0.4 MeV, $\Gamma = 1.8 \pm 0.5$ MeV (84AL1F), 2.6 ± 0.5 MeV, $\Gamma = 1.3 \pm 0.5$ MeV (86BE35). The value adopted in the previous review (88AJ01) is 2.7 ± 0.3 MeV, $\Gamma = 1.6 \pm 0.4$ MeV. See also (87BO40). The atomic mass excess of ^{6}H using the (95AU04) masses for ^{3}H and n, is then 41.9 ± 0.3 MeV. However, there is no evidence for the formation of ^{6}H in the ^{6}Li(π^-, π^+) reaction at $E_{\pi^-} = 220$ MeV (90PA25). An analysis of the proton spectra for the ^{7}Li(π^-, p) reaction (90AM04) showed no evidence for ^{6}H.

The ground state of ^{6}H is calculated to have $J^\pi = 2^-$. Excited states are predicted at 1.78, 2.80 and 4.79 MeV with $J^\pi = 1^-$, 0^- and 1^+ [$(0 + 1)\ \hbar\omega$ model space] (85PO10) [see also for $(0 + 2)\ \hbar\omega$ calculations]. See also the additional references cited in (88AJ01).

^{6}He

GENERAL: References to articles on general properties of ^{6}He published since the previous review (88AJ01) are grouped into categories and listed, along with brief descriptions of each item, in Table 6.2.

Other Ground State Properties

The interaction radius of ^{6}He, obtained from measurements of the total interaction cross section, is 2.18 ± 0.02 fm (85TA13, 85TA18). These authors have also derived nuclear matter, charge and neutron rms radii.

^{6}He is considered to be a neutron-halo nucleus because its interaction radius, which is deduced from the total interaction cross section in (85TA13, 85TA18), is appreciably larger than that of ^{6}Li. A Glauber calculation using proton and neutron densities from an alpha-core valence-neutron model leads to the conclusion that the matter radius is much larger than the charge radius, as predicted by theoretical models of the ^{6}He ground-state wave function. These theoretical models include three-body models (93ZH1J, 95HI15), cluster-orbital shell models (91SU03, 94FU04), no-core microscopic shell models (96NA24), and microscopic cluster models for various effective nucleon-nucleon interactions (93CS04, 97WU01). See also (92TA18). The point proton and point neutron radii are often compared in order to enhance the effect, and are found to differ by 0.4–0.8 fm. For other typical properties of halo nuclei see (95HA2B).

Table 6.2: ^{6}He – General

Reference	Description
	Shell model
88SU10	Cluster-orbital shell model and its application to the neutron-rich He isotopes
90SU01	Cluster-orbital shell model with continuum discretization applied to $^{6-8}$He
90WO10	p-shell nuclei in a $(0-2)\hbar\omega$ model space; calc. spectra and intruder states for ^{6}He
91SU03	Ground-state structure and the soft dipole mode of ^{6}He
91ZH10	Cluster shell-model calcs. of neutron & α-particle momentum distributions in ^{6}He
93CH06	Gamow-Teller beta-decay rates for $A \leq 18$ nuclei
93PO11	Shell-model calcs. of several properties of exotic light nuclei (Z = 2–9; A = 4–30)
95AO06	Cluster orbital shell model predictions of low-lying three-body resonance states in ^{6}He
95WA1F	Physical mech. of neutron halo on drip line light nucl. studied in unmodified shell model
95WA33	Structure of ^{6}He & ^{11}Li calc. using self-similar-structure shell model
96KU20	Realistic effective interactions for halo nuclei; 2-frequency shell-model approach
96NA24	No-core SM calcs. with starting-energy-independent multivalued effective interactions
96WA35	Ground state properties of halo nuclei calc. using SSM (see also 95WA1F)
97KU07	Suppression of core polarization in halo nuclei; calc. pairing energies, comp. to exp.
97ST14	Polarization of single-particle orbitals and structure of exotic He & Be nuclei
	Cluster and alpha-particle models
Review:	
94VA30	Clustering aspects of light exotic nuclei: ^{6}He & ^{11}Li
Other articles:	
88DA22	Pauli focusing of particles & structure of the ground state of ^{6}He in the $\alpha + 2$N model
88SU10	Cluster-orbital shell model and its application to the neutron-rich He isotopes
89DA05	Calculation of 0^+ $T = 1$ states of $A = 6$ nuclei in $\alpha + 2$N model with local potentials
89TR18	Two- and four-nucleon clusters in light and heavy nuclei
90DAZS	Matter & nucleon transition densities of ^{6}He (0^+), ^{6}Li (1^+) in micro. $\alpha + 2$N model
90DAZR	β-decay of the ground state of ^{6}He in three-particle $\alpha + 2$N model
90SU01	Cluster-orbital shell model with continuum discretization applied to $^{6-8}$He
90ZH09	Fragmentation of ^{6}He nucleus at high energies; microscopic $\alpha + 2$n model
90ZH16	Unusual structure of ^{6}He nucleus; momentum correlations of α-particles & neutrons
91DA08	Dyn. multicluster model with hyperspherical harmonics; electroweak & charge-exch. rxns
91KU1B	Multicluster models of light nuclei predict strong, EM and weak interactions
91SU03	Ground-state structure and the soft dipole mode of ^{6}He
91ZH10	Cluster shell-model calcs. of neutron & α-particle momentum distributions in ^{6}He
91ZH1S	Neutron halo structure and particle momentum distribution in ^{6}He and ^{11}Li
92ZH1D	3-body structure of ^{6}He: α-particle and neutron momentum distributions
93CS04	Neutron halo of ^{6}He in a realistic parameter-free microscopic multicluster model
93RY01	Properties of a 6-nucleon system in multicluster dynamic model with antisymmetrization
93RY1B	β-decay and muon-capture in $A = 6$ system, calculated in the dynamical $\alpha + 2$N model

Table 6.2: ^{6}He – General (continued)

Reference	Description
	Cluster and alpha-particle models (continued)
93SH1G	Microscopic calc. of weak interaction in $A = 6$ nuclei; three particle $\alpha + 2$N model
93VAZV	Multicluster model of $^{6-8}$He; calc. 2n removal spectrosc. factors, α-part. momen. distr.
93ZH09	^{6}He beta decay to the $\alpha +$ d channel in a three-body model
94BA42	Lagrange-mesh calculation of a three-body ($\alpha +$ n $+$ n) model for ^{6}He
94CS01	Dynamical micro. cluster model descrip. of β-delayed deuteron emission from ^{6}He
94CS04	3-body resonances in $A = 6$ nuclei; soft dipole mode problem of neutron halo nuclei
94FE01	Three-body halos: gross properties calc. using hyperspherical harmonics
94FI13	Realization of algebraic version of RGM for 3-cluster systems (incl. ^{6}He)
94FU04	Halo structure and soft dipole mode of the ^{6}He in the $\alpha +$ n $+$ n cluster model
94KO1A	Mechanisms in fragmentation of ^{6}He; microscopic calc. of ^{6}He wave function
94VA07	Microscopic multicluster descrip. of neutron-halo nucl. with stochastic variational method
94VA16	Microscopic multicluster description of the neutron halo structure of ^{6}He & ^{8}He
95AO06	Cluster orbital shell model predictions of low-lying three-body resonance states in ^{6}He
95HI15	Three-body structure of ^{6}He=^{4}He+n $+$ n using realistic n-n potentials
95KA20	Binding and excitation mechanisms of ^{6}He, ^{10}He, and ^{11}Li studied with 3-body models
95KU08	3-body $\alpha + 2$N model with realistic nuclear forces; calc. Coulomb displac. of ^{6}He levels
95KU1G	Spectra, Coulomb displacements, static characteristics using the New Dynamic Model
95SU13	Study of halo structure in light nuclei with a multicluster model
95VAZV	^{6}He in three-cluster oscillator basis; calc. ground state energy
95VEZY	Variational calc. of ^{6}He ground state in resonating group method 3-cluster approx.
96FI05	Phenomenological 3-cluster model of ^{6}He; hyperspherical functions
96FI07	Ground state of ^{6}He calc. with microscopic 3-cluster $\alpha +$ n $+$ n model
96FI11	^{6}He as a 3-cluster system: investigation of the ground state and continuum 0^{+} states
96SU11	Occupation prob. of harmonic-oscillator quanta for micro. cluster-model wave functions
96VA1B	New modes of ^{6}He halo excitation studied with 3-body $\alpha +$ n $+$ n cluster model
96VE05	Variational calc. of ^{6}He ground state in 3-cluster resonating group method approx.
97CO22	Computations of three-body continuum spectra
97DA01	$\alpha +$ n $+$ n model predicts 2^{+} resonance, soft dipole mode, unnatural parity modes in ^{6}He
97GA10	Pauli principle in 3-body cluster model; momentum distrib. after ^{6}He & ^{11}Li fragment.
97LU08	Exactly solvable model for multineutron halo nuclei (^{6}He & ^{11}Li)
97VA09	3-cluster model of $A = 6$ nuclei; uses algebraic version of RGM; reveals n-halo in ^{6}He
97WU01	Structure of $^{4-8}$He; calc. ground state wave functions for ^{6}He & ^{8}He
	Other models
94BB03	Evidence for halo in quenching of ^{6}He β-decay into alpha and deuteron
94CS1B	Three-body resonances by complex scaling; studied soft dipole resonance in ^{6}He
94KO1A	Mechanisms in fragmentation of ^{6}He; microscopic calc. of ^{6}He wave function
97PU03	Quantum Monte Carlo calculations of ground & low-lying excited states in $A \leq 7$ nuclei

Table 6.2: ^{6}He – General (continued)

Reference	Description
	Special States
88GU13	Correlated basis functions theory of light nuclei: spectra of light nuclei ($4 \leq A \leq 16$)
90AS06	Calculation of the energy of monopole giant resonances by the phase-space method
90DAZT	($J = 0, 1$; $T = 1, 0$) multiplet in micro. $\alpha + 2$N model with realistic αN & NN potentials
90DAZS	Matter & nucleon transit. densities of ^{6}He(0^+) & ^{6}Li(1^+) in microscopic $\alpha + 2$N model
90WO10	p-shell nuclei in a $(0 + 2)\hbar\omega$ model space; calc. spectra and intruder states for ^{6}He
91BO31	Super-allowed beta-decay of light nuclei at the neutron drip-line
91SU03	Ground-state structure and the soft dipole mode of ^{6}He from cluster-orbital shell model
92DAZT	3-3 resonant scattering and $A = 6$ nuclei excited states ($\alpha + 2$N model)
92DAZU	Faddeev and hyperspherical study of $A = 6$ nuclei excited states ($\alpha + 2$N model)
93DA07	Resonance $3 \rightarrow 3$ scattering & structure of excited states of $A = 6$ nuclei ($\alpha + 2$N model)
94CS1B	Three-body resonances by complex scaling; studied soft dipole resonance in ^{6}He
94CS04	3-body res. in $A = 6$ nucl.; soft dipole mode of neutron halo nucl. from complex scalng
94FU04	Halo structure and soft dipole mode of ^{6}He in the $\alpha + n + $n cluster model
95AO05	Binding mechanism of ^{6}He and its excited states from hybrid-TV model
95FU1B	Coulomb excitation of soft dipole states, effects on elastic scat., micro. CC method
96SA1K	Multipole excit. in light neutron-rich nucl. (incl. ^{6}He, ^{11}Li, ^{12}Be); Hartree-Fock RPA
96VA1B	New modes of ^{6}He halo excitation studied with 3-body $\alpha + n + $n cluster model
97DA01	$\alpha + n + $n model predicts 2^+ resonance, soft dipole mode, unnatural parity modes in ^{6}He
	Electromagnetic transitions
Review:	
89RA16	Predictions of B(E2; $0^+_1 \rightarrow 2^+_1$) values for even-even nuclei
Other articles:	
91JA13	Matrix elements of magnetic and electric moments in the supermultiplet scheme
91SU03	The ground-state structure and the soft dipole mode of ^{6}He ($\alpha + 2$N model)
93DA01	Monopole & dipole strength functions for ^{6}He excitations ($\alpha + n + $n model)
93DA1P	Continuum response of ^{6}He, ^{11}Li; calc. monopole & elec. dipole excit. (see 93DA01)
94BA1G	Importance of nuclear effects in the dissociation of ^{6}He & ^{11}Li at $E/A = 65$ MeV
96FI05	Phenomenological 3-cluster model of ^{6}He; hyperspherical functions
97LU08	Exactly solvable cluster model for multineutron ^{6}He & ^{11}Li; hyperspherical expansion
97WU01	Structure of $^{4-8}$He; grnd. state wave functions for ^{6}He & ^{8}He calc. with RGM algorithm
	Complex reactions involving ^{6}He
Review:	
89OG1B	Neutron decay of very neutron-rich light nuclei studied with heavy-ion accelerators
Other articles:	
87JA1D	Fragment production in intermediate energy heavy ion reactions

Table 6.2: ^{6}He – General (continued)

Reference	Description
	Complex reactions involving ^{6}He (continued)
87MA2F	Study of cluster emission and transfer in heavy ion reactions
88BE34	Study of properties of helium isotopes in reaction with heavy ions
88BE56	Formation of light nuclei in rxns. with ^{11}B & ^{20}Ne at energies of 18–20 MeV/nucleon
88GR09	Energy & angular distributions for ^{6}He emitted in spontaneous fission of ^{252}Cf
88HA2E	Quantum stat. model of fragment formation: entropy & temp. in heavy ion collisions
88KE07	Measured cross sections for ^{16}O(^{7}Li, ^{6}He) & analyzed using finite-range DWBA
88KO10	Projectile fragmentations of ^{6}He, ^{8}He, ^{11}Li measured at 0.79 GeV/nucleon
89HA1L	Statistical decay of fragments from C + ^{12}C at 2.1 GeV/nucleon
89SA10	Total cross sections of reactions induced by neutron-rich light nuclei
90BEYY	Production of neutron-rich He isotopes in ^{9}Be + ^{18}O
90SKZY	Investigation of scattering of ^{6}He & ^{8}Li on Ag; measured cross section at 55 MeV
90UT01	Quasifree fragment. of radioact. projectiles (incl. ^{6}He); extended Serber model calcs.
94SK04	Elastic scat. data of lightest radioactive isobar $A = 6$–11 nucl. below 10 MeV/nucleon
	Applications
88KO1J	Radioactive beam facility at Notre Dame produces secondary beams of ≤ 20 MeV ^{6}He
89BR1L	Discrete nucl. rxns. studied with secondary, radioactive ^{8}Li & ^{6}He beams at 14 MeV
89KO17	Radioactive beam fac. uses large supercond. solenoid; produces ≤ 20 MeV ^{6}He beams
	Astrophysics
88CA1N	Reaction rates of astrophysically important thermonuclear reactions involving light nucl.
95GO1P	Two-neutron capture reactions on ^{6}He & ^{8}He in supernovae neutrino bubbles
95OB1A	3-body & direct capture calc. of ^{4}He(nn, γ)^{6}He, ^{6}He(γ, nn)^{4}He reaction rates
96EF02	3-body calc. ^{4}He(nn, γ)^{6}He reaction rate (same work as 95OB1A)
	Muon and neutrino capture and reactions
Review:	
89BR1O	Muon-catalyzed fusion; summary of theor. & exp. work
Other articles:	
88MA1V	Theor. results on initial sticking, stripping, and X-ray intensities for μCF reactions
89CH2F	Muon production for energy applications: Cold fusion
90HA1V	Muon catalysed fusion of nuclei with $Z > 1$
90KA44	Nuclear-structure effects in the polarization parameters of negative-muon capture
93RY1B	β-decay and muon-capture in $A = 6$ system, calculated in the dynamical $\alpha + 2$N model
94MU1E	^{6}Li(μ^-, ν_μ)^{6}He studied for info. on weak hadron form factors in nucl.

Table 6.2: ^{6}He – General (continued)

Reference	Description
	Reactions involving pions, other mesons and baryon states
89GE10	Threshold pion-nucleus amplitudes as predicted by current algebra
95DO24	Exclusive charged pion photoproduction in ^{6}He, ^{12}B and ^{14}C
	Hypernuclei
Reviews:	
89CH2D	Nuclear systems with strangeness
92DO14	Open problems and future prospects for hypernuclear physics
92GA1L	Summary: Shimoda International Symp. on Hypernuclear & Strange Particle Physics
Other articles:	
88BO1W	Hypernuclear interactions & binding energies of Λ and $\Lambda\Lambda$ hypernuclei (incl. ${}^{6}_{\Lambda\Lambda}$He)
88HU1F	The $\Lambda - \Lambda$ interaction and the structure of the hypernuclei ${}^{6}_{\Lambda\Lambda}$He and ${}^{9}_{\Lambda}$Be
88TA14	$\Sigma^- + {}^{11}$B and $\Sigma^- + {}^6$He produced using (K$^-$, π^+) reaction on ^{12}C & ^{7}Li at 715 MeV/c
89BA1E	Production of hypernuclei in relativistic ion beams
89BA2N	Evaluation of hypernucl. production cross sections in relativistic heavy-ion collisions
89DA1B	The ${}^{6}_{\Lambda\Lambda}$He hypernucleus and the $\Lambda\Lambda$ interaction; method of hyperspherical functions
89HU1I	α-particle model of ${}^{6}_{\Lambda\Lambda}$He; calc. binding energy, spatial structs. & $\Lambda\Lambda$ interact. params.
89TA1P	Binding energies of light $\Lambda\Lambda$ hypernucl. from observed values for ${}^{6}_{\Lambda\Lambda}$He & ${}^{10}_{\Lambda\Lambda}$Be
89TA1T	Schmidt diagrams & configuration mixing effects on hypernuclear magnetic moments
89ZH1A	Few-body dynamics of doubly Λ hypernuclei ${}^{6}_{\Lambda\Lambda}$He & ${}^{10}_{\Lambda\Lambda}$Be
91AK03	Few-body problems with hyperons
91DU1C	Three-body structure & interparticle correlations of the doubly Λ hypernucleus ${}^{6}_{\Lambda\Lambda}$He
91MO14	Continuum pion spectra for three-body decays calc. for ${}^{6}_{\Lambda\Lambda}$He
91MO19	Continuum pion spectra in the weak decays of ${}^{4}_{\Lambda}$H, ${}^{5}_{\Lambda}$He and ${}^{6}_{\Lambda\Lambda}$He
91MO1H	(π, K) hypernuclear production and pionic decay
91PO07	Variational calc. of props. of ${}^{6}_{\Lambda\Lambda}$He & ${}^{9}_{\Lambda}$Be in $\alpha\alpha\Lambda$ and $\alpha\Lambda\Lambda$ models using H.O. basis
91ZH26	Formation of $\Lambda\Lambda$ hypernuclei by Ξ^- capture in light nuclei
92LI17	Hyperspherical harmonic method for solving few-body probs. applied to ${}^{6}_{\Lambda\Lambda}$He & ${}^{9}_{\Lambda}$Be
92MO30	Mesonic weak decays of Λ- and $\Lambda\Lambda$-hypernuclei
92SAZD	The strangeness $S = -2$ hypernuclei and the predicted H-particle
92YA16	Production and structure of double-Λ hypernuclei
93AD04	${}^{5}_{\Lambda}$He and ${}^{6}_{\Lambda\Lambda}$He calculations by means of the integrodifferential equation approach
93HI1C	Binding energies of double-Λ hypernuclei (${}^{6}_{\Lambda\Lambda}$He) and $\Lambda\Lambda$ G-matrix
93HI1G	General formula for the coalescence model applied to formation of ${}^{6}_{\Lambda\Lambda}$He
93MI22	Binding energy of ${}^{6}_{\Lambda\Lambda}$He hypernucleus calc. in $\alpha + 2\Lambda$ cluster model
94GI1C	Novel aspects of hypernuclei; suppression of $\Lambda\Lambda$-ΞN coupling in ${}^{6}_{\Lambda\Lambda}$He hypothesized
94GI1G	Importance of baryon-baryon coupling; hypothesize suppressed $\Lambda\Lambda$-ΞN conv. in ${}^{6}_{\Lambda\Lambda}$He
94LI52	Description of hypernucleus ${}^{6}_{\Lambda\Lambda}$He by the $\Lambda\Lambda\alpha$ model
95BR1E	Non-mesonic decay of hypernuclei and the $\Delta I = 1/2$ rule, measured for ^{6}He(Λ)

Table 6.2: ^{6}He – General (continued)

Reference	Description
	Hypernuclei (continued)
96HI1B	Three-body model study of $A = 6$–7 hypernuclei: halo and skin structures
97CA1Q	$^{6}_{\Lambda\Lambda}$He as a $\Lambda\Lambda$ interaction constraint: considers the $\Lambda\Lambda$-ΞN channel coupling
	Other topics
Reviews:	
86AU1D	Studies of nucl. struct. in antinucleon charge-exchange rxns: planned ^{6}Li($\bar{\text{p}}$, $\bar{\text{n}}$)^{6}He exp.
96DA31	Nuclei with two-particle neutron halo: theory and recent experiments
Other articles:	
88TR02	Interacting boson scheme for light nuclei
89GO24	Microscopic calculations of hydrogen and helium isotopes
94SU02	Fragmentation cross sections of He isotopes and neutron correlations, Glauber theory
97OR03	Fragment momentum distributions from the breakup of halo nuclei
97PO12	Coulomb energies of light nuclei
97TA12	Exploration of E & Γ of res. by analytic continuation in the coupling constant (ACCC)
97WE03	On isotope thermometers
	Ground state properties
Reviews:	
89TA1O	Methods of production of & possible uses for secondary radioactive beams
90BA06	Radii & lifetimes of low-lying states of neutron-rich light nuclei
90HA29	Nuclear structure at the drip lines
93ZH1J	Bound state properties of Borromean halo nuclei: ^{6}He and ^{11}Li (as 3-body systems)
94JO04	Halo nuclei, β-decay studies of drip-line nuclei, influence of halo on decay rates
94RI1C	Nuclear halo states — distinguishing features & experimental signatures
94VA30	Clustering aspects of light exotic nuclei: ^{6}He & ^{11}Li
96BA60	Few-body aspects of Borromean halo nuclei; compare calcs. & theory for ^{6}He
Other articles:	
88DA22	Pauli focusing of particles & structure of the ground state of ^{6}He in the $\alpha + 2$N model
88SU10	Cluster-orbital shell model and its application to the neutron-rich He isotopes
88UC03	Narrow component of momentum width, neutron halo in ^{11}Li, also ^{6}He in DEM model
89CH28	Nuclear-reaction cross-sections at high E & radii of radioactive nuclei incl. ^{6}He
89ES05	Inelastic EM form factor of ^{6}Li (3-body model); uses ^{6}He gnd-st. 3-body wave function
89SA10	Total cross sections of reactions induced by neutron-rich light nuclei incl. ^{6}He
89TR18	2-nucleon and 4-nucleon clusters in light and heavy nuclei
89WIZO	Microscopic 6-body calcs. of ground-state binding energies & density dist. of ^{6}He, 6Li
90CH26	The charge and mass dependence of nuclear interaction cross sections

Table 6.2: ^{6}He – General (continued)

Reference	Description
	Ground state properties (continued)
90DAZR	β-decay of the ground state of ^{6}He in three-particle $\alpha + 2N$ model
90DO04	Particle-hole symmetry & meson exchange corrections to the ^{6}He beta decay amplitude
90LO10	Semi-empirical model description of nuclear radii comp. with exp. data for light nuclei
90SU01	Cluster-orbital shell model with continuum discretization, $^{6-8}$He, calc. rms radii
90ZH09	Fragmentation of the radioactive ^{6}He nucleus at high energies ($\alpha + 2N$ model)
91DA04	$J^\pi = 0^+$, 1^+ states studied in micro. $\alpha + 2N$ model & method of hyperspherical functions
91DA24	Decay of the ground state of the ^{6}He nucleus in the three-particle $\alpha + 2N$ model
91SU03	Ground-state structure and the soft dipole mode of ^{6}He in $^4He + n + n$ model
91WI05	Variational calcs. of few-body nucl. (^{3}H & ^{4}He); extension to ^{5}He, ^{6}He, ^{6}Li discussed
92DAZV	Faddeev & hyperspher. study of $A = 6$ nucl.: static EM characteristics & β-decay of ^{6}He
92DAZW	Faddeev & hyperspher. study of $A = 6$ nucl.: geometrical features of ^{6}He & ^{6}Li g.s.
92DAZX	Faddeev & hyperspher. study of $A = 6$ nucl.: ground states
92GO09	Halo effect in light nucl.; microscopic calc. of loosely bound nucleon systems incl. ^{6}He
92LA13	Influence of the separation energy on the radius of neutron rich nuclei
92TA18	Revelation of thick neutron skins in ^{6}He & ^{8}He nuclei
92VA1K	Breakup of halo nuclei from 1 GeV/A down to 30 MeV/A, phenomemological
93DA1P	Continuum response of ^{6}He, ^{11}Li; calc. ground state wave function
93FE02	The separation energy dep. of the nucl. rxn. Xsect., Coulomb mod. Glauber model
93FE04	Cross sections for Coulomb break-up of the halo nucleus ^{6}He, 3-body model, no exp.
93FE1H	Nuclear interaction radii for light exotic nuclei; Coulomb-modified Glauber model
93PA14	Relativistic mean field study of light nucl. (calc. binding E, rms radii, deform. params.)
93PA19	Effects of pairing correlation in light nucl. (calc. binding E, rms radii, deform. params.)
94VA07	Microscopic multicluster descrip. of neutron-halo nucl. with stochastic variational method
94VA16	Microscopic multicluster description of the neutron halo structure of ^{6}He & ^{8}He
94VA32	Microscopic multicluster description of neutron halos
95AO05	Binding mechanism of ^{6}He and its excited states ($^4He + n + n$ 3-body model)
95BE26	Probing the ground-state and transition densities of halo nucl. with sec. radioactive beams
95FIZZ	Microscopic theory of nuclear reactions with 3-cluster channels
95PU05	Green's function quantum Monte Carlo calculations of $A \leq 6$ nuclei
95VAZV	^{6}He in three-cluster oscillator basis; calc. ground state energy
95VEZY	Variational calc. of ^{6}He ground state in resonating group method 3-cluster approx.
96AL1J	Radii of halo nuclei from cross section measurements, Glauber model
96FI05	Phenomenological 3-cluster model of ^{6}He; hyperspherical functions
96FI07	Ground state of ^{6}He calc. with microscopic 3-cluster $\alpha + n + n$ model
96SH12	Skyrme-Hartree-Fock calculation: ground-state properties of He, Li, and Be isotopes
96SH13	Analysis of exp. with radioactive beams yield rms matter radii, suggest neutron halo in ^{6}He
96VE05	Variational calc. of ^{6}He ground state in 3-cluster resonating group method approx.
96WA35	Ground state props. of halo nucl. calc. using self-similar-structure shell model (SSM)

Table 6.2: ^{6}He – General (continued)

Reference	Description
	Ground state properties (continued)
97BA23	Neutron halo in light nuclei studied by mean-field approximation, Skyrme force fits
97BA54	Microscopic study of the ground state properties of light nuclei
97BA1P	Lagrange-mesh calculations of halo nuclei
97KA32	Root-mean-square radii of light atomic nuclei: neutron skin
97KR10	Ground state energies & decay widths of particle-unstable nucl., Hartree-Fock approx.
97LU08	Exactly solvable model for multineutron halo nuclei (^{6}He & ^{11}Li)
97PU03	Green's function quantum Monte Carlo calcs. of ground & low-lying excited states
97ST14	Polarization of single-particle orbitals and structure of exotic He & Be nuclei
97WU01	Structure of $^{4-8}$He; calc. ground state wave functions for ^{6}He & ^{8}He using RGM

1. ^{6}He(β^-)^{6}Li $\qquad Q_{\rm m} = 3.508$

The half-life is 806.7 ± 1.5 ms (84AJ01). The decay to the ground state of ^{6}Li ($J^\pi = 1^+$) is via a super-allowed Gamow-Teller transition; $\log ft = 2.910 \pm 0.002$ (88AJ01, 84AJ01). A second beta-decay branch leading to an unbound final state consisting of a deuteron and an α particle was reported (90RI01) based on the observation of beta-delayed deuterons. The branching ratio for $E_{\rm d} > 350$ keV was measured (93BO24, 93RIZY) to be $(7.6 \pm 0.6) \times 10^{-6}$. Calculations are presented which consider alternative decay routes. (One considers a decay to an unbound state of ^{6}Li which then decays into α + d. In the other route ^{6}He breaks up into an alpha particle plus a di-neutron which β decays to a deuteron. The calculation of (94BA11) successfully reproduces the deuteron spectrum shape and branching ratios. References to theoretical work on the ^{6}He(β^-)^{6}Li decay are presented in Table 6.4.

1.3 ^{1}H(^{6}He, ^{6}He)^{1}H $\qquad E_{\rm b} = 9.975$

The use of elastic and inelastic scattering with secondary beams to probe ground-state transition densities of halo nuclei has been explored in a theoretical study (95BE26).

2. (a) ^{3}H(t, n)^{5}He $\qquad Q_{\rm m} = 10.39 \qquad E_{\rm b} = 12.306$
(b) ^{3}H(t, 2n)^{4}He $\qquad Q_{\rm m} = 11.333$
(c) ^{3}H(t, t)^{3}H

Figure 1: Energy levels of ^{6}He. For notation see introduction.

Table 6.3: Energy levels of ^{6}He

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ or Γ_{cm}	Decay	Reactions
g.s.	$0^+; 1$	$\tau_{1/2} = 806.7 \pm 1.5$ ms	β^-	1, 3, 4, 5, 6, 7, 8, 9, 9.3, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20
1.797 ± 25	$2^+; 1$	$\Gamma = 113 \pm 20$ keV	n, α	3, 4, 5, 7, 8, 9.3, 10, 11, 12, 13, 14, 15, 16, 20
5.6 ± 300	$(2^+, 1^-); 1$	12.1 ± 1.1 MeV		9.3
14.6 ± 0.7	$(1^-, 2^-); 1$	7.4 ± 1.0 MeV		4, 9.3, 11, 14, 16
(15.5 ± 500)		4 ± 2 MeV		5, 6, 10, 11, 15, 16
23.3 ± 1.0		14.8 ± 2.3 MeV		6, 9.3
(32)		≤ 2 MeV		15
(36)		≤ 2 MeV		15

Table 6.4: ^{6}He(β^-)^{6}Li – Theoretical work

Reference	Description
89DO1B	Meson exchange corrections to the ^{6}He$_{g.s.}$–^{6}Li$_{g.s.}$ beta decay
89SA20	Polarisation effects of second-class currents in the direct and inverse decay of nuclei
89TE04	Neutral current effect in nuclear β-decays
90DA1H	Two body phase space in alpha-deuteron breakup at 40 MeV
90DAZR	Beta-decay of the ground state of ^{6}He in three-particle $\alpha + 2$n model
90DO04	Particle-hole symmetry and meson exchange corrections to the ^{6}He beta decay amplitude
90HA29	A review of recent results on nuclear structure at the drip lines
91DA24	Decay of the ground state of the ^{6}He nucleus in the three-particle $\alpha + 2$n model
92DAZV	Static electromagnetic characteristics and beta-decay of ^{6}He
92DE12	Beta-delayed deuteron emission of ^{6}He in a potential model
93CH06	Gamow-Teller beta-decay rates for $A \leq 18$ nuclei, a comprehensive analysis
93ZH09	^{6}He beta decay to the $\alpha +$ d channel in a three-body model
94BB03	Evidence for halo in quenching of ^{6}He β-decay into alpha and deuteron
94CS01	Microscopic description of the beta delayed deuteron emission from ^{6}He
94SK01	Improved limits on time-reversal-violating, tensor weak couplings in ^{6}He
94SU02	Glauber theory microscopic analysis of fragmentation and beta-delayed particle emission
95SU13	Study of halo structure in light nuclei with a multicluster model

The cross section for reaction (b) was measured for $E_t = 30$ to 115 keV by (86BR1K, 85JA16) who also calculated the astrophysical S-factors [the extrapolated $S(0) \approx 180$ keV·b] and discussed the earlier measurements. See also (74AJ01, 79AJ01) and (86JA1E). Calculations have also been made within the framework of the two-channel resonating group method (89VA20), the microscopic multichannel resonating group method (91TY01) and the generator coordinate method (90FU1H). For muon-catalyzed fusion see (88MA1V, 89BR23, 89CH2F, 90HA1V). For earlier work see (88AJ01).

2.5 ^{4}He(nn, γ)^{6}He $\quad Q_m = 0.973$

A mechanism for this reaction in astrophysical processes is suggested, and a reaction rate is calculated (96EF02).

3. ^{4}He(t, p)^{6}He $\quad Q_m = -7.507$

Angular distributions of the protons to ^{6}He*(0, 1.80) have been measured at $E_t = 22$ and 23 MeV. [No L-values were assigned.] No other states are observed with $E_x \leq 4.2$ MeV: see (79AJ01). Cross sections and angular distributions for the reaction products of the ^{3}H(α, p)^{6}He reaction were measured at $E_\alpha = 27.2$ MeV (92GO21). A potential description of ^{3}H + ^{4}He elastic scattering is discussed in (93DU09).

3.5 ^{6}He(p, p)^{6}He $\quad E_b = 9.975$

Calculations of the elastic scattering of protons from ^{6}He at $E_p \geq 100$ MeV are described in (92GA27). A folding model with target densities which reproduce the rms radii and a range of electroweak data was used.

4. ^{6}Li(e, π^+)^{6}He $\quad Q_m = -142.565$

(86SH14) report breaks in (e, π^+) spectra at $E_e = 202$ MeV corresponding to $E_x = 7$, 9, 12, 13.6, 17.7 and 24.0 MeV. Using the shape of the virtual photon spectrum results in groups with angular distributions that suggest that the states at 13.6, 17.7 and 24.0 MeV are spin-dipole isovector states [$J^\pi = 1^-, 2^-$]. See also (90SH1I). For the earlier work see (84AJ01). [Note: The states reported here at 7, 9 and 12 MeV are inconsistent with the work reported in reactions 7, 8, 14 and 15, and with the work on the analog region in ^{6}Be].

5. (a) ^{6}Li(π^-, γ)^{6}He $\quad Q_m = 136.060$
(b) ^{6}Li(π^-, π^0)^{6}He $\quad Q_m = 1.086$

The excitation of ^{6}He*(0, 1.8) and possibly of (broad) states at $E_x = 15.6 \pm 0.5$, 23.2 ± 0.7 and 29.7 ± 1.3 MeV has been reported: see (79AJ01). A study of capture branching ratios to ^{6}He*(0, 1.8) was reported in (86PE05). For reaction (b) see (84AJ01).

6. ^{6}Li(n, p)^{6}He $\quad Q_m = -2.726$

Angular distributions of the ground state proton group, p_0 have been reported at $E_n = 4.7$ to 6.8 MeV, at 14 MeV and at 59.6 MeV [see (79AJ01, 84AJ01)] and at 118 MeV (87PO18, 88HA2C, 88WA24). At $E_n = 59.6$ MeV broad structures in the spectra are ascribed to states at $E_x = 15.5 \pm 0.5$ and 25 ± 1 MeV with $\Gamma = 4 \pm 1.5$ and 8 ± 2 MeV (83BR1C, 84BR03) [see for discussions of the GDR strength]. The ground state reaction has also been studied at $E_n = 198$ MeV (88JA01).

An angular distribution of the proton group corresponding to population of the $E_x = 1.8$ MeV $J^\pi = 2^+$ state in ^{6}He was also reported (88WA24). See also (89WA1F). Angular distributions were measured for p_0 at $E_n = 280$ MeV in tests of isospin symmetry in (n, p), (p, p$'$) and (p, n) reactions populating the $T = 1$ isospin triads in $A = 6$ nuclei (90MI10). Cross sections for $\theta_{lab} = 1°$–$10°$ for $E_n = 60$–260 MeV were measured to obtain the energy dependence of the Gamow Teller strength (91SOZZ, 92SO02).

Several theoretical studies have been reported since the previous review. A dynamical multicluster model was used to generate transition densities for ^{6}He and ^{6}Li (91DA08). A microscopic calculation in the framework of the $\alpha + 2$N model (93SH1G) reproduced energy spectra and cross sections reliably. Predictions for the structure of a second $2^{(+)}$ resonance in the ^{6}He continuum were made with a $\alpha +$ N $+$ N cluster model (97DA01). Halo excitation of ^{6}He in ^{6}Li(n, p)^{6}He were studied using four-body distorted wave theory (97ER05); see also (97VA06). The status of experimental and theoretical research on nuclei featuring a two-particle halo is reviewed in (96DA31).

7. ^{6}Li(d, 2p)^{6}He $\quad Q_m = -4.950$

The previous review (88AJ01) notes that at $E_d = 55$ MeV, ^{6}He*(0, 1.8) [the latter weak] are populated: no other states are observed with $E_x \leq 25$ MeV [see (84AJ01)]. More recently cross sections at 0° were measured at $E_d = 260$ MeV (93OH01) and at $E_d = 125.2$ MeV (95XU1A). In both studies the cross section for (d, ^{2}He) showed a linear relationship with Gamow Teller strength from β decay or (p, n) reactions.

Table 6.5: Levels in ^{6}He from ^{6}Li(^{7}Li, ^{7}Be)^{6}He [a]

E_x (MeV)	J^π	Γ (MeV)	$d\sigma/d\Omega$ [b] (mb/sr)	G [c]
g.s.	0^+		0.72 ± 0.08	0.46 ± 0.05
1.92 ± 0.17	2^+		0.25 ± 0.04	0.40 ± 0.10
5.6 ± 0.3	2^+	12.1 ± 1.1	4.56 ± 0.48	0.39 ± 0.04
14.6 ± 0.7	$(1,\ 2)^-$	7.4 ± 1.0	2.11 ± 0.23	0.43 ± 0.06
23.3 ± 1.0		14.8 ± 2.3	1.75 ± 0.19	0.47 ± 0.07

[a] (96JA11). $E(^7\text{Li}) = 350$ MeV.
[b] $\theta_{cm} = 4.5°$.
[c] Averaged spin-flip signatures $G = Y_{coinc}/Y_{singles}$.

8. ^{6}Li(t, ^{3}He)^{6}He $\qquad Q_m = -3.489$

The ground-state angular distribution has been studied at $E_t = 17$ MeV. At $E_t = 22$ MeV only ^{6}He*(0, 1.8) are populated for $E_x \le 8.5$ MeV: see (79AJ01). Differential cross sections for the transition to ^{6}He*(1.8) are reported at $E(^6\text{Li}) = 65$ MeV (87AL1L).

9. ^{6}Li(^{6}Li, ^{6}Be)^{6}He $\qquad Q_m = -7.796$

Angular distributions have been studied for $E(^6\text{Li}) = 32$ and 36 MeV for the transitions to $^6\text{He}_{g.s.}$, $^6\text{Be}_{g.s.}$ and, in inelastic scattering of ^{6}Li [see ^{6}Li], to the analog state ^{6}Li*(3.56): for a discussion of these see the references quoted in (79AJ01).

9.3 ^{6}Li(^{7}Li, ^{7}Be)^{6}He $\qquad Q_m = -4.370$

Measurements of differential cross sections at $E(^7\text{Li}) = 82$ MeV are reported in (92GLZX, 93GLZZ, 94SAZZ) and at $E(^7\text{Li}) = 78$ MeV in (93SA35, 94RUZZ). The ^{6}He levels at $E_x = 0$ $J^\pi = 0^+$ and $E_x = 1.80$ $J^\pi = 2^+$ were identified. A maximum at $E_x \approx 6$ MeV is interpreted as consistent with a soft-dipole response expected in neutron-halo nuclei. A recent study at $E(^7\text{Li}) = 350$ MeV utilized magnetic analysis to observe transitions to the $J^\pi = 0^+$ ground state, and the $J^\pi = 2^+$ state at $E_x = 1.8$ MeV, as well as pronounced resonances at ≈ 5.6 MeV, ≈ 14.6 MeV and ≈ 23.3 MeV (96JA11). See Table 6.5.

10. (a) ^{7}Li(γ, p)^{6}He $\qquad Q_{\rm m} = -9.975$

(b) ^{7}Li(e, ep)^{6}He $\qquad Q_{\rm m} = -9.975$

At $E_\gamma = 60$ MeV, the proton spectrum shows two prominent peaks attributed to ^{6}He*(0+ 1.8, 18 ± 3): see (79AJ01). Reactions (a) and (b) have been studied by (85SE17). See also ^{7}Li, (84AJ01) and (86BA2G). An analysis of the available experimental data on ^{7}Li photodisintegration at energies up to $E_\gamma = 50$ MeV is presented in (90VA16, 90VAZM). See also the discussion of reactions involving scattering of polarized electrons from polarized targets (93CA11).

11. ^{7}Li(n, d)^{6}He $\qquad Q_{\rm m} = -7.751$

At $E_{\rm n} = 60$ MeV, the deuteron spectrum shows two prominent peaks attributed to states centered at $E_{\rm x} = 13.6$, 15.4 and 17.7 MeV ($\pm$ 0.5 MeV) and a possible state or states (populated with an $l_{\rm p}$ transfer ≥ 2) at $E_{\rm x} = 23.7$ MeV. DWBA analyses of the $\rm d_0$ and $\rm d_1$ groups are consistent with $l_{\rm p} = 1$ and $S(1{\rm p}_{3/2}) = 0.62$ for $^{6}{\rm He}_{\rm g.s.}$ and to $S(1{\rm p}_{1/2}) = 0.35$ for ^{6}He*(1.8): see (79AJ01). Measurements of the cross section as a function of energy for $E_{\rm x} = 10$–30 MeV were reported in (89CO22). See also the measurements at $E_{\rm n} = 14.1$ MeV (89SH1L).

11.3 ^{7}Li(π^+, pp)^{6}He $\qquad Q_{\rm m} = 122.304$

Cross sections were measured at $E_\pi = 50$, 100, 140, 180 MeV as part of a systematic study of pion absorption in light nuclei (92RA11).

11.7 ^{7}Li(π^-, ^{6}He)n $\qquad Q_{\rm m} = 128.811$

The results of measurements of inclusive spectra made with π^- mesons with momentum 90 MeV/c are presented in (93AM09). The probability of one-neutron emission was found to be $Y = (1.1 \pm 0.2) \times 10^{-3}$ per stopped π^-.

12. ^{7}Li(p, pp)^{6}He $\qquad Q_{\rm m} = -9.975$

From measurements at $E_{\rm p} = 1$ GeV (85BE30, 85DO16), the separation energy between 6–7 MeV broad $1{\rm p}_{3/2}$ and $1{\rm s}_{1/2}$ peaks is reported to be 14.1 ± 0.7 MeV. See also (83GO06) and (79AJ01). Differential cross section measurements at $E_{\rm p} = 70$ MeV are reported in

(88PA26). Contributions from 1p and 1s nucleons in ^{7}Li were distinguished. See also the review of experimental and theoretical nucleon and cluster knockout reactions in light nuclei presented in (87VD1A).

13. ^{7}Li(d, ^{3}He)^{6}He $\qquad Q_m = -4.481$

As summarized in the previous review (88AJ01), angular distributions of the ^{3}He ions to ^{6}He*(0, 1.8) have been measured at $E_d = 14.4$ and 22 MeV: they have an $l_p = 1$ character and therefore these two states have $J^\pi = (0\text{–}3)^+$. There is no evidence for any other states of ^{6}He with $E_x < 10.7$ MeV: see (79AJ01). (87BO39) [$E_d = 30.7$ MeV] deduce that the branching ratio of ^{6}He*(1.8) into a dineutron [n^2: $T = 1$, $S = 0$] and an α-particle is 0.75 ± 0.10. See also (85BO55) and (87DA1N). More recently, the energy spectrum of neutrons from the ^{6}He excited state at $E_x = 1.8$ MeV populated in this reaction was measured at $E_d = 23$ MeV (94BO46).

14. ^{7}Li(t, α)^{6}He $\qquad Q_m = 9.839$

As summarized in (88AJ01), the energy of the first-excited state is 1.797 ± 0.025 MeV, $\Gamma = 113 \pm 20$ keV. ^{6}He*(1.80) decays into ^{4}He + 2n. The branching ratio $\Gamma_\gamma/\Gamma_\alpha \leq 2 \times 10^{-6}$: for $\Gamma_{c.m.} = 113 \pm 20$ keV, $\Gamma_\gamma \leq 0.23$ eV. Angular distributions of the α_0 and α_1 groups have been measured at $E_t = 13$ and 22 MeV. No other α-groups are reported corresponding to ^{6}He states with $E_x < 24$ MeV (region between $E_x \approx 13$ and 16 MeV was obscured by the presence of breakup α-particles): see (79AJ01). Angular distributions were reported at $E_t = 0.151$ and 0.272 MeV (87AB09; α_0, α_1) and at $E(^7\text{Li}) = 31$ MeV. (87AL1L; to ^{6}He*(0, 1.8, 13.6)).

In more recent work, differential cross sections were measured at $E_t = 38$ MeV (92CL04). DWBA calculations are presented and spectroscopic factors are deduced.

The resonance theory of threshold phenomena was used to analyze differential cross sections for ^{7}Li(t, α)^{6}He*(1.8) for $\theta < 90°$ at $E_t = 80$–500 keV in a study of ^{10}Be levels (91LA1D).

15. ^{7}Li(^{3}He, p^{3}He)^{6}He $\qquad Q_m = -9.975$

At $E(^3\text{He}) = 120$ MeV the missing mass spectra show ^{6}He*(0, 1.8) and a strong, broad peak corresponding to ^{6}He*(16) [possibly due to unresolved states]. There is no indication of a state near 23.7 MeV but there is some evidence of structures at $E_x = 32.0$ and 35.7 MeV, with $\Gamma \leq 2$ MeV (85FR01).

16. (a) ^{7}Li(^{6}Li, ^{7}Be)^{6}He $\quad Q_m = -4.370$

(b) ^{7}Li(^{7}Li, ^{8}Be)^{6}He $\quad Q_m = 7.281$

In reaction (a) at $E(^6\text{Li})$ = 93 MeV a broad peak (Γ = 5.5 MeV) was reported at E_x = 14 MeV. A second structure may also be present at 15.5 MeV (87GLZW, 88BUZH). ^{6}He*(0, 1.8) are also populated (88BUZH). For reaction (b) see ^{8}Be. See also ^{7}Be, (84AJ01) and (88BU1Q, 84BA53), and see (96SO17) which involves ^{10}Be excited states. Measurements of differential cross sections at $E(^7\text{Li})$ = 22 MeV were reported in (88BO18).

17. ^{9}Be(n, α)^{6}He $\quad Q_m = -0.600$

Angular distributions have been reported for E_n = 12.2 to 18.0 MeV (α_0, α_1). No other states are observed with $E_x \leq 7$ MeV: see (79AJ01). For a study of possible dineutron breakup of ^{6}He*(1.8) see (83OT02). An analysis of the alpha and neutron spectra observed in this reaction for $E_n \approx 14$ MeV is presented in (88FE06). See also ^{10}Be and (83SH1J).

17.5 ^{9}Be(^{6}He, ^{6}He)^{9}Be $\quad E_b = 19.069$

Elastic scattering measurements for $E(^6\text{He})$ = 8.8–9.3 MeV were reported in (91SM01). The data are well reproduced with calculations using ^{6}Li or ^{7}Li optical model parameters. See also ^{9}Be.

17.8 ^{9}Be(^{9}Be, ^{6}He)^{12}C $\quad Q_m = 5.102$

Angular distributions were measured at $E(^9\text{Be})$ = 40 MeV. See ^{9}Be and ^{12}C.

18. ^{9}Be(^{6}Li, ^{9}B)^{6}He $\quad Q_m = -4.576$

Vector and tensor analyzing powers were measured for detection of the ^{6}He nuclei at $\theta_{cm} = 14°–80°$ at $E(^6\text{Li})$ = 32 MeV. See ^{9}B.

18.5 ^{9}Be(^{7}Li, ^{6}He)^{10}B $\quad Q_m = -3.389$

This reaction has been used as a source of ^{6}He beams for elastic scattering experiments at $E(^6\text{He}) = 8.8$–9.3 MeV (91SM01) and at $E(^6\text{He}) = 10.2$ MeV (95WA01).

20. ^{11}B(^{7}Li, ^{12}C)^{6}He $\quad\quad Q_\text{m} = 5.982$

At $E(^{11}\text{B}) = 88$ MeV the population of the ground state and the first-excited state at $E_\text{x} = 1.8 \pm 0.3$ MeV ($\Gamma \leq 0.2$ MeV) is reported (87BEYI). See also (88BEYJ).

21. ^{12}C(^{6}He, n)X

Peripheral fragmentation of ^{6}He at 240 MeV/A was studied (97CH1C, 97CH1G) in a kinematically complete experiment. It was found that one-neutron stripping to ^{5}He is the dominant mechanism. See also (93FE02).

22. ^{12}C(^{6}He, α)X

Fragmentation cross sections of ^{6}He were analyzed in the Glauber theory to investigate the importance of neutron correlation (94SU02). Fragmentation reaction data and beta-delayed particle emission data are reproduced successfully. Detailed structure is described with a multicluster model and halo-like structure is discussed in (95SU13).

23. ^{12}C(^{6}He, ^{6}He)^{12}C $\quad\quad E_\text{b} = 18.376$

Elastic and quasielastic scattering of ^{6}He on ^{12}C was studied at $E(^6\text{He}) = 10.2$ MeV (95WA01). See also (95PE1D). Measurements of cross sections were made at 41.6 MeV/A (96AL11). The results were successfully analyzed within a 4-body ($\alpha + \text{n} + \text{n} + {}^{12}\text{C}$) eikonal scattering model.

Potential parameters were deduced and differential cross sections were calculated for ^{6}He scattering at 50 and 100 MeV/A (93GO06). The possibility of studying the structure of the neutron halo in ^{6}He elastic rainbow scattering is discussed. See also (89SI02, 92CL04, 93FE02, 95GA24).

GENERAL:

References to articles on general properties of ^{6}Li published since the previous review (88AJ01) are grouped into categories and listed, along with brief descriptions of each item in Table 6.6.

Other Ground State Properties

$$\mu = +0.8220467(6) \text{ nm}, +0.8220560(4) \text{ nm: see (78LEZA)},$$
$$Q = -0.818(17) \text{ mb (98CE04)}.$$

The interaction nuclear radius of ^{6}Li is 2.09 ± 0.02 fm (85TA18). These authors have also derived nuclear matter, charge and neutron rms radii.

Quadrupole moment: The tiny quadrupole moment of ^{6}Li poses a difficult task for theoretical calculations. Except for a phenomenological (85ME02), a microscopic cluster (86ME13), and a Greens-Function Monte-Carlo (97PU03) calculation, the models fail to even predict the sign. See the discussion of three-body models in (93SC30). In (91UN02), this failure of the three-body models is blamed on the missing antisymmetrization of the valence nucleons with the nucleons in the alpha-core. Another microscopic cluster calculation (92CS04) considers the findings of (86ME13) to be due to a fortuitious choice of the model space.

Asymptotic D/S ratio [1] : The ratio of the D- and S-state asymptotic normalization constants, referred to in the literature as η, has been used widely to quantify the properties of the D-state wave function. There is general agreement in the $A = 2$–4 systems between theoretical calculations and empirical determinations of the normalization constants. See (88WE1C, 90EI01, 90LE24). The S-state α + d normalization constant for ^{6}Li appears to be well determined (93BL09, 99GE02), but both the magnitude and sign of η are uncertain.

In a two-body α + d model it was found (84NI01) that in order to reproduce the experimental quadrupole moment Q, the wave functions must have $\eta < 0$. However, three-body (α + n + p) models consistently result in predictions of $\eta > 0$ (90LE24, 95KU08). Recent microscopic six-body calculations using realistic NN potentials predict $\eta = -0.07$ (96FO04).

The asymptotic D/S ratio has been probed empirically by studying scattering processes, transfer reactions, and ^{6}Li breakup. These determinations usually rely on an underlying assumption as to the scattering or reaction mechanism. The S- and D-state asymptotic normalization constants were determined in a study of d-α scattering (78BO1A) from which η was found to be $+0.005 \pm 0.014$. Several $^{6}\vec{\text{Li}}$+^{58}Ni elastic scattering studies (84NI01, 95DE06, 95RU14) have described polarization observables with $\eta \approx -0.01$, while an investigation of the breakup of $^{6}\vec{\text{Li}}$ on ^{1}H suggests $\eta > 0$ (92PU03). A study of the ^{6}Li($\vec{\text{d}}$, α)^{4}He reaction (90SA47) found that η should lie in the range -0.010 to -0.015. Recently, a phase shift

[1] We are very grateful to K.D. Veal and C.R. Brune for providing these comments on the asymptotic D/S ratio for ^{6}Li

Table 6.6: ^{6}Li – General

Reference	Description
	Shell model
88GU13	Correlated basis functions calcs. of low-lying excited states of p-shell nuclei
88LOZW	Correlation effect on the shape of ^{6}Li; calc. quad. moment & quad. transition
89BA60	Investigation of E1 strength in Coulomb excitation of light nuclei (incl. ^{6}Li)
89LOZZ	Shape deformation and transition width of ^{6}Li in intermediate coupling
90HO01	Shell-model study of light neutron-rich nuclei (mostly ^{11}Li & ^{11}Be, also ^{6}Li)
90RY07	Spect. factor of ^{6}Li $\rightarrow \alpha +$ d; $\alpha +$ 2N model (antisymmetrization) comp. with shell model
90SK05	Effective interactions in the 0p-shell and calcs. of $A = 5$–15 nuclei
90VA01	Three-body forces in p-shell nuclei; $(0+1)\hbar\omega$ shell model space; improved E-levels
90WO10	p-shell nucl. in $(0-2)\hbar\omega$ model space; calc. spectra & ground state props. for ^{6}Li
91LU07	Magnetic form factor of ^{6}Li calc. in shell model, harm. oscill. potential with hard core
91PO10	Effective shell-model interactions; calc. spectra of ^{4}He & ^{6}Li
92GO17	Hartree-Fock shell model struct. of $^{6-11}$Li, $^{7-14}$Be; calc. binding energies, matter radii
92HE21	Nuclear moments & radii used to test shell & collective models of nuclei
92JU1C	Deduced new effective 0p-shell interactions; evaluated results for 0p-shell nuclei
92KW01	Two & three-fragment clustering of 1p-shell nucl. in the framework of the shell model
92LOZX	Double oscillator shell model with short-range correlations; gnd. & first 2 exc. states
92MA49	Baryonic decay & 1p-shell hypernucl. spectrosc.; translationally invariant shell model
92WA22	Effective interactions for the 0p1s0d nuclear shell-model space
93GO03	Shell-model description of nuclei with $4 \leq A \leq 16$ using Skyrme forces
93PO11	Shell-model calcs. of several properties of exotic (and normal) light nuclei, $A = 4$–30
93SK05	Calc. spectra & EM props. of states in ^{6,7,11}Li in shell model with various 2-body forces
93ZH15	Microscopic shell-model calcs. of the spectra of light nuclei vs. experiment (G-matrix)
94BA24	Realistic microscopic shell-model calculations for $A = 2$–7 nuclei
94BO04	Shell-model calcs. of transverse electron scat. form factors of states in p-shell nucl.
94BO1J	Descrip. of light nucl. with realistic interactions; analysis of gnd. & low-energy states
94ZH07	Simple approx. for starting-energy-indep. 2-body effective interaction applied to ^{6}Li
94ZH10	Nuclear shell-model calculations for ^{6}Li and ^{14}N with different NN potentials
94ZH23	Large-space shell-model calcs. for $A = 2$–6 nuclei; binding energies comp. with exp.
95DA1J	Study of some exotic properties of $^{6-11}$Li nuclei (quad. mom. ^{6}Li in the shell model
95YP01	Nucleon momentum distribution in light nuclei; single particle potential model
95ZA02	Self-weakening of the tensor interaction in a nucleus
95ZH32	Large-basis SM studies of ^{4,5}He, ^{6,7}Li with multivalued G-matrix effective interaction
96CS01	Comment on 94ZH23: questions adequacy of model for calc. of ^{6}Li quad. moment
96KU20	Realistic effective interactions for halo nuclei; 2-frequency shell-model approach
96NA24	No-core SM calcs. with starting-energy-independent multivalued effective interactions
96TH02	Test of SM interactions for nucl. structure calcs.; calc. binding energy & spectra of ^{6}Li
96ZH06	Reply to 96CS01's comment on 94ZH23
97KA1N	Shell model structures of low-lying excited states in ^{6,7}Li; analyzed e & p scatt. data
97NA03	Microscopic origins of effective charges in the shell model; calc. props. of ^{6}Li

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Cluster models
Review:	
90HO1Q	Alpha clustering in nuclei
Other articles:	
87LE1N	Coincidence reactions and the 3-body structure of ^{6}Li; $\alpha + \mathrm{d}$, $\mathrm{p} + (\mathrm{n}\alpha)$ models
88KA25	Convergence features in the pseudostate theory of the $\mathrm{d} + \alpha$ system
88KA38	Coulomb field influence on res. maxima in (α-n) cm system from $\mathrm{d} + \alpha \rightarrow \alpha + \mathrm{n} + \mathrm{p}$
88LI1N	Analysis of E2 transitions between $\mathrm{d} + \alpha$ cluster states of ^{6}Li with the RGM
88NE1C	Possibility of observing weak neutral currents in light clustering nuclei (^{6,7}Li)
88SR03	Features of direct and sequential Coulomb breakup of ^{6}Li ions
88SU12	2-body forces & amplitudes in 3-body model for ^{4}He(d, p)n with $E_{\mathrm{d}} = 12$, 17 MeV
88WE1C	Manifestations of the D-state in ^{2}H, ^{3}H, ^{3}He, ^{4}He, ^{6}Li
89BR23	Study of isospin violation in ^{4}He(d, ^{3}He)^{3}H; refined RGM used to describe ^{6}Li
89DA05	Calculation of 0^{+} $T = 1$ states of $A = 6$ nuclei in $\alpha + 2\mathrm{N}$ model with local potentials
89ER07	Exchange and correlation effects in the electromagnetic structure of light nuclei
89HE17	Interference and off-shell effects of fragment scattering in elastic breakup of light ions
89IS1A	Equations of RGM for a given permutation symmetry [f]; scattering of light clusters
89KU21	Study of electromagnetic form factors of light nuclei; multicluster dynamic model
89LE07	Knockon exchange contribution in resonating-group study of nucl.-nucl. interaction
89RU06	Spin-dependence of the ^{6}Li-^{120}Sn interaction; d-α cluster folding (CF) model
89SA08	Breakup effect on ^{6}Li-nucleus scattering at intermediate energies; CF model
89SE06	(^{6}Li, d) stripping into high-lying unbound states of ^{16}O
89TR18	Two- and four-nucleon clusters in light and heavy nuclei
90CR04	Tensor interaction effects in the ^{4}He(^{2}H, γ)^{6}Li capture reaction
90DAZT	Calc. $A = 6$ ($J = 0{,}1$; $T = 1{,}0$) multiplet in micro. $\alpha + 2\mathrm{N}$ model; binding E, Coulomb E
90DAZS	Matter & nucleon transition densities of ^{6}He (0^{+}), ^{6}Li (1^{+}) in micro. $\alpha + 2\mathrm{N}$ model
90DAZR	β-decay of the ground state of ^{6}He in three-particle $\alpha + 2\mathrm{N}$ model
90KU12	Detailed study of the cluster struct. of light nucl. in a 3-body model; EM structure of ^{6}Li
90KU1S	Effects of the internal structure of the alpha particle in the 3-body problem
90LO14	Cluster-model interpretation of the ^{6}Li(e, e$'$p) reaction
90RY07	Spect. factor of $^{6}\mathrm{Li} \rightarrow \alpha + \mathrm{d}$; $\alpha + 2\mathrm{n}$ model (antisymmetrization) comp. with shell model
90VA16	Cluster effects & interaction in the final state of photodisintegration products of ^{6,7}Li
90WA17	Spectral function of p-n pairs in ^{6}Li, from the ^{6}Li(p, pα)pn reaction at 200 MeV
91DA08	Dyn. multicluster model with hyperspherical harmonics; electroweak & charge-exch. rxns
91ER1C	^{6}Li as three body α-2n system; role of exchange effects in electromagnetic form factors
91HI07	Anomalous renormalization of cluster-folding interactions for ^{6}Li-nucl. scatt. at low E
91KU1B	Multicluster models of light nuclei predictive power for strong, EM and weak interacts.
91KU05	3-body deuteron-nucleus scattering with extra resonance channels
92ALZV	Parity-violating α-decay of the 0^{+}, $T = 1$ state of ^{6}Li; RGM calc.

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Cluster models (continued)
92CS04	Dynamical microscopic 3-cluster ($\alpha + p + n$) description of the ground state of ^{6}Li
92ES04	α-d resonances and the low-lying states of ^{6}Li
92FU10	Reaction mechanisms in the 6-nucleon system with the multiconfiguration RGM
92KA06	Self-consistent calculation of the interactions of very light nuclei with ^{6}Li
92KU16	Supersymmetric potentials & Pauli principle in the problem of dα scattering lengths
92RA22	(^{6}Li, d) reaction on $16 \leq A \leq 90$ nuclei in ZR-DWBA & FR-DWBA formalisms
92RYZY	EM props. of 6-nucleon system in multicluster dynamic model with antisymmetrization
92VA12	Cluster effects in ^{6,7}Li photodisintegration; photonuclear reactions on $A = 3,4$ nucl.
93AR1H	Coupling of collective states in the continuum of light nuclei incl. ^{4}He & ^{6}Li
93DU02	Potential description of cluster channels of ^{6,7}Li nuclei
93KU27	Prohibition & suppression of multicluster states by Pauli prin. in dynamical approach
93MU12	Calculation of the vertex constant for $^6\text{Li} \rightarrow \alpha + d$ in the 3-body model
93RY01	Properties of a 6-nucleon system in multicluster dynamic model with antisymmetrization
93RY1B	β-decay and muon-capture in $A = 6$ system, calculated in the dynamical $\alpha + 2N$ model
93SCZV	Polarization of nucleons in ^{6}Li, a possible polarized isoscalar nucleon target
93SC30	Nucleon polarization in three-body models of polarized ^{6}Li
93SH1G	Microscopic calc. of weak interaction in $A = 6$ nuclei; three particle $\alpha + 2N$ model
94CS01	Dynamical micro. cluster model descrip. of β-delayed deuteron emission from ^{6}He
94CS04	3-body resonances in $A = 6$ nuclei; soft dipole mode problem of neutron halo nuclei
94DU07	Calc. Coulomb form factors of ^{6,7}Li; clus. mod. based on potentials with forbidden states
94FE01	Three-body halos: gross properties calc. using hyperspherical harmonics
94WE10	^{6}Li inelastic form factors in a cluster model; transition into low-lying $T = 0,1$ states
95AR10	Neutron-proton halo structure of the 3.563-MeV 0^+ state in ^{6}Li; $\alpha + p + n$ model
95DU12	Photonuclear processes on ^{6}Li in cluster models based on potentials with forbidden states
95EI1A	Search for ^{6}Li D-state effects; discuss uses of polarized Li induced transfer reactions
95ER1B	Calc. pion photoproduction & inelastic scattering off ^{6}Li ($\alpha + 2n$ model)
95KU08	3-body $\alpha + 2N$ model with realistic nuclear forces; calc. many props. of $A = 6$ nucl.
95KU1G	Spectral EM and weak interaction properties using the New Dynamic Model
95SH1R	Democratic 3-body ($\alpha + 2N$) decay of $A = 6$ nucl.
95SU13	Study of halo structure in light nuclei with a multicluster model
95ZH21	One-nucleon spectroscopy in 3-particle model of ^{6}Li nucleus
96CS03	Parity-violating α-decay of 3.56 MeV $J^\pi = 0^+$, $T = 1$ state of ^{6}Li; micro. 3-cluster model
96RY06	Shell expansion of wave function in multicluster dynamical mod. with antisymmetrization
96SU11	Occupation prob. of harmonic-oscillator quanta for micro. cluster-model wave functions
97VA09	3-cluster model of $A = 6$ nuclei; uses algebraic version of RGM
97VA05	Microscopic description of light unstable nuclei with the stochastic variational method

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Special States
Review:	
92GO1Q	Study of high-spin stretched states in light nucl.; M4 excitation of p-shell nucl.
Other articles:	
88GU13	Correlated basis functions theory of light nuclei: spectra of light nuclei ($4 \leq A \leq 16$)
88HA25	Proton & neutron transition densities in ^{6,7}Li from low energy neutron & proton scatt.
88SR03	Features of direct and sequential Coulomb breakup of ^{6}Li ions
88WA29	Spectral function of the $p_{3/2}$ nucleons in ^{6}Li, exp. and theory
89BA60	Investigation of E1 strength in Coulomb excitation of light nuclei (incl. ^{6}Li)
89LOZZ	Shape deformation and transition width of ^{6}Li
90AS06	Calculation of the energy of monopole giant resonances by the phase-space method
90DAZT	($J = 0,1$; $T = 1,0$) multiplet in micro. $\alpha + 2$N model with realistic αN & NN potentials
90DAZS	Matter & nucleon transit. densities of ^{6}He(0^{+}) & ^{6}Li(1^{+}) in microscopic $\alpha + 2$N model
90KU12	Detailed study of the cluster struct. of light nucl. in a 3-body model; EM structure of ^{6}Li
90KU16	Ener.-dependent phase-shift analysis of low-ener. ^{4}He + ^{2}H scatt. (Pade-approx. tech.)
90SK05	Effective (3-body) interactions in the 0p-shell and calcs. of $A = 5$–15 nuclei
91AF1A	Resonances in few-body systems (^{2}H, ^{4}He, ^{6}Li)
91AN1J	Search for exotic states $T = 2$, $Q = +3$ & $T = 3$, $Q = +4$ in 1 GeV proton-nucl. collisions
91VA12	Decay properties of giant dipole resonance of ^{6,7}Li studied in photonuclear reactions
92DAZT	3-3 resonant scattering and $A = 6$ nuclei excited states (calc. 3-3 scatt. via hyp. harm. meth.)
92DAZU	Faddeev/hyperspherical study of $A = 6$ nuclei excited states
92LOZX	Short-range correlation in 6-body wave function of ^{6}Li; calc. gnd. & first 2 exc. states
93DA07	Resonance $3 \rightarrow 3$ scattering & structure of 3-particle excited states of $A = 6$ nuclei
	Electromagnetic transitions
Review:	
90IS08	Configurational splitting of the giant dipole resonance in light atomic nuclei (incl. ^{6}Li)
93EN03	Strengths of γ-ray transitions in $A = 5$–44 nuclei
97FA1E	Effects of the nuclear tensor interaction, incl. E1 & M1 moments
Other articles:	
88ES01	Elastic electromagnetic form factors of ^{6}Li from 3-body ($\alpha + 2$N) models
88LI1N	Analysis of E2 transitions between $d + \alpha$ cluster states of ^{6}Li with the RGM
89ASZZ	Calculation of giant monopole resonances in light nuclei by phase space method
89BA60	Investigation of E1 strength in Coulomb excitation of light nuclei (incl. ^{6}Li)
89ER07	Exchange and correlation effects in the electromagnetic structure of light nuclei
89KU21	Study of electromagnetic form factors of light nuclei; multicluster dynamic model

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Electromagnetic transitions (continued)
89LI1N	Analysis of E2 transitions between $d+\alpha$ cluster states of ^{6}Li with the RGM
89LOZZ	Shape deformation and transition width of ^{6}Li (shell model)
90BU29	Possibility of observing an isoscalar E1-multipole in ^{6}Li; potential cluster model
90KU12	Detailed study of the cluster struct. of light nucl. in a 3-body model; EM structure of ^{6}Li
90LU06	Magnetic form factor of ^{6}Li using hard-core common H.O. potential vs. data
91BO1Q	MEC corrections to M1 transitions in $A = 4$–16 (p-shell) nuclei; shell model
91ER1C	^{6}Li as three body $\alpha - 2$n system; role of exchange effects in electromagnetic form factors
91JA13	Matrix elements of magnetic and electric moments in the supermultiplet scheme
91UN02	^{6}Li elastic form factors and antisymmetrization
92DAZV	Faddeev & hyperspher. study of $A = 6$ nucl.: static EM props. & β-decay of ^{6}He
92JU1C	Potential model, 2-body matrix elements used to obtain many props. of $A = 5$–16 nucl.
92RYZY	EM props. of 6-nucleon system in multicluster dynamic model with antisymmetrization
94BA1G	Importance of nuclear effects in the dissociation of ^{6}He & ^{6}Li at $E/A = 65$ MeV
94NA02	E2 properties of $A = 6$–10 nucl. (incl. some far from stability); shell model
	Astrophysics
Reviews:	
89RE1D	The galactic evolution of lithium
90MA1Z	Nuclear reaction uncertainties in standard and non-standard cosmologies
90ST1H	Predictions of primordial nucleosynthesis in standard big-bang vs. light element abunds.
93MA1M	Review of primordial nucleosynthesis beyond the standard big bang
93ST1D	Cosmic ray nucleosynthesis in the early galaxy; abundances of Li, Be, B
94BA1A	Coulomb dissociation studies as a tool of nuclear astrophysics
96RE16	Coulomb dissociation experiments of astrophysical significance
Other articles:	
88BA2I	Correlation between Li abund. & proj. rot. vel. in lower-main-sequence stars of α-Per
88BR1H	Li isotope ratio in Pop. II halo dwarfs; test of late-decaying massive particle nucleosyn.
88CA1N	Reaction rates of astrophysically important thermonuclear reactions involving light nucl.
88DI1C	Effects of late-decaying massive part. on nucleosyn. & primordial abund. of light nucl.
88HA1V	Li isotope ratios from (p, α) cross sections
89AU1C	Primordial lithium and galactic chemical evolution
89BA2S	Angular correlation in the Coulomb dissociation method for radiative capture processes
89BO1F	Photoerosion and the abundances of the light elements (incl. ^{6}Li)
89BR1M	Search for and suggested explanation for existence of Li-rich giant stars
89CH1Z	Li abund. in cluster giants; constraints on meridional circulation transport on main seq.
89DE1L	Analysis of primordial Li abundance; standard big-bang and stellar-evolution models

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Astrophysics (continued)
89GI1E	Carbon isotope ratios and lithium abundances in open cluster giants
89GU1J	Thermonucl. breakup reactions of light nucl.; γ-ray line production & other applications
89JI1A	Nucleosynthesis inside thick accretion disks around massive black holes
89KI1I	Observation of resonant and nonresonant Coulomb break-up of ^{6}Li
89PI1K	Absence of ^{6}Li in HD 84937 appears to rule out some non-standard theories of BBN
89ST1L	Lithium abundances among solar-type pre-main-sequence stars
90DE1O	Lithium in halo stars from standard stellar evolution
90FU1H	Calc. ^{3}He(^{3}H, γ)^{6}Li reaction rate using gen. coord. meth.; possible source of ^{6}Li in BBN
90MA1O	CNO & ^{6}Li from big-bang nucleosynthesis (BBN); impact of unmeasured reaction rates
90SI1D	Spallation processes and nuclear interaction products of cosmic rays
91AB1B	Discovery of IY Hya, a super Li-rich carbon star
91BE05	Direct projectile break-up and its relation to the astrophysically relevant fission reactions
91DE1E	Lithium abundances in carbon stars found to be lower than those for M giants
91SC23	A simple expression for the cross-section factor in sub-barrier nuclear fusion
92ST1A	Li, Be, B prod. via collisions of cosmic rays & interstellar gas nucl. in the early galaxy
93LE1C	Deduced the ^{7}Li/^{6}Li ratio toward the ρ Ophiuchi diffuse cloud from observation
93RE1D	The ^{7}Li/^{6}Li ratio and the stellar yield of ^{7}Li
93SM1A	The ^{6}Li/^{7}Li ratio in the sub-dwarfs HD-19445 and HD-84937 vs. Yale models
93ST1F	Significance of the interstellar ^{7}Li/^{6}Li ratio
94CH1K	Primordial abundance of ^{6}Li and ^{9}Be from stellar evolution models
94KH1D	Nonequilibrium cosmological nucleosyn. of light elements; Monte-Carlo calcs.
95IG06	Calc. astrophysical S-factor of $\alpha + \mathrm{d} \rightarrow {}^6\mathrm{Li} + \gamma$: $S(0) = 1.441$ mb MeV
95LA1G	In situ synthesis of ^{6}Li by galactic cosmic rays in halo stars
95SC29	Cosmology and unstable nuclei and the dark matter argument
95SZ1A	Reaction rate for ^{6}Li(p, α)^{3}He and ^{6}Li(d, α)^{4}He deduced from meas. cross sections
97KI02	Optical theorem formulation of low-energy nuclear reactions
97NO04	Nuclear reaction rates and primordial ^{6}Li; discusses BBN production possibility
97TA1A	Possible inhibition of fusion for weakly bound nuclei
	Complex reactions involving ^{6}Li
Reviews:	
89OG1B	Neutron decay of very neutron-rich light nuclei studied with heavy-ion accelerators
89SI1H	Exp. results on light-charged particle emission in fission and scissions point params.
90GE07	Fragmentation experiments at intermediate energies
Other articles:	
87ST01	Projectile-like fragments from ^{14}N beams at 15, 25, and 35 MeV/nucleon
88BA53	Isotopic yield ratios of complex fragments from heavy ion induced reactions

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Complex reactions involving ^{6}Li (continued)
88BE56	Formation of light nuclei in rxns. with ^{11}B & ^{20}Ne at energies of 18–20 MeV/nucleon
88FO03	Angular correlations between light particles; heavy ion collisions near Fermi energy
88GR32	Role of the Pauli principle in heavy-ion elastic scattering; generalized optical model
88HA2E	Quantum stat. model of fragment formation: entropy & temp. in heavy ion collisions
88KE07	Cross sects. for ^{16}O(^{7}Li, ^{6}Li) analyzed using finite-range DWBA (features disagree)
88KH08	Exchange effects in nuclear rainbow scattering; microscopic calc.
88KI06	Target mass depend. of neutron emission in collisions with 35 MeV/nucleon ^{14}N ions
88NAZV	Optical model analyses of cross sections for 210 MeV ^{6}Li + ^{90}Zr, ^{208}Pb elas. scatt.
88RA27	DWBA analysis of (d, ^{6}Li) reaction on nucl. between ^{12}C and ^{68}Zn at various energies
88TR03	Entropy in ^{12}C+^{197}Au at intermediate energies; quantum stat. model
89BA2N	Evaluation of hypernucl. production cross sections in relativistic heavy-ion collisions
89BO1Q	Temperatures in heavy ion reactions; simulation via quasiparticle dynamics
89CA14	ID of projectile sequential decay& incomplete fusion in ^{27}Al(^{10}B, ^{6}Liα) & other rxns.
89GE1A	Complex fragments emitted in excited states
89GR04	Fission barriers of light nuclei; rotating finite range & rotating liquid drop models
89HA1L	Statistical decay of fragments from C + ^{12}C at 2.1 GeV/nucleon
89KI13	Fragment production in ^{14}N + C, Ni, Ho reactions at 35 MeV/nucleon
89NA03	Fragmentation products with nonstatistical excited-state populations
89SA08	Breakup effect on ^{6}Li-nucleus scattering at intermediate energies; CF model
89YO02	Nucleon transfer in ^{197}Au + ^{16}O at $E < 10$ MeV/u; projectile-like products observed
90CH09	Coulomb-modified Glauber model description of heavy-ion reaction cross sections
90GL06	Projectile-like fragment prod. in ^{14}N-induced rxns. at projectile energies of 60 MeV A
90TA1I	The imaginary part of channel-coupling potentials for ^{6}Li-induced reactions
92AR11	α-cluster struct. of excited states of light nucl. from comp. of α-clus. and (^{6}Li, d) data
94SA33	Elastic scattering of ^{6}Li from nucl. between ^{12}C and ^{208}Pb; strong-absorption model
	Applications
88MC1E	Propagation chain & chain branching reactions for p + ^{6}Li fueled fusion reactors
88PO1J	Aneutronic, nonradioactive nucl. energy generation in ^{3}He-induced fission of ^{6}Li
89EU1A	Production of isotopically enriched ^{6}Li targets by ion implantation
89GA09	Pionic distortion factors for radiative pion capture studies
89LE1P	Searches for low-temp. nuclear fusion of deuterium in palladium (none observed)
89ZI1A	Electrochemical experiments in cold nuclear fusion (no nuclear fusion observed)
90KO1W	Meas. LANSCE neutron flux from 0.025 eV to 100 keV rel to ^{6}Li(n, α)^{3}H
96PE28	^{6}Li nucl. quad. coupling const. in tri(isopropyl)phenyllithium; chem. shift anisotropy

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Muon and neutrino capture and reactions
Review:	
89MU1G	Study of fundamental interactions with nuclear muon capture
Other articles:	
89KA33	Second-class currents and muon-neutrino rest mass in muon capture by ^{6}Li & ^{3}He
89KA35	Meson exchange 2nd class currents and neutrino mass in muon capture by light nucl.
89NA01	Calc. radiative-pion-capture and muon-capture rates using sum rule techniques
89TE04	Weak neutral current effect on electron energy spectrum in nuclear β-decays
90CH13	Muon capture rates in nuclei calculated & compared to experimental values
90HA1V	Muon catalysed fusion of nuclei with $Z \geq 1$
92ZH04	Pred. of constituent quark model (EMC effect) consistent with New Muon Collab. data
93RY1B	β-decay and muon-capture in $A = 6$ system, calculated in the dynamical $\alpha + 2$N model
93SH05	3-body model calcs. of disinteg. of ^{6}Li by solar neutrino & reactor antineutrino
94BE1P	Nuclear transition in the muonic molecule tμ^{3}He through intermed. state of ^{6}Li(3^{+},0)
94MU1E	^{6}Li(μ^{-}, ν_{μ})^{6}He studied for info. on weak hadron form factors; test standard model
94TR1A	Study of (γ, η) rxns. on nucl.; phenomenological amplitudes of the γp $\rightarrow \gamma\eta$ process
95AM10	Re-evaluation of nucl. struct. function ratios for ^{6}Li & other nucl. (New Muon Collab.)
95KU35	Calc. μ-cap. rates on p-shell nucl. to determine const. of induced pseudoscalar interact.
96MA65	Mesonic & binding contributions to EMC effect in relativistic many-body approach
97BA1B	T-noninvariant effect in muon capture by ^{6}Li with decay to a continuum
	Reactions involving pions, other mesons and baryon states
Reviews:	
89DO1K	Production mechanisms and spectroscopy of Σ-hypernuclei
89KH1E	Theor. & exp. papers presented at IV Int. Symp. on Mesons and Light Nuclei
89PA18	Exp. situation of Σ-hypernuclei; results from joint Heidelberg-Tokyo effort at KEK
91CH1D	History, current status, and ideas for future research involving the (π^{+}, K^{+}) reaction
94YA1J	Highly excited states of light Λ-hypernuclei (including $^{6}_{\Lambda}$Li)
95HU05	K^{+} scattering from nuclei; present status, implications of new cross section data
Other articles:	
87BE2B	Inclusive differential cross sections of photoproduction of π^{0} mesons in ^{6}Li
88ER06	Calc. inelastic & elastic pion scattering by ^{6}Li near the Δ_{33}-resonance energy
88GR1E	Systematics of inclusive double charge exchange deduced from data
88NA06	π-^{6}Li scattering investigated within Watson's multiple-scattering theory
88ZHZZ	Meas. ^{6}Li(π^{+}, 2p)^{4}He & ^{6}Li(π^{+}, p) over the Δ(1232) resonance region
89BE1B	Photoproduction of π^{0} mesons on nuclei (incl. ^{6}Li) at low angles near Δ_{33} resonance
89DO1I	Production mechanisms & spectroscopy of Σ hypernuclei; experiments suggested
89DO1L	Nuclear structure in Δ & S_{11} resonance regions; examines M1 trans. in ^{6}Li

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Reactions involving pions, other mesons and baryon states (continued)
89GA09	Pionic distortion factors for radiative pion capture studies
89GE10	Threshold pion-nucleus amplitudes predicted by current algebra
89KA27	K^{+}-nucl. total cross section analysis; nucl. corrections calc. for $q = 550$–800 MeV/c
89NA01	Calc. radiative-pion-capture and muon-capture rates using sum rule techniques
90AM04	Production of ultraheavy hydrogen isotopes in absorption of π-mesons by ^{6,7}Li nucl.
90BO1Z	Measurement of the vector analyzing power iT_{11} in $\pi^{\pm}$-^{6}Li scattering
90CH12	Inclusive radiative pion capture in nuclei analyzed from a many-body point of view
90RA05	Charged-part. multiplicities after pion absorption on ^{6}Li meas. at $E(\pi) = 150$ MeV
90RAZZ	Systematics of pion absorption on ^{6}Li meas. from 50–200 MeV
90TA1H	Spin effects in pion-nucleus scattering; iT_{11} & A_{y} obtained for scatt. from ^{6}Li & ^{15}N
90ZHZZ	Measured ^{6}Li(π^{+}, 2p) reaction around the $\Delta(1232)$ resonance region (A)
90ZH1U	Measured ^{6}Li(π^{+}, 2p) reaction around the $\Delta(1232)$ resonance region
91BE22	Coherent and incoherent η-photoproduction from nuclei, incl. ^{6}Li
91CI08	Momentum-space method calc. of strong-interaction shifts & widths in pionic atoms
91GO21	Pionic atoms, relativistic mean-field theory and the pion-nucleon scattering lengths
91KA1R	Calc. ^{6}Li and ^{12}C diff. cross sections for two-stage pion photoproduction processes
91SE06	Evidence for dineutrons in extremely neutron-rich nuclei (some from ^{6}Li(π^{-}, π^{+})^{6}H)
91TR02	Inelastic photoprod. of mesons on nucl. with γ deexcitation of the excited recoil nucl.
92AL23	K^{+} nucleus total cross section experiment and nuclear medium effects
92KH04	Pion absorption on polarized nuclear targets
93CH33	π^{-}, nucleon yields from light targets irradiated by ^{2}H & ^{3}H beams at 1 GeV/nucleon
93MA14	Effect of isospin on three nucleon pion absorption in light nucl.; comp. ratios to data
93SA19	Influence of the nuclear medium on K^{+} cross sections
94FE21	Spectroscopy of Λ-hypernuclei and hyperon-nucleon interactions
95CA44	Unconventional medium effect in K^{+} scattering; microscopic optical model calcs.
95ER1B	Calc. pion photoproduction & inelastic scattering off ^{6}Li ($\alpha + 2$n model)
96CA45	Relativistic Schrödinger equation of meson-nucl. scatt.; includes recoil of target nucl.
97FR08	Medium effect in K^{+} nucl. interact.; consistent analysis of integral & diff. X sections
	Reactions involving antiprotons
86AU1D	Studies of nuclear structure in antinucleon charge-exchange reactions
89DI11	Intranuclear Cascade model calc. of (π^{+}, p), ($\bar{\mathrm{p}}$, p) and (K^{+}, p) spectra near 1 GeV/c
90JO01	The strong-interaction fine and hyperfine structure of antiprotonic atoms
92ZH19	$\bar{\mathrm{p}}$ elastic scatt. on ^{6}Li, ^{4}He at 180 MeV; Glauber-Sitenko multiple scatt. theory
93PL05	Antiproton-nucleus annihilation at rest
93SU06	Production of light particles after antiproton-nucleus annihilation; statistical models
94ZH28	Elastic, inelastic scattering of protons and antiprotons by ^{6}Li at intermediate energies

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Hypernuclei
Reviews:	
89CH2D	Experimental and theoretical status of strange-particle nuclear physics
89DO1K	Production mechanisms and spectroscopy of Σ-hypernuclei
89PA18	Exp. situation of Σ-hypernuclei; results from joint Heidelberg-Tokyo effort at KEK
89ZO1A	Hypernuclear physics; partial review of 4th Int. Symp. on Mesons and Light Nuclei
92DO14	Open problems and future prospects for hypernuclear physics
92GA1L	Summary of Shimoda Int. Symp. on hypernuclear and strange particle physics
94YA1J	Highly excited states of light Λ-hypernuclei (including ${}^{6}_{\Lambda}$Li)
95BA20	Strange exotic atoms; optical model and density dependent potentials
Other articles:	
89BA1E	Production of hypernuclei (including ${}^{6}_{\Lambda}$Li) in relativistic ion beams
89BA2N	Evaluation of hypernucl. production cross sections in relativistic heavy-ion collisions
89DE1Y	Observation of two non-mesonic decays in flight of Li and B hyperfragments
89TA1T	Schmidt diagrams & configuration mixing effects on hypernuclear magnetic moments
91AK1E	Few-body Σ and $\Lambda\Lambda$ hypernuclear systems
92MA49	Baryonic decay & 1p-shell hypernucl. spectrosc.; translationally invariant shell model
92MO30	Mesonic weak decays of Λ- and $\Lambda\Lambda$-hypernuclei (including ${}^{6}_{\Lambda}$Li)
93OH04	Highly excited states of ${}^{6}_{\Lambda}$Li studied in microscopic cluster model (^{3}He + d + Λ)
94FE21	Spectroscopy of Λ-hypernuclei and hyperon-nucleon interactions
94LI1A	Ground state energy of the hypernucleus ${}^{6}_{\Lambda}$Li; α + p + Λ cluster model
95SA17	Poss. narrow Σ hypernuclear states; meas. hypernuclear mass spectra for ^{6}Li(K^{-}, $\pi^{\pm}$)
96HI1B	Three-body model study of $A = 6$–7 hypernuclei: halo and skin structures
	Other topics
Review:	
96DA31	Nuclei with two-particle neutron halo: theory and recent experiment
Other articles:	
87LI34	Probability of forming 6-quark clusters and the increase of nucleon radius in nuclei
88BE1Q	Theoretical explanation of the two deuteron alpha particle vertex
88TR02	Interacting boson scheme for light nuclei
89AR02	Quark degrees of freedom and nuclear photoabsorption
89BA60	Investigation of E1 strength in Coulomb excitation of light nuclei (incl. ^{6}Li)
89KI07	Observation of nonresonant Coulomb break-up of 156 MeV ^{6}Li projectiles
89SR1D	Coulomb dissociation of light ions (incl. ^{6}Li) predicted, comp. with exp.
90MU10	Microscopic calculations of nucleon-separation vertex constants for 1p-shell nuclei
90SR01	Prior-form DWBA analysis of the elastic breakup of 156 MeV ^{6}Li projectiles
94ME05	Quark antisymmetrization & deep-inelastic scattering; nuclear structure functions

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Other topics (continued)
94SP02	Quark antisymmetrization & deep-inelastic scatt.; nucl. quark momentum distributions
95DO23	Phenomenological transition amplitudes in selected 1p-shell nuclei, incl. ^{6}Li
96FO04	Femtometer toroidal nucl. struct.; two-nucleon density distrib. in $T = 0$, $S = 1$ states
96ME16	Relativistic Hartree-Bogoliubov description of ^{11}Li neutron halo; $^{6-11}$Li calcs.
96TS1A	Cross comparison of nucl. temps. from excited state populations and isotope yields
96XU05	Quark and gluon distributions in nuclei investigated with parton model
97ME11	Relativistic Hartree-Bogoliubov description of $^{6-11}$Li
97PO12	Formula for Coulomb energy reproduces energy levels of light nuclei
97SA33	Extrapolation method for determining nuclear vertex constants; Pade approximants
97TA12	Exploration of E & Γ of res. by analytic contin. of bound-state as fit of coupling const.
97WE03	On isotope thermometers: using isotope yield ratio to extract nuclear temps.
	Ground state properties of ^{6}Li
Reviews:	
89RA17	Compilation of exp. data on nuclear moments for ground & excited states of nuclei
89OT1A	Nuclear radii and moments of unstable isotopes (covers $^{6-11}$Li)
90BA06	Radii & lifetimes of low-lying states of neutron-rich light nuclei
92PY1A	Nuclear quad. moments for $Z = 1$–20 rev., related to numerical methods in quant. chem.
Other articles:	
88DO17	Classical simulation of nuclear systems; calc. sizes and binding energies of finite nuclei
88ES01	Elastic electromagnetic form factors of ^{6}Li from 3-body ($\alpha + 2$N) models
88KA25	Convergence features in the pseudostate theory of the d + α system
88TA10	Meas. interaction cross sections using Be & B beams; isospin dependence of nucl. radii
88WE1C	Manifestations of the D-state in ^{2}H, ^{3}H, ^{3}He, ^{4}He, ^{6}Li
89BA60	Investigation of E1 strength in Coulomb excitation of light nuclei (incl. ^{6}Li)
89BE03	High-energy reaction cross sections of light nuclei (Glauber model)
89DA05	Calculation of 0^{+} $T = 1$ states of $A = 6$ nuclei in $\alpha + 2$N model with local potentials
89ES05	Inelastic electron scattering M1 transition form factor of ^{6}Li (3-body model)
89RU06	Spin-dependence of the ^{6}Li-^{120}Sn interaction; d-α cluster folding (CF) model
89TR18	Two- and four-nucleon clusters in light and heavy nuclei; evidence from data noted
89WIZO	Microscopic 6-body calcs. of gnd.-st. bind. energies & density dist. of ^{6}He, ^{6}Li (VMC)
90CH26	Charge and mass dependence of nucl. interaction cross sections; Thomas-Fermi model
90HO01	Shell-model study of light neutron-rich nuclei (mostly ^{11}Li & ^{11}Be, also ^{6}Li)
90KU12	Detailed study of the cluster struct. of light nucl. in a 3-body model; EM structure of ^{6}Li
90LI39	Matter distribution in neutron-rich light nuclei from total reaction cross section data
90LO14	Cluster-model interpretation of the ^{6}Li(e, e′p) reaction
90SH12	Extreme collective limits for the magnetic moments of odd-odd nuclei

Table 6.6: ^{6}Li – General (continued)

Reference	Description
	Ground state properties of ^{6}Li (continued)
90VA01	Three-body forces in p-shell nuclei; $(0+1)\hbar\omega$ shell model space with schematic 3BF
90WA17	Spectral function of p-n pairs in ^{6}Li, from the ^{6}Li(p, pα)pn reaction at 200 MeV
90WO10	p-shell nucl. in $(0-2)\hbar\omega$ model space; calc. spectra & ground state props. for ^{6}Li
91DA04	$J^{\pi}=0^{+}$, 1^{+} states studied in micro. $\alpha+2$N model & method of hyperspherical functions
91DA24	Decay of ^{6}He grnd. st.; calc. ground-state wave functions of ^{6}He & ^{6}Li ($\alpha+2$N model)
91KO36	Relativistic mean-field approach to neutron halos in $^{6-11}$Li; calc. BE, radii, sep. energ.
91LU07	Magnetic form factor of ^{6}Li calc. in shell model, harm. oscill. potential with hard core
91WI05	Variational calcs. of few-body nucl. (^{3}H & ^{4}He); extension to ^{5}He, ^{6}He, ^{6}Li discussed
92BLZX	^{6}Li $\rightarrow$ ^{4}He + d vertex constant inferred from ^{4}He + d phase-shift analysis
92CS04	Dynamical microscopic 3-cluster (α + p + n) description of the ground state of ^{6}Li
92DAZV	Faddeev & hyperspher. study of $A=6$ nucl.: static EM props. & β-decay of ^{6}He
92DAZW	Faddeev & hyperspher. study of $A=6$ nucl.: geometrical features of ^{6}He & ^{6}Li g.s.
92DAZX	Faddeev & hyperspher. study of $A=6$ nucl.: ground states
92GO09	Halo effect in light nucl.; microscopic calc. of loosely bound nucleon systems incl. ^{6}Li
92JU1C	Potential model, 2-body matrix elements used to obtain many props. of $A=5$–16 nucl.
92LA13	Influence of the separation energy on the radius of neutron rich nucl. & momentum distr.
92LOZX	Short-range correlation in 6-body wave function of ^{6}Li; calc. gnd. & first 2 exc. states
92WI07	Monte Carlo calculations of few-body and light nuclei incl. ^{6}Li
93GO16	Contrib. of unbound ^{6}Li* states to inclusive spectra of deuterons in (α, d) on ^{3}H & ^{3}He
93JA11	Effects of the single-particle potential insertions in the effective interaction
93PA14	Relativistic mean field study of light nucl. (calc. binding E, rms radii, deform. params.)
94BU25	Microscopic descrip. of $^{6-11}$Li; calc. binding E, form factors using hyperspherical basis
95KI25	Relativistic calculation of two-body correlations in neutron-rich light nuclei
95PU05	Green's function quantum Monte Carlo calculations of $A \leq 6$ nuclei
95VA30	Precise soln. of few-body probs. with stochastic var. method on correlated Gaussian basis
96SH12	Skyrme-Hartree-Fock calculation: ground-state properties of He, Li, and Be isotopes
96SH13	Analysis of exp. with radioactive beams yield rms matter radii, suggest neutron halos
97BA23	Neutron halo & other props. stud. in light nucl.; mean-field approx. with Skyrme force fit
97BA54	Microscopic study of the ground state props. of light nuclei; Skyrme Hartree-Fock model
97KA32	Root-mean-square radii of light atomic nuclei: neutron skin
97PU03	Green's function quantum Monte Carlo calcs. of gnd. & low-lying excited states, $A \leq 7$

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

analysis of $^6\vec{\rm Li} + {}^4$He scattering determined $\eta = -0.025 \pm 0.006 \pm 0.010$ (99GE02) while an analysis of ($^6\vec{\rm Li}$, d) transfer reactions resulted in a near zero value of $\eta = +0.0003 \pm 0.0009$ (98VE03).

Based on these theoretical and empirical results, we conclude that both the magnitude and sign of η for the ^{6}Li $\rightarrow \alpha +$ d wave function are not well determined. See also (99GE02, 98VE03).

Isotopic abundance: $(7.5 \pm 0.2)\%$ (84DE1A). See also (87LA1J, 88LA1C).

For estimates of the parity-violating α-decay width of ^{6}Li*(3.56) $[0^+; T = 1]$ see (83RO12, 84BU01, 86BU07).

1. (a) ^{3}He(^{3}H, γ)^{6}Li $\quad Q_{\rm m} = 15.795$
   (b) ^{3}He(^{3}H, n)^{5}Li $\quad Q_{\rm m} = 10.130 \quad E_{\rm b} = 15.795$
   (c) ^{3}He(^{3}H, d)^{4}He $\quad Q_{\rm m} = 14.320$
   (d) ^{3}He(^{3}H, ^{3}H)^{3}He

In the previous review (88AJ01), information on radiative capture of ^{3}H on ^{3}He was summarized as follows: Capture γ-rays (reaction (a)) to the first three states of ^{6}Li [γ_0, γ_1, γ_2] have been observed for $E(^3{\rm He}) = 0.5$ to 25.8 MeV, while the yields of γ_3 and γ_4 have been measured for $E(^3{\rm He}) = 12.6$ to 25.8 MeV. The γ_2 excitation function does not show resonance structure. However, the γ_0, γ_1, γ_3 and γ_4 yields do show broad maxima at $E(^3{\rm He}) = 5.0{\pm}0.4$ [γ_0, γ_1], $20.6{\pm}0.4$ [γ_1], ≈ 21 [γ_3] and $21.8{\pm}0.8$ [γ_4] MeV. The magnitude of the ground-state-capture cross section is well accounted for by a direct-capture model; that for the γ_1 capture indicates a non-direct contribution above $E(^3{\rm He}) = 10$ MeV, interpreted as a resonance due to a state with $E_{\rm x} = 25 \pm 1$ MeV, $\Gamma_{\rm cm} = 4$ MeV, $T = 1$ (because the transition is E1, to a $T = 0$ final state) [the E1 radiative width $|{\rm M}|^2 \geq 5.2/(2J + 1)$ W.u.], $J^\pi = (2, 3, 4)^-$, $\alpha +$ p + n parentage. The γ_4 resonance is interpreted as being due to a broad state at $E_{\rm x} = 26.6$ MeV with $T = 0$. $J^\pi = 3^-$ is consistent with the measured angular distribution. The ground and first excited state reduced widths for ^{3}He + t parentage, $\theta_0^2 = 0.8 \pm 0.2$ and $\theta_1^2 = 0.6 \pm 0.3$: see (74AJ01). See also (85MO1C, 86MO1G, 87MO1I).

Since the previous review (88AJ01), a new resonance analysis has been applied to the ^{3}He+^{3}H elastic scattering in odd parity states and to the ^{3}He(^{3}H, γ) data (88MO1I, 90MO10, 90HE20, 92HE1E). This analysis explains the shape of the capture cross sections and angular distribution in terms of very weak overlapping resonances. These correspond to ^{6}Li states at $E_{\rm x} = 17.89 \pm 0.025$ MeV, $J^\pi = 2^-$, $S = 1$, $T = 1$; $E_{\rm x} = 24.779 \pm 0.054$ MeV, $J^\pi = 3^-$, $S = 1$, $T = 1$; $E_{\rm x} = 24.890 \pm 0.055$ MeV, $J^\pi = 4^-$, $S = 1$, $T = 1$; $E_{\rm x} = 26.590 \pm 0.065$ MeV, $\Gamma_{\rm cm} < 8.68$ MeV, $J^\pi = 2^-$, $S = 1$, $T = 1$. The analysis is compatible with an almost pure ^{3}He–^{3}H cluster structure of the negative parity unbound ^{6}Li states with $S = 1$, $T = 1$. These results are supported by calculations described in (95OH03) which utilize a complex-scaled ^{3}He + t resonating group method to calculate the energies and widths of the ^{6}Li ^{3}He + t

Figure 2: Energy levels of ^{6}Li. For notation see introduction.

Table 6.7: Energy levels of ^{6}Li

E_x (MeV ± keV)	$J^\pi; T$	Γ_{cm} (MeV)	Decay	Reactions
g.s.	$1^+; 0$		stable	1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54
2.186 ± 2	$3^+; 0$	0.024 ± 0.002	γ, d, α	1, 2, 3, 6, 7, 8, 12, 13, 14, 15, 16, 18, 19, 20, 21, 24, 25, 28, 29, 30, 31, 32, 33, 35, 37, 39, 40, 41, 42, 48, 49
3.56288 ± 0.10	$0^+; 1$	$(8.2 \pm 0.2) \times 10^{-6}$	γ	1, 3, 11, 12, 13, 15, 16, 17, 18, 20, 29, 31, 32, 33, 35, 37, 54
4.31 ± 22	$2^+; 0$	1.7 ± 0.2 [a]	γ, d, α	1, 6, 12, 13, 15, 16, 24, 31, 35, 48
5.366 ± 15	$2^+; 1$	0.540 ± 0.020	γ, n, p, α	1, 12, 15, 31, 32, 33, 35
5.65 ± 50	$1^+; 0$	1.5 ± 0.2	d, α	6, 15, 33, 35
17.985 ± 25 [b]	$2^-; 1$	3.012 ± 0.007	γ, t, ^{3}He	1
24.779 ± 54 [b]	$3^-; 1$	6.754 ± 0.110	γ, n, t, ^{3}He	1
24.890 ± 55 [b]	$4^-; 1$	5.316 ± 0.112	γ, n, t, ^{3}He	1
26.590 ± 65 [b]	$2^-; 1$	8.684 ± 0.125	γ, n, d, t, ^{3}He	1
[c]				

[a] See also Tables 6.12 and 6.14.
[b] See remarks under reaction 1, and see Table 6.9.
[c] For possible states at high E_x see reactions 6, 31, 33 and 38 and Tables 6.8 and 6.11.

states. Note, however, that the calculated scattering phase shifts rise only gradually with energy and stay well below 90°. Therefore the extraction of level parameters yields wide margins (or cannot be too precise). See also Table 6.9. The radiative capture reaction as a source of ^{6}Li production in big bang nucleosynthesis is discussed in (90FU1H, 90MA1O, 97NO04). See also (95DU12).

The angular distribution and polarization of the neutrons in reaction (b) have been measured at $E(^3\text{He}) = 2.70$ and 3.55 MeV. The excitation function for $E(^3\text{He}) = 0.7$ to 3.8 MeV decreases monotonically with energy. The excitation function for n_0 has been measured for $E(^3\text{He}) = 2$ to 6 MeV and for $E(^3\text{He}) = 14$ to 26 MeV; evidence for a broad structure at $E(^3\text{He}) = 20.5 \pm 0.8$ MeV is reported [^{6}Li*(26.1)]: see (79AJ01).

Angular distributions of deuterons (reaction (c)) have been measured for $E_t = 1.04$ to 3.27 MeV and at $E(^3\text{He}) = 0.29$ to 32 MeV. Polarization measurements are reported for $E_t = 9.02$ to 17.27 MeV [see (79AJ01)], as well as at $E(^3\vec{\text{He}}) = 18.0$ and 33.0 MeV (86RA1C). See also (86KO1K) and (85CA41). A microscopic calculation for reaction (c) and its inverse with special emphasis on isospin breaking in the analyzing power is described in (90BR09). See also the calculations of (90BLZW, 93DU02, 93FI06).

Elastic scattering (reaction (d)) angular distributions have been measured at $E(^3\text{He}) =$ 5.00 to 32.3 MeV and excitation functions have been reported for $E(^3\text{He}) = 4.3$ to 33.4 MeV: see (79AJ01). At the lower energies the elastic yield is structureless and decreases monotonically with energy. Polarization measurements are reported for $E_t = 9.02$ to 33.3 MeV. A strong change occurs in the analyzing power angular distributions at $E_t = 15$ MeV. A phase-shift analysis [single level R-matrix formalism, $L \leq 4$] yields P-states [0^-, 2^-; $T = 1$] at $E_x \approx 21.5$ and 21.0 MeV and F-states [3^-, 4^-; $T = 1$] at $E_x \approx 26.7$ and 25.7 MeV. There is some indication also of $T = 0$, 3^-, 5^- and 3^+ states at $E_x \approx 25$, 29.5 and 31.5 MeV which decays presumably primarily by $d + \alpha$: see (79AJ01).

For other channels see (84AJ01). See also (84KR1B). For thermonuclear reaction rates see (88CA1N).

2. ^{3}H(α, n)^{6}Li $\qquad\qquad$ $Q_m = -4.782$

^{6}Li*(0, 2.19) have been populated: see (74AJ01). See also ^{7}Li, (83CO1E) and (83FU11). Cross sections for $E(^3\text{H}) < 20$ MeV were calculated with a resonating group method by (91FU02).

2.5 ^{3}H(α, d)^{5}He $\qquad\qquad$ $Q_m = -7.151$

Measurements of differential cross sections at $E_\alpha = 27.2$ MeV were reported in (91GOZP, 94GOZX). ^{6}Li level widths were deduced.

3. ^{3}He(^{3}He, π^+)^{6}Li $\qquad Q_m = -123.792$

Differential cross sections are reported for the transitions to ^{6}Li*(0, 2.19) for $E(^3\text{He}) =$ 350, 420, 500 and 600 MeV (83LE26). See also (84AJ01), (83BR1B, 83JA13) and (84GE05). More recently, analyses of data for $E(^3\text{He}) = 295$–810 MeV and microscopic reaction model calculations have been done (91HA22).

4. ^{4}He(d, γ)^{6}Li $\qquad Q_m = 1.475$

The previous review (88AJ01) summarized the information on this reaction as follows: No resonance has been observed corresponding to formation of ^{6}Li*(3.56) [0^+; $T = 1$]: the parity-forbidden $\Gamma_\alpha \leq 6 \times 10^{-7}$ eV (84RO04). See also Table 6.7.

The cross section for the capture cross section has been measured for $E_\alpha = 3$ to 25 MeV by detecting the recoiling ^{6}Li ions: the direct capture is overwhelmingly E2 with a small E1 contribution. The spectroscopic overlap between the $^6\text{Li}_{\text{g.s.}}$ and $\alpha + \text{d}$ is 0.85 ± 0.04: see (84AJ01). See also (82KI1A), (85CA41, 86LA22, 86LA27) and theoretical work presented in (84AK01, 85AK1B, 86AK1C, 86BA1R).

Since the previous review (88AJ01), measurements of the cross section at energies $E_\alpha \approx$ 2 MeV corresponding to the 3^+ resonance at $E_x = 2186$ keV in ^{6}Li have been reported (94MO17). Values extracted for the total width Γ and the radiative width Γ_γ confirm the adopted value (88AJ01). An experimental search for the reaction at $E_{\text{cm}} \approx 53$ keV (96CE02) gave an upper limit for the S factor of 2×20^{-7} MeV $\cdot$ b at the 90% confidence level. Implications for big bang nucleosynthesis of ^{6}Li are discussed.

A considerable amount of theoretical work has been devoted to this reaction — much of it related to its importance in astrophysics. A list of references with brief descriptions is provided in Table 6.8.

5. (a) ^{4}He(d, np)^{4}He $\qquad Q_m = -2.224 \qquad E_b = 1.475$
(b) ^{4}He(d, t)^{3}He $\qquad Q_m = -14.320$

Reaction (a) has been studied to $E_\alpha = 165$ MeV and to $E_d = 21.0$ MeV: see (79AJ01, 84AJ01). Measurements are also reported at $E_d = 5.4$, 6.0 and 6.8 MeV (85LU08; VAP, TAP), 6 to 11 MeV (85OS02; VAP), 10.05 MeV (83BR23; VAP, TAP) and 12.0 and 21.0 MeV (83IS10; VAP, TAP) and at $E_\alpha = 11.3$ MeV (87BR07). See also (86DO1K).

More recently, measurements of the cross section and transverse tensor analyzing power at $E_d = 7$ MeV were made (88GA14) with kinematic conditions chosen to correspond to production of the singlet deuteron. Coulomb and nuclear field effects in these reactions are discussed in (87KO1X, 88KA38). Cross sections and polarization observables from data at $E_d < 12$, 17 MeV are compared with three-body model predictions in (88SU12).

Table 6.8: ^{4}He(d, γ)^{6}Li – Theoretical work

Reference	Description
89CR01	D-state effects in the ^{4}He(d, γ)^{6}Li reaction
89SC25	The reaction rate at $T = 300$ K for ^{2}H(α, γ)^{6}Li and other reactions
90CR04	Tensor interaction effects in ^{4}He(d, γ)^{6}Li
90KRZX	Polarization observables for ^{4}He(d, γ)^{6}Li and the D state of ^{6}Li
90SC22	The extended elastic model II applied to ^{2}H(α, γ)^{6}Li
91SC23	A simple expression for the cross-section factor in nuclear fusion
91TY02	Low-energy ^{2}H(α, γ)^{6}Li and ^{208}Pb(^{6}Li, dα)^{208}Pb cross sections
93JA02	Polarizability and E1 radiation in ^{4}He(d, γ)^{6}Li
93MU12	Calculation of the ^{6}Li $\rightarrow \alpha + $ d vertex constant
94MO17	Direct capture in the 3^+ resonance of ^{2}H(α, γ)^{6}Li
95DU12	Cluster model descriptions of ^{6}Li photodisintegration
95IG06	Analysis of the nuclear astrophysical reaction ^{4}He(d, γ)^{6}Li
95MU21	Astrophysical factor for ^{4}He(d, γ)^{6}Li
95MU1J	Peripheral astrophysical radiative capture processes, a survey
95RY01	^{4}He(d, γ)^{6}Li capture and the isoscalar E1 multipole
97NO04	Nuclear reaction rates and primordial ^{6}Li

For reaction (b), measurements of vector and tensor analyzing power at $E_{\rm d} = 35$, 45 MeV have been reported (86BR1N, 86VU1A, 86VA1B, 87VU1A). Cross sections and polarization observables were measured at $E_{\rm d} = 32.1$, 35.15, 39.6, 49.7 MeV to investigate ^{3}H and ^{3}He asymptotic normalization constants (87VU1B) and charge symmetry breaking (88VU01). Cross sections and polarization observables measured at $E_{\rm cm} = 14$–33 MeV (89BR23) were compared with microscopic-model predictions in a study of isospin violation. See also (90BR09). The role of tensor force was explored in (88BR18).

For earlier work and other breakup channels, see references cited in (88AJ01).

6. ^{4}He(d, d)^{4}He $\qquad E_{\rm b} = 1.475$

Elastic differential cross-section and polarization measurements have been carried out up to $E_\alpha = 166$ MeV and $E_{\rm d} = 45$ MeV: see (74AJ01, 79AJ01, 84AJ01). Measurements were also reported at $E_{\rm d} = 0.87$ to 1.43 MeV (84BA19, 85BA1K), at $E_{\rm d} = 11.9$ MeV (88EL01; TAP), 21 MeV (see 86MI1E; VAP, TAP), 24.0 and 38.2 MeV (86GR1D; TAP), 31.8 to 39.0 MeV (86KO1M; TAP), 40 MeV (89DE1A), 56 MeV (85NI1A; VAP, TAP) and at $E_\alpha = 7.0$ GeV/c (84SA1C). A compilation of data for energies $E_{\rm d} = 1$–56 MeV is presented in (87GR08). For a study of the inclusive inelastic scattering at $E_\alpha = 7.0$ GeV/c see (87BA13).

Table 6.9: Levels of ^{6}Li from ^{4}He(d, d)^{4}He [a]

E_d (MeV)	$J^\pi; T$	E_x (MeV)	Γ_{cm} (MeV)	Γ_d/Γ [b]	γ_d^2 [c]
1.070 ± 0.003	$3^+; 0$	2.187			0.27
4.34 ± 0.04	$2^+; 0$	4.36	1.32 ± 0.04	0.967	0.511
5.7 ± 0.1 [d]	$1^+; 0$	5.3	1.9 ± 0.1	0.74	0.34
(19.3 ± 1.3)	$3^+; 0$	(14.3)	26.7 ± 1.0	0.34	1.69
(21.6 ± 1.1)	$3^+; 0$	(15.8)	17.8 ± 0.8	0.76	0.77
33 ± 2	4^+	23	12 ± 2	0.15	0.14
34 ± 5	3^-	24	16 ± 3	0.30	0.24
39^{+3}_{-9}	2^-	27	22 ± 7	0.43	0.42

[a] The data in this table are mostly from the S-matrix analysis of (83JE03). The results are unique up to $E_d = 15$ MeV. See also table 6.4 in (74AJ01), and tables 6.3 in (79AJ01) and (84AJ01).
[b] The errors in Γ_d/Γ are typically 0.03.
[c] In units of the Wigner limit $\gamma_w^2 = 2.93$ MeV for a radius of 4.0 fm. See (88AJ01).
[d] 6.26 MeV (R-matrix analysis): $E_x = 5.65$ MeV.

Phase-shift analyses, particularly that by (83JE03) which uses all available differential cross section, vector and tensor analyzing power measurements and $L \leq 5$, in the range $E_d = 3$ to 43 MeV lead to the results displayed in Table 6.9. It is found that the d-wave shifts are split and exhibit resonances at $E_x = 2.19$ ($^3D_3$), 4.7 ($^3D_2$) and 5.65 MeV ($^3D_1$). (83JE03) suggest very broad G_3 and G_4 resonances at E_d = (19.3) and 33 MeV, a D_3 resonance at 22 MeV and F_3 and F_2 resonances at ≈ 34 and ≈ 39 MeV, corresponding to states which are primarily of $(d + \alpha)$ parentage.

(85JE04) have investigated the points where $A_{yy} = 1$ and report four such points at $E_d = 4.30$ [$\theta_{cm} = 120.7°$], 4.57 (58.0°), 11.88 (55.1°) and 36.0 ± 1.0 MeV ($150.1 \pm 0.3°$). [For the latter see also (86KO1M)]. The correspondence of these polarization maxima to ^{6}Li states is discussed by (85JE04). For a discussion of the M-matrix see (88EL01). For work on $(\alpha + d)$ correlations involving ^{6}Li*(0, 2.19, 4.31 + 5.65) see (87CH08, 87CH33, 87PO03) and (87FO08).

For additional references to early work see references cited in (88AJ01).

A considerable body of theoretical work on the ^{4}He + d channel has been done since the previous review (88AJ01). A list of references with brief descriptions is provided in Table 6.10.

7. (a) ^{4}He(^{3}He, p)^{6}Li $\qquad Q_m = -4.019$

   (b) ^{4}He(^{3}He, pd)^{4}He $\qquad Q_m = -5.494$

Table 6.10: ^{4}He(d, d)^{4}He – Theoretical work

Reference	Description
88BE58	Polarization phenomena in ^{4}He(d, d) at intermediate energies
88KA25	Convergence features in the pseudostate theory of the d + α system
88WE1C	Manifestations of the D-state in light nuclei
89ET1A	Description of diffraction scattering on nuclei
89FI1E	Microscopic theory of collective resonances of light nuclei
89KR08	Pade approximation technique for processing scattering data
90BL13	Analysis of higher partial waves in ^{4}He(d, d)in 3-body framework
90DA1H	Two body phase space in α-d breakup at 40 MeV
90GU23	D-wave effect in α-d elastic scattering at intermediate energies
90HO1R	Microscopic study of clustering phenomena
90HU09	A geometric model for nucleus-nucleus scattering at high energies
90KU06	Reconstruction of interaction potential from scattering data
90KU16	Padé-approximation techniques for processing scattering data
90LI11	Further study of α elastic scattering on light nuclei
91BL04	Manifestation of Pauli-forbidden states in ^{4}He(d, d) at low energies
91KR02	Energy-dependent phase-shift analysis of ^{4}He(d, d) at low energies
91KU09	d-α scattering in a three-body model
91KU27	Recovering α+d potential from Faddeev and measured phase shifts
92ES04	α-d resonances and the low-lying states of ^{6}Li
92FU10	Reaction mechanisms in $A = 6$ with the multiconfiguration RGM
92KU16	Supersymmetric potentials and the Pauli Principle in ^{4}He(d, d)
92KU1G	Deuteron size effects in d-α scattering
93BL09	Determination of ^{6}Li $\rightarrow \alpha +$ d vertex constant for d-α phase-shifts
93FI06	Study of continuous spectrum of ^{6}Li in RGM
94CS01	Microscopic description of beta-delayed deuteron emission in ^{6}He
95DU12	Cluster model description of photonuclear processes in ^{6}Li
97DU15	Electromagnetic effects in light nuclei and the cluster potential
97KU14	Reconstruction of analytic S matrix from experimental d-α data

Angular distributions have been measured at $E(^3\text{He})$ = 8 to 18 MeV and E_α = 42, 71.7 and 81.4 MeV: see (74AJ01). More recently, proton polarization was measured as a function of angle at E_{cm} = 12.6 MeV (89GR02). At E_α = 28, 63.7, 71.7 and 81.4 MeV the α-spectra show that the sequential decay (reaction (b)) involves ^{6}Li*(2.19) and possibly ^{5}Li: see (79AJ01). See also the recent theoretical work of (93GO16) and the multiconfiguration RGM calculations of (95FU16).

8. (a) $^4\text{He}(\alpha, \text{d})^6\text{Li}$ $\qquad Q_m = -22.372$
   (b) $^4\text{He}(\alpha, \text{pn})^6\text{Li}$ $\qquad Q_m = -24.596$
   (c) $^4\text{He}(\alpha, \alpha\text{d})^2\text{H}$ $\qquad Q_m = -23.847$

Reactions (a) and (b) have been studied to E_α = 158.2 MeV [see (79AJ01, 84AJ01)] and at 198.4 MeV (85WO11). The dependence of the cross section on energy shows that the $\alpha+\alpha$ process does not contribute significantly to ^{6}Li (and ^{7}Li) synthesis above E_α = 250 MeV (85WO11) [and see for additional comments on astrophysical problems]. For reaction (c) [and excited states of ^{4}He] see (84AJ01): ^{6}Li*(2.19) is involved in the process.

9. $^6\text{He}(\beta^-)^6\text{Li}$ $\qquad Q_m = 3.508$

See ^{6}He, reaction 1.

9.5 $^6\text{He}(\text{p}, \text{n})^6\text{Li}$ $\qquad Q_m = 2.726$

An experiment utilizing a secondary ^{6}He beam with $E(^6\text{He})$ = 42 MeV/nucleon was reported by (95CO05). The ^{6}Li ground state and E_x = 3.56 MeV state were observed. Angular distributions were reported and the ratio of the cross section for the Gamow Teller transition to the ground state and the Fermi transition to the isobaric analog state was measured. The reaction was also studied at E/A = 93 MeV (96BR30). The 0° ground state cross section was measured to be $\frac{d\sigma}{d\Omega} = 43 \pm 16$ mb/sr. The ratio of Gamow Teller to Fermi strength was found to be $(87 \pm 6)\%$ of that expected from p,n systematics and beta decay. Differential cross sections at E/A = 41.6–68 MeV were measured by (97CO04) to study the effects of halo structure.

The current status of theoretical and experimental research on nuclei featuring a two-particle halo is reviewed in (96DA31).

9.7 $^6\text{Li} \rightarrow \alpha + \text{d}$ $\qquad E_b = -1.475$

A theoretical study in a microscopic three-cluster model of the parity-violating $\alpha + \mathrm{d}$ decay of the lowest 0^+ state is described in (96CS03). A phase shift analysis of $^4\mathrm{He} + \mathrm{d}$ was used in a determination of the vertex constant for the $^6\mathrm{Li}(1^+\ 0) \rightarrow \alpha + \mathrm{d}$ virtual decay by (92BLZX, 93BL09, 97KU14). See also (90RY07, 93BO38, 91KR02).

10. (a) $^6\mathrm{Li}(\gamma,\ \mathrm{n})^5\mathrm{Li}$ $\qquad Q_\mathrm{m} = -5.665$

(b) $^6\mathrm{Li}(\gamma,\ \mathrm{p})^5\mathrm{He}$ $\qquad Q_\mathrm{m} = -4.593$

(c) $^6\mathrm{Li}(\gamma,\ \mathrm{d})^4\mathrm{He}$ $\qquad Q_\mathrm{m} = -1.475$

(d) $^6\mathrm{Li}(\gamma,\ \mathrm{np})^4\mathrm{He}$ $\qquad Q_\mathrm{m} = -3.699$

(e) $^6\mathrm{Li}(\gamma,\ \mathrm{t})^3\mathrm{He}$ $\qquad Q_\mathrm{m} = -15.795$

The previous review (88AJ01) summarizes the information on these reactions as follows: The (γ, n) and (γ, Xn) cross sections increase from threshold to a maximum at $E_\gamma \approx$ 12 MeV then decrease to $E_\gamma = 32$ MeV: see (84AJ01) and (88DI02). (84DY01) also report a broad peak at 16 MeV. The cross section for photoproton production (reaction (b)) is generally flat up to 90 MeV. [The previously reported hump at $E_\gamma \approx 16$ MeV is almost certainly due to oxygen contamination: see (84AJ01).] See also (88CA11) and ^{5}He. The cross section for reaction (c) is $\leq 5\ \mu$b in the range $E_\gamma = 2.6$ to 17 MeV consistent with the expected inhibition of dipole absorption by isospin selection rules: see (66LA04). The onset of quasideuteron photodisintegration between 25 and 65 MeV is suggested by the study of (84WA18; E_γ(bremsstrahlung) = 67 MeV). The 90° differential cross section for reaction (e) decreases monotonically for $E_\gamma = 18$ to 70 MeV: reaction (e) contributes $\approx \frac{1}{3}$ of the total cross section for $^6\mathrm{Li}+\gamma$, consistent with a $^3\mathrm{H}+^3\mathrm{He}$ cluster description of $^6\mathrm{Li}_\mathrm{g.s.}$ with $\theta^2 \approx 0.68$. The agreement with the inverse reaction, $^3\mathrm{H}(^3\mathrm{He},\ \gamma)$ [see reaction 1] is good: see (84AJ01). See also (86LI1F).

The absorption cross section has been studied in the range $E_\gamma \approx 100$ to 340 MeV; it shows a broad bump centered at ≈ 125 MeV and a fairly smooth increase to a maximum at ≈ 320 MeV: see (84AJ01). For spallation studies see (74AJ01, 84AJ01). For pion production see (86GL07, 87GL01) and (84AJ01).

Since the previous review (88AJ01) tagged photons were used to study $^6\mathrm{Li}(\gamma,\ \mathrm{p})$ at $\theta_\mathrm{p} = 0°$ for $E_\gamma \approx 59$ and 75 MeV. Strong evidence for the photo-deuteron mechanism was found. Measurements made for angles between 30° and 150° (95DI01) showed most of the strength occurring in three-body breakup channels. Studies at these same energies of the (γ, d) and (γ, t) reaction were reported in (97DI01). See also (94RY01). Measurements of $^6\mathrm{Li}(\gamma,\ \mathrm{d})$ at $E_\gamma \approx 60$ MeV indicated strict obedience of the isospin selection rule for E1 absorption.

The (γ, pn) reaction was also studied at $E_\gamma = 55$–100 MeV with Bremsstrahlung photons and with linearly polarized tagged photons for $E_\gamma = 0.3$–0.9 GeV. See also (90RIZX).

Linearly polarized photons were used to measure the cross section asymmetry in $^6\mathrm{Li}(\gamma,\ \mathrm{t})^3\mathrm{He}$ up to $E_\gamma \approx 70$ MeV (89BU10) and differential cross sections up to $E_\gamma \approx 90$ MeV (93DE07,

Table 6.11: ^{6}Li(γ, X) – Theoretical work

Reference	Description
88DU04	Calculation of the ^{6}Li(γ, dγ') cross section at $E_\gamma = 2.23$ MeV
89AR02	Quark degrees of freedom and nuclear photoabsorption
90BU29	Possibility (?) of observing an isoscalar E1 multipole in ^{6}Li(γ, d)
90VA16	Cluster effects in ^{6}Li photodisintegration
90ZH19	Manifestations of cluster structure in ^{6}Li(γ, d)
91BE05	^{6}Li $\rightarrow \alpha +$ d break-up — astrophysical significance
95DU12	Description of photonuclear processes in ^{6}Li

95BU08). Results of a measurement of the absolute total photoabsorption cross section for $E_\gamma = 300$–1200 MeV are presented in (94BI1B).

A list of theoretical references relating to ^{6}Li photonuclear reactions with brief descriptions is provided in Table 6.11.

11. ^{6}Li(γ, γ)^{6}Li

The width, Γ_γ, of ^{6}Li*(3.56) $= 8.1 \pm 0.5$ eV: see (74AJ01) and Table 6.4 in (79AJ01); $E_x = 3562.88 \pm 0.10$ keV: see (84AJ01). See also (87PI06). The results of an absolute measurement of the total photoabsorption cross section are described in (94BI1B). Photon absorption and photon scattering for light elements is discussed in terms of a collective resonance phenomenon in (90ZI1C).

11.5 (a) ^{6}Li(γ, π^0)^{6}Li $\quad Q_m = -134.974$

(b) ^{6}Li(γ, π^+)^{6}He $\quad Q_m = -143.076$

(c) ^{6}Li(γ, π^-)^{6}Be $\quad Q_m = -143.856$

Measurements of neutral-pion photoproduction yield (reaction (a)) for $E < 10$ MeV above threshold were reported in (89NA23). The total cross section was measured in the energy region from the reaction threshold to $E_\gamma \approx 146.5$ MeV (89GL07) and analyzed in the impulse approximation. The cross section increases monotonically to $\sigma = 6.50 \pm 0.96$ μb at $E_\gamma = 146.5$ MeV. See also (86GL07, 87GL01) and (84AJ01). An analysis (91TR1C) of early measurements suggests that anomalously large measured values of the cross section are due to target impurities. The differential cross section at small angles at energies $E \approx 300$–450 MeV has been measured by (91BE16). Differential cross sections for reaction (b) leading to the ^{6}He ground state have been measured at $E_\gamma = 200$ MeV (91SH02) and analyzed by DWBA. See also the measurements of (91GA26). The energy distributions of electroproduced π^+ at $E_e \approx 200$ MeV were measured and (γ, π^+) cross sections were deduced (94SH38). The ^{6}Li(γ, pn) reaction was studied in the Δ-resonance region by angular correlation measurements (92TE1A).

Theoretical studies of pion photoproduction include an impulse-approximation calculation for (γ, π^0) at $E_\gamma = 300$ MeV (89TR09), an impuse approximation and shell model study of inelastic photoproduction of pions (91TR02), a DWIA Feynman-diagram production-operator-based calculation of (γ, π^+) at $E_\gamma = 200$ MeV (90BE49), and multicluster dynamic-model calculation of π^+ photoproduction off ^{6}Li (95ER1B), and an exclusive (γ, π^+) production calculation for $E_\gamma = 200$ MeV (95DO24).

12. (a) ^{6}Li(e, e)^{6}Li

(b) ^{6}Li(e, ep)^{5}He	$Q_m = -4.593$
(c) ^{6}Li(e, ed)^{4}He	$Q_m = -1.475$
(d) ^{6}Li(e, et)^{3}He	$Q_m = -15.795$

The previous review (88AJ01) summarizes the information then available on electron scattering as follows: The elastic scattering has been studied for $E_e = 85$ to 600 MeV: see (74AJ01, 79AJ01, 84AJ01). The results appear to require that the ground state be viewed as an α-d cluster in which the deuteron cluster is deformed and aligned. The ground-state M1 current density has also been calculated (82BE11). A model-independent analysis of the elastic scattering yields $r_{rms} = 2.51 \pm 0.10$ fm. See also the discussion in (84DO1A).

Table 6.12 summarizes the results obtained in the inelastic scattering of electrons. Form factors have been measured for ^{6}Li*(2.19, 3.56, 5.37) as well as for the t + ^{3}He continuum up to 4 MeV above threshold [no narrow structures corresponding to ^{6}Li states are observed]: see (84AJ01).

For reaction (b) see ^{5}He and (87VA08) and (87VA1N). Angular distributions for the d_0 group in the (e, d_0) reaction have been measured for $E_x = 10$ to 28 MeV. The deduced E1 and E2 components of the (γ, d_0) cross section show no structure. The E1 strength implies non-negligible isospin mixing in this energy region (86TA06). At $E_e = 480$ MeV (reaction (c)) the α-d momentum distribution in the ground state of ^{6}Li has been studied. The results are well accounted for by an αNN model. The α-d probability in the ground state of ^{6}Li is 0.73 [estimated ± 0.1]. The data are consistent with the expected $2S$ character of the α-d relative wave function (86EN05). See also (86EV1A). π^0 production involving ^{6}Li*(2.19, 3.56, 5.37) is reported at $E_e = 500$ MeV (87NA1I).

For the earlier work see (79AJ01, 84AJ01) and the references cited in (88AJ01).

Since the previous review (88AJ01), experimental results on quasielastic response have been reviewed (88LO1E). Measurements of the quasielastic scattering cross section for electrons on ^{6}Li are reported at momentum transfer 0.85–2.3 F^{-1} (88BU25). See also the measurements at $E_e = 80$–680 MeV by (89LI09). Cross sections for ^{6}Li(e, ep) were measured in

Table 6.12: Levels of ^{6}Li from ^{6}Li(e, e′) and ^{6}Li(γ, γ') [a]

E_x (MeV)	J^π; T	Γ_{γ_0} (eV)	Multipolarity
2.183 ± 0.009 [b]	3^+; 0	$(4.40 \pm 0.34) \times 10^{-4}$	E2
3.56288 ± 0.00010[c]	0^+; 1	8.19 ± 0.17 [d]	M1
4.27 ± 0.04	2^+; 0	$(5.4 \pm 2.8) \times 10^{-3}$	E2
5.379 ± 17 [c,e]	2^+; 1	0.27 ± 0.05	M1

[a] See tables 6.4 in (79AJ01, 84AJ01) for references and for the earlier work.
[b] $B(\text{E2})\uparrow = 21.8 \pm 4.8\ e^2 \cdot \text{fm}^4$.
[c] (81RO1D.)
[d] Weighted mean of values shown in table 6.4 in (79AJ01).
[e] $\Gamma = 540 \pm 20$ keV.

the missing energy region $0 \leq E_m \leq 30$ MeV and in the range $-100 \leq p_m \leq 200$ MeV/c of missing momentum (89LA22). The ^{6}Li → p+(nα) spectral function was measured (89LA13). The ratio of tranverse and longitudinal response function was investigated in (90LA06). See also the review (90DE16) of proton spectral functions and momentum distributions in (e, e′p) experiments and see the report (90GH1E) on nuclear density dependence of electron proton coupling in ^{6}Li(e, e′p).

Reaction (c) was used (90JO1D) in a study of correlation functions in ^{6}Li. A measurement in parallel kinematics to study the mechanism of the ^{6}Li(e, e′α)^{2}H reaction is reported in (91MI19, 94EN04). Cross sections for ^{6}Li(e, e′t)^{3}He (reaction (d)) at $E_e = 523$ MeV were measured by (90ZUZZ).

A list of references to theoretical work related to electron scattering on ^{6}Li is provided, along with brief descriptions, in Table 6.13.

13. (a) ^{6}Li($\pi^\pm$, $\pi^\pm$)^{6}Li
(b) ^{6}Li(π^+, π^+p)^{5}He $\quad Q_m = -4.593$
(c) ^{6}Li(π^+, ^{3}He)^{3}He $\quad Q_m = 123.792$
(d) ^{6}Li(π^+, π^+d)^{4}He $\quad Q_m = -1.475$
(e) ^{6}Li(π^-, π^+)^{6}H $\quad Q_m = -27.774$
(f) ^{6}Li(π^-, p)^{5}H $\quad Q_m = 109.535$
(g) ^{6}Li(π^+, pp)^{4}He $\quad Q_m = 136.651$
(h) ^{6}Li(π^-, ^{3}He)^{3}n $\quad Q_m = 114.510$
(i) ^{6}Li(π^+, p)^{5}Li $\quad Q_m = 134.685$
(j) ^{6}Li(π^+, pd)^{3}He $\quad Q_m = 118.298$
(k) ^{6}Li(π^-, pp)^{4}n $\quad Q_m = 106.792$

Table 6.13: ^{6}Li(e, e)^{6}Li – Theoretical work

Reference	Description
87KR07	EM properties of ^{6}Li in cluster model
87LE1N	Coincidence reactions and the 3-body structure of ^{6}Li
88AL1J	Second Born approximation correction to ^{6}Li electron scattering
88ES01	Elastic electromagnetic form factors of ^{6}Li from 3-body models
89ER07	Exchange and correlation effects in EM structure of ^{6}Li
89ES05	Inelastic ($1^{+} \to 0^{+}$) EM form factor of ^{6}Li with 3-body models
89KU21	Correlation and exchange effects in EM form factors
90BE54	Analysis of ^{6}Li(e, e$'$)^{6}Li transitions to the low-lying ^{6}Li levels
90DE1V	NN correlations, evidence from ^{6}Li(e, e$'$p)^{5}He
90KU12	Detailed study of EM structure of ^{6}Li from 3-body model
90LO14	Cluster-model interpretation of ^{6}Li(e, e$'$p)^{5}He
90LU06	Calculation of the magnetic form factor of ^{6}Li
90RE1I	Parity-invariance violation in ^{6}Li(e, e$'$d)^{4}He
90WA1J	Occupation probabilities of shell-model orbitals
91LU07	Magnetic form factor of ^{6}Li
91UN02	^{6}Li elastic form factors and antisymmetrization
92JO02	Two-body correlations in ^{6}Li through the (e,e$'$d) reaction
92LO09	Multiquark configuration effect on nuclear charge form factor
92LOZX	Short-range correlation in the 6-body ^{6}Li wave function
92RYZY	EM properties of ^{6}Li in multicluster dynamic model
92ZH18	Calculation of ^{6}Li(e, ed) cross section in α2N model
93KU27	Prohibition and suppression of multicluster states by Pauli principle
93RY01	^{6}Li properties — multicluster dynamic model
93SC30	Nucleon polarization iin three-body models of polarized Li
94BO04	Shell model calculation of magnetic electron scattering
94WE10	^{6}Li inelastic form factors in a cluster model
95AR10	Halo structure in ^{6}Li $E_{\mathrm{x}} = 3.563$ 0^{+} state
95DO23	Phenomenological transition amplitudes in selected p-shell nuclei
95KU08	Cluster structure of ^{6}Li low-lying states
95MA59	Finite-size effects in quasi-elastic scattering — Fermi gas model
98WI10	Quantum Monte Carlo calculations for light nuclei

Elastic angular distributions have been measured at $E_{\pi^+} \approx 50$ MeV [see (84AJ01)] and at $E_{\pi^\pm} = 100$, 180 and 240 MeV (86AN04; also to ^{6}Li*(2.19)). Differential cross sections are also reported for $E_{\pi^+} = 100$ to 260 MeV to ^{6}Li*(0, 2.19, 3.56, 4.25). The excitation function for the unnatural-parity transition to ^{6}Li*(3.56) has an anomalous energy dependence (84KI16).

More recently, a number of experimental studies with polarized targets have been reported for elastic and inelastic ($E_x(^6\text{Li}) = 2.19$ MeV, $J^\pi = 3^+$) scattering. Measurements of polarization observables are reported at $E_{\pi^+} = 134$, 164 MeV (89TA21, 90TA1L, 91BO1R), $E_{\pi^+} = 160$–219 MeV (91RI01, 94RI06). Comparison of these data with a coupled channels model is discussed in (95BO1H). See also the Δ-hole model analysis of (92JU1B) and the multicluster dynamic model analysis by (95RY1C). Calculations of cross sections and polarization observables at $E_{\pi^+} = 80$–260 MeV are presented in (88ER06, 88NA06).

Cross section measurements for reaction (b) at $E_{\pi^+} = 130$, 150 MeV are reported in (87HU02).

Measurements of pion double-charge exchange cross section (reactions (e) and (i)) at incident pion energies $E_\pi = 180$, 240 MeV are reported in (89GR06, 95FO1J). In (91SE06) it is shown that continuum missing mass spectra from reaction (e) can be explained in terms of the presence of dineutrons in the reaction products.

Pion absorption followed by nucleon emission (reactions (c), (f), (g), (h), (j), (k)) has been studied in a number of experiments. For reaction (c) see (83BA26, 83LO10, 85MC05, 86MC11). Measurements have been reported for cross sections for reaction (g) at $E_{\pi^+} = 30$, 50, 80, 115 MeV (89ROZY); reactions (b) and (g) angular distributions at $E_\pi = 70$, 130, 165 MeV (89YO05); reactions (g) and (l) angular correlations at $E_\pi = 165$ MeV (89YO07); cross sections for reaction (g) at $E_{\pi^+} = 115$, 140, 165, 190, 220 MeV (89ZHZZ); angular distributions for reaction (k) at $E_{\pi^+} = 70$, 130, 165 MeV (89YO03); two-particle coincidences for reactions (g) and (k) at low energies (91YO1C); cross sections at $E_{\pi^+} = 50$, 100, 150, 200 MeV (90RA20, 90RA05, 92RA01, 92RA11); differential and total cross sections for reaction (g) at $E_{\pi^+} = 100$, 165 MeV (95PA22, 96LO04); inclusive spectra of ^{3}He produced in reaction (h) (92AM1H, 93AM09); total reaction cross sections for (π^+, X), (π^-, X) at $E_\pi = 42$–65 MeV (96SA08). See also the earlier work on reaction (g) at $E_{\pi^+} = 59.4$ MeV (86RI01), and see the compilation and review of (92BA57, 93IN01).

Analysis of particle emission following π^+ absorption on ^{6}Li (90RA20) has produced evidence for a three-nucleon absorption model. Distorted-wave impulse approximation calculations of cross sections and analyzing powers have been made (92KH04) for two-nucleon pion absorption on polarized ^{6}Li targets. A model based solely on isospin was used (93MA14) in a calculation of ratios of pion absorption on three nucleons and agreement with experiment suggest a one-step process.

14. (a) ^{6}Li(n, n)^{6}Li

(b) ^{6}Li(n, nd)^{4}He	$Q_m = -1.475$
(c) ^{6}Li(n, p)^{6}He	$Q_m = -2.726$
(d) ^{6}Li(n, d)^{5}He	$Q_m = -2.369$

(e) ^{6}Li(n, t)^{4}He $\qquad Q_m = 4.782$

(f) ^{6}Li(n, α)^{3}H $\qquad Q_m = 4.782$

Angular distributions involving the groups to ^{6}Li*(0, 2.19) have been reported at $E_n = 1.0$ to 14.6 MeV [see (84AJ01)] and at 4.2, 5.4 and 14.2 MeV (85CH37; n_0, n_1), 7.5 to 14 MeV (83DA22; n_0), 8.9 MeV (84FE1A; n_0), 8.0 and 24 MeV (86HA1S; n_0, n_1) and at $E_n = 5$ to 17 MeV (86PF1A; n_0).

An analysis (88HA25) of (n, n) and (n, n′) data at $E_n = 24$ MeV indicated that neutron and proton transition densities were approximately equal ($\rho_n \approx \rho_p$) in ^{6}Li. Cross sections and analyzing powers for $E_n = 8$–40 MeV were analyzed (89HAZV) with microscopic optical model potentials. Secondary neutron spectra induced by 14.2 MeV neutrons on ^{6}Li were measured by (93XI1A).

An analysis of (n, n′) data at $E_n = 7.45$–14 MeV is discussed in (90BE54). See also the calculation for elastic coherent and incoherent scattering of thermal neutrons on ^{6}Li (90GO26) and the multi-cluster dynamic model calculation for ^{6}Li(n, n) at $E_n = 12$ MeV (92KA06).

Theoretical studies of ^{6}Li(n, n) include multiconfiguration resonating group calculations (88FU09, 91FU02), folding model descriptions for $E_n = 25$–50 MeV (93PE13), study of antisymmetry in NN potentials (95CO18), study of optical model potentials for intermediate energies (96CH33).

For reaction (b) see (85CH37, 84AJ01, 93XI1A, 94EL08).

A number of experiments on the (n, p) charge exchange (reaction (c)) have been reported. They include measurements of $\sigma(E_p)$ and $\sigma(\theta)$ at $E_n \approx 198$ MeV (87HE22), $\sigma(\theta,\ E_p)$ at $E_n \approx 118$ MeV (87PO18, 88HA12, 98HA24), $\sigma(\theta)$ at $E_n = 198$ MeV (88JA01), $\sigma(\theta)$ to explore Gamow Teller sum rule (88WA24), $\sigma(\theta)$, $\sigma(E_p)$ at $E_n = 280$ MeV for an isospin symmetry test (90MI10), $\sigma(\theta,\ E)$ at $E_n = 60$–260 MeV (92SO02), polarization observables at $E_n = 0.88$ GeV (96BB23).

For reaction (e), measurements were reported at thermal neutron energies (94IT04) and at $E_n < 10$ MeV (94DR11). For reaction (f), measurements of parity violation with cold polarized neutrons are described in (90VE16, 93VE1A, 96VE02). A discussion of nuclear reaction rates and primordial ^{6}Li is presented in (97NO04). See also the application-related calculation of (93FA01).

Theoretical work related to reactions (b), (c), (d), (e), (f) include: dynamical cluster-model calculation (91DA08); microscopic calculation in a 3-particle α+2N model (93SH1G); supermultiplet-symmetry-approximation calculation at $E_n = 6.77$ MeV (93DU09); multiconfiguration RGM calculation (95FU16); three-body cluster model calculations of ^{6}Li(n, p) at $E_n = 50$ MeV (97DA01, 97ER05).

15. (a) ^{6}Li(p, p)^{6}Li

(b) ^{6}Li(p, 2p)^{5}He $\qquad Q_m = -4.593$

(c) ^{6}Li(p, pd)^{4}He $Q_m = -1.475$

(d) ^{6}Li(p, p^{3}H)^{3}He $Q_m = -15.795$

(e) ^{6}Li(p, pn)^{5}Li $Q_m = -5.665$

Proton angular distributions have been measured for $E_p = 0.5$ to 800 MeV [p_0, p_1, p_2, p_3] [see (66LA04, 74AJ01, 84AJ01)] and at $E_{\vec{p}} = 5$ to 17 MeV (86PF1A; prelim.; p_0). Double-differential cross sections for the continuum yield [$E_x = 1.5$–3.5 MeV] are reported at $E_p = 65$ MeV (87TO06; prelim.). See also (83GL1A, 83PO1B, 83PO1C). More recently differential cross sections and/or polarization observables have been measured at $E_p = 6$–10 MeV (89HA17) [optical model analysis]; $E_p = 1.6$–10 MeV (89HA18) [phase shift analysis]; $E_p = 65$, 80 MeV (89TO1C) [DWIA analysis]; $E_p = 200$ MeV (90GL1B); $E_p = 65$ MeV (92NA02) [microscopic DWBA analysis]; $E_p = 72$ MeV (94HE11) [depolarization parameters]; $E_p < 2.2$ MeV (95SK01) [deduced resonance parameters]; $E_p = 0.88$ GeV (96BB23) [polarized target]; $E_p = 250$–460 keV (97BR37), $E_p = 280$ MeV (90MI10) [deduced isospin symmetry test]; $E_p = 14$ MeV [optical model, coupled channels]; $E(^6\text{Li} = 62, 72, 75$ MeV$/A$, ^{1}H(^{6}Li, p) [neutron halo states]. For a summary of the results on excited states see Table 6.14.

Reaction (b) was studied at 70 MeV (83GO06), at 50–100 MeV (84PA1B, 85PA1B; prelim.) and 1 GeV (85BE30, 88BE2B): see ^{5}He and (84AJ01) for the earlier work. Reaction (c) has been studied at $E_p = 9$ MeV to 1 GeV [see (74AJ01, 79AJ01, 84AJ01)] and at 20 and 42 MeV (83CA13) [report involvement of ^{6}Li*(4.31, 5.65)], at 70 MeV (83GO06, 85PA1C, 85PA04) and at 119.6 and 200.2 MeV (84WA09, 85WA25). In the latter experiments the spectroscopic factors for $^6\text{Li}_{\text{g.s.}}$ are deduced to be 0.76 [at 119.6 MeV] and 0.84 [at 200.2 MeV] using DWIA and a bound-state Woods-Saxon 2S wave function (84WA09, 85WA25).

Work on reaction (d) has suggested that the ^{3}He + t parentage of ^{6}Li is comparable with the α + d parentage: see (84AJ01). See also (85PA1C). Reaction (e) was studied at $E_p = 70$ MeV (88PA27). See also ^{5}Li, ^{6}Be and (85BE30, 93ST06). The (p, 3p) reaction has been studied by (84NA17). The spectral function for pn pairs in ^{6}Li was obtained in a study of the ^{6}Li(p, pα)pn reaction at $E_p = 200$ MeV (90WA17). A measurement of tensor analyzing powers in ^{1}H(^{6}Li, d or α or t)X with 4.5 GeV polarized ^{6}Li deuterons provided information on the ^{6}Li D state (92PU03). Systematic studies of electron screening effects on low energy reactions including ^{6}Li + p are reported in (92EN04, 92EN01, 95RO1J). For antiproton studies see (87AS06). See also (84AJ01, 88AJ01) for the earlier work.

Theoretical work on these reactions reported since the previous review (88AJ01) is listed in Table 6.15 along with brief descriptions.

16. (a) ^{6}Li(d, d)^{6}Li

(b) ^{6}Li(d, pn)^{6}Li $Q_m = -2.224$

(c) ^{6}Li(d, 2d)^{4}He $Q_m = -1.475$

(d) ^{6}Li(d, αp)^{3}H $Q_m = 2.558$

Table 6.14: Parameters of levels of ^{6}Li [a]

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Reactions
2.185 ± 3	20.0 ± 2.8	^{4}He(d, d)^{4}He
2.187 ± 3		^{4}He(d, d)^{4}He
2.188 ± 6	24 ± 2[b]	^{6}Li(p, p′), (d, d′), ^{7}Li(d, t)^{6}Li
2.203 ± 6		^{9}Be(p, α)^{6}Li
2.186 ± 2	24 ± 2	"best" values
3.56288 ± 0.10[c]	$(8.2 \pm 0.2) \times 10^{-3}$	^{6}Li(γ, γ')^{6}Li
4.36 ± 40		^{4}He(d, d)^{6}Li
4.27 ± 40		^{6}Li(e, e′)^{6}Li
4.40 ± 120	1490 ± 150	^{6}Li(p, p′)^{6}Li
4.32 ± 40	1820 ± 110	^{6}Li(d, d′)^{6}Li
4.3 ± 100	600 ± 100	^{7}Li(^{3}He, α)^{6}Li
4.3 ± 200	1600 ± 300	^{7}Li(^{3}He, αd)^{4}He
4.3	1600 ± 350 [d]	^{7}Li(^{3}He, αd)^{4}He
4.30 ± 10	850 ± 50, 480 ± 80	^{9}Be(p, α)^{6}Li
4.312 ± 22	1700 ± 100	"best" values
5.379 ± 17 [e]	540 ± 20 [d]	^{6}Li(e, e′)^{6}Li
5.33 ± 80	560^{+340}_{-100}	^{6}Li(p, p′)^{6}Li
5.34 ± 20	560 ± 40 [b]	^{7}Li(^{3}He, α)^{6}Li
5.325 ± 5	270 ± 12	^{9}Be(p, α)^{6}Li
5.366 ± 15	540 ± 20	"best" values
5.65 ± 50 [f]		^{4}He(d, d)^{4}He
5.7	1000^{+600}_{-400} [g]	^{6}Li(p, p′)^{6}Li
5.65 ± 200	1650 ± 300	^{7}Li(^{3}He, αd)^{4}He
5.65 ± 40	900 ± 60, 1260 ± 120	^{9}Be(p, α)^{6}Li
5.65 ± 50	1500 ± 200	"best" values

[a] For references and other values see tables 6.5 in (79AJ01, 84AJ01).
[b] And C.P. Browne, private communication.
[c] (81RO1D).
[d] Average of measurements of $E(^3$He)4, 5, 6 MeV (95AR14).
[e] See table 6.4 in (79AJ01).
[f] See table 6.3 in (79AJ01).
[g] See references (c) and (d) in table 6.5 in (79AJ01).

Table 6.15: ^{6}Li(p, p)^{6}Li – Theoretical work

Reference	Description
88HA25	^{6}Li proton and neutron transition densities from elastic scattering
90ZH1R	Quasi resonating group method analysis of ^{6}Li(p, p)^{6}Li
92GA27	Folding-model study of elastic scattering in halo nuclei
93DU09	Potential description of N+^{6}Li elastic scattering
93KO44	Description of ^{6}Li(p, p)^{6}Li with microscopic effective interaction
93PE13	Folding model description of ^{6}Li(p, p)^{6}Li at 25–50 MeV
93SA10	DWBA analysis of ^{6}Li(p, p)^{6}Li near the α-d breakup threshold
94ZH34	Glauber-Sitenko diffraction theory calculation of ^{6}Li(p, p)^{6}Li
94ZH28	Elastic and inelastic proton scattering on ^{6}Li nucleus at intermediate energies
95GA24	Analysis of properties of exotic nuclei in elastic scattering
95KA07	Continuum-continuum coupling in ^{6}Li(p, p)^{6}Li at $E_p = 65$ MeV
95KA03	Folding-model analysis of ^{6}Li(p, p$'$)^{6}Li at $E_p = 10$–136 MeV
95KA43	Folding-model analysis of ^{6}Li(p, p$'$)^{6}Li at $E_p = 10$–136 MeV
97DO01	Fully microscopic model analyses of ^{6}Li(p, p$'$)^{6}Li at $E_p = 200$ MeV
97KA1N	Shell model structures of ^{6}Li states excited in ^{6}Li(p, p$'$)^{6}Li

Angular distributions of deuterons have been measured at $E_d = 4.5$ to 19.6 MeV [see (79AJ01)] and at 50 MeV (88KO1C, 96RU1A). The 0^+, $T = 1$ state, ^{6}Li*(3.56) is not appreciably populated. For a summary of the results on excited states see Table 6.14. Gaussian potentials were derived for the description of ^{6}Li+d elastic scattering by (92DU07).

At $E_d = 21$ MeV reaction (b) shows spectral peaking (characteristic of $^{1}S_0$ for the pn system [$T = 1$]) when ^{6}Li*(3.56) is formed, in contrast with the much broader shape (characteristic of $^{3}S_1$) seen when ^{6}Li*(0, 2.19) are populated. A study of reaction (c) at $E_d = 52$ MeV shows that the α-clustering probability, $N_{\text{eff}} = 0.12^{+0.12}_{-0.06}$ if a Hankel function is used. The α-particle and the deuteron clusters in ^{6}Li have essentially a relative orbital momentum of $l = 0$. The D-state probability of the ground state of ^{6}Li is $\approx 5\%$ of the S-state. Quasi-free scattering is an important process even for $E_d = 6$ to 11 MeV. Interference effects are evident in reaction (c) proceeding through ^{6}Li*(2.19, 4.31): this is due to the experiment being unable to determine whether the detected particle was emitted first or second in the sequential decay. Reactions (c) and (d) studied at $E_d = 7.5$ to 10.5 MeV indicate that the three-body breakup of ^{6}Li at these low energies is dominated by sequential decay processes (79AJ01, 90YA11). Differential cross sections for cluster pickup by 20 MeV/nucleon deuterons on ^{6}Li were measured by (95MA57).

See also ^{8}Be and (87AL1L, 82CH28, 83GO1J, 83LY04, 84BL21, 84KU15, 85LI1C, 86AV1C).

17. ^{6}Li(t, t)^{6}Li

At $E_t = 17$ MeV angular distributions have been measured for the tritons to ^{6}Li*(0, 3.56): see (79AJ01).

18. (a) ^{6}Li(^{3}He, ^{3}He)^{6}Li
    (b) ^{6}Li(^{3}He, pα)^{4}He $Q_m = 16.878$

Angular distributions have been measured at $E(^3\text{He}) = 8$ to 217 MeV [see (79AJ01, 84AJ01)] and at 34, 50, 60 and 72 MeV (86BR1M; elastic).

More recently, differential cross sections were measured for elastic scattering at $E(^3\text{He}) = 93$ MeV (94DO32), and at $E(^3\text{He}) = 60$ MeV (95MA57), and for inelastic scattering to ^{6}Li* ($E_x = 2.185$ MeV, $J^\pi = 3^+$) at $E(^3\text{He}) = 50$, 60, 72 MeV (95BU20). A microscopic-potential analysis of data at $E(^3\text{He}) = 34$, 50, 60, 72 MeV is described in (93SI06). Experimental and theoretical evidence for ^{4}H clustering in ^{6}Li is reviewed (95MI16). For reaction (b), cross sections have been measured at $E(^3\text{He}) = 11$, 13, 14 MeV (89AR08, 89ARZR); $E(^3\text{He}) = 2.5$ MeV (89AR20); $E(^3\text{He}) = 1.6$ MeV (91AR25); $E(^3\text{He}) = 1.6$–9 MeV (92AR20); $E(^3\text{He}) = 8$–14 MeV (95KO51); $E(^3\text{He}) = 2.0$, 22 MeV (92DA1K); $E(^3\text{He}) = 7$, 9 MeV (93AR12). A calculation of near-threshold two-fragment resonance amplitudes and widths for this reaction at $E(^3\text{He}) = 8$–14 MeV was reported in (95KO51). See also ^{5}Li (84AR17, 87ZA07) and see ^{9}B.

19. (a) ^{6}Li(α, α)^{6}Li
    (b) ^{6}Li(α, 2α)^{2}H $Q_m = -1.475$

Angular distributions (reaction (a)) have been measured at $E_\alpha = 1.39$ to 166 MeV [see (74AJ01, 79AJ01, 84AJ01)] and at $E_\alpha = 36.6$ and 50.5 MeV (86BR1M). See also (87BU1E, 86RO1M). See also ^{10}B.

More recent measurements at $E_\alpha = 50.5$ MeV of elastic and inelastic ^{6}Li*($E_x = 2.185$ MeV, $J^\pi = 3^+$) were reported by (94BUZY, 96BU06). Tensor polarization for inelastic scattering to ^{6}Li*(2.185, 3^+) has been measured at $E_\alpha = 80$ MeV (92KO19, 93KO33). Angular distributions for (α, α') in the continuum region were studied at $E_\alpha = 50$ MeV (92SA01) and at $E_\alpha = 40$ MeV (94SA32), at $E_\alpha = 10$ MeV/A (96SI13) and $E_\alpha = 119$ MeV (93OK1A). Cross sections and analyzing powers for elastic scattering of polarized ^{6}Li by ^{4}He are reported for $E(^6\text{Li}) = 50$ MeV (95KE10) and $E_{cm} = 11.1$ MeV (96GR08).

Studies of continuum coupling effects in inelastic scattering are described in (95KA1Y, 95KA43, 97RU06). Folding-model potential analyses of elastic scattering are reported in (93SI09, 95SA12). Multiconfiguration resonating group methods applied to the ^{6}Li + α system are discussed in (94FU17, 95FU11). See also (88KO32, 89LE07).

Reaction (b) has been studied at $E_\alpha = 6.6$ to 700 MeV: see (74AJ01, 79AJ01, 84AJ01). At the latter energy and using a width parameter of 60.6 MeV/c the effective number of

α + d clusters for ^{6}Li$_{\rm g.s.}$, $n_{\rm eff}$ = 0.98 ± 0.05. The results are very model dependent: see (84AJ01). At E_α = 27.2 MeV ^{6}Li*(2.19) is very strongly populated (85KO29). See also (82CH28, 83AV1A, 83BE1H, 83BU15, 85BE60, 86GA1F, 86ZE01, 87KO1L, 88LE06).

In more recent work, two dimensional coincidence spectra of charged particles were measured at $E_\alpha \approx 100$ MeV (92GA18). Quasifree scattering processes were studied at E_α = 77–119 MeV (92OK01), E_α = 118 MeV (93OK1B), and E_α = 118.4 MeV (97OK1A). The four-body ^{6}Li(α, 2α)pn breakup reaction was measured at E_α = 77–119 MeV (92WA18, breakup cross sections); E_α = 118 MeV (88WA29, 89WA26, spectral functions of pn pair).

20. (a) ^{6}Li(^{6}Li, ^{6}Li)^{6}Li
    (b) ^{6}Li(^{6}Li, 2d)2 ^{4}He $Q_{\rm m} = -2.950$
    (c) ^{6}Li(^{6}Li, α)2 ^{4}He $Q_{\rm m} = 20.897$

Angular distributions of ^{6}Li ions have been studied for $E(^6$Li) = 3.2 to 36 MeV [see (74AJ01, 79AJ01, 84AJ01)] and at $E(^6$Li) = 2.0 to 5.5 MeV (83NO08) and 156 MeV (85SA36; ^{6}Li*(0, 2.19)), (85MI05; elastic; ^{6}Li*(2.19, 3.56) are also populated), (87EY01; several states in ^{12}C). Reaction (b) has been studied for $E(^6$Li) = 36 to 47 MeV: enhancements in yield, due to double spectator poles, have been observed in d-d and α-α but not in α-d double coincidence spectra. The widths of the peaks are smaller than those predicted from the momentum distribution of α + d clusters in ^{6}Li. ^{6}Li*(2.19) was also populated. See references in (84AJ01). Other work on reaction (b) is reported by (84LA19: 2.4 and 4.2 MeV) and by (85NO1A).

For reaction (c), the energy dependence of quasifree effects were investigated in the range $E(^6$Li) = 2.4–6.7 MeV (87LA25, 88LA1D). An analysis (96CH1C) used quasifree data from reaction (c) to extract the ^{6}Li(d, α)^{4}He excitation function at astrophysical energies. See also ^{12}C in (85AJ01) and (83CH59, 84CH1E, 86KA1B, 86SA1D, 87AR13, 87SA1C).

More recently, elastic scattering angular distributions were measured for $E(^6$Li) = 5–40 MeV (97PO1B, optical model analysis). Eikonal-approximation calculations of differential cross sections and phase shifts for $E(^6$Li) = 156 MeV were reported in (92EL1A).

21. ^{6}Li(^{7}Li, ^{7}Li)^{6}Li

Angular distributions have been measured at $E(^7$Li) = 78 MeV to ^{6}Li*(0, 2.19) (86GL1D).

22. ^{6}Li(^{9}Be, ^{9}Be)^{6}Li

The elastic scattering has been studied in inverse kinematics at $E(^6$Li) = 4.0, 6.0 and 24 MeV [see (79AJ01)], at 32 MeV (85CO09) and at 50 MeV (88TRZY; prelim.; also inelastic). Recently angular distributions for elastic and inelastic scattering to ^{6}Li*(3$^+$, 2.186) were measured (95MU01) at E_{cm} = 7, 10, 12 MeV. Excitation functions for $E_{cm} \approx$ 4–12 were also reported. See also ^{9}Be. For the interaction cross section at $E(^6\text{Li})$ = 790 MeV/A see (85TA18).

23. ^{6}Li(^{10}B, ^{10}B)^{6}Li

The elastic scattering has been studied at $E(^6\text{Li})$ = 5.8 and 30 MeV: see (79AJ01).

24. (a) ^{6}Li(^{12}C, ^{12}C)^{6}Li
(b) ^{6}Li(^{13}C, ^{13}C)^{6}Li
(c) ^{6}Li(^{14}C, ^{14}C)^{6}Li

The elastic and inelastic scattering (reaction (a)) has been studied at $E(^6\text{Li})$ = 4.5 to 156 MeV [see (84AJ01)] and at $E(^6\text{Li})$ = 19.2 MeV (83RU09), 36 and 45 MeV [and $E(^{12}\text{C})$ = 72 and 90 MeV] (84VI02, 85VI03; also to ^{6}Li*(2.19, 4.31) and to various states of ^{12}C), at $E(^{12}\text{C})$ = 58.4 MeV (87PA12), 90 MeV (87DE02; also to various states of ^{12}C), 123.5 and 168.6 MeV (88KA09; and to various states of ^{12}C), 150 MeV (87TA21, 88TA08; also VAP), 156 MeV (87EY01; and to various states in ^{12}C) and at 210 MeV (88NA02). See also (86SH1Q, 87PA12). More recently, measurements of cross sections and/or analyzing power observables have been reported at $E(^6\text{Li})$ = 93 MeV (89DE34), at E_{cm} = 13.3 MeV (89HN1A, 95CA26 and to ^{6}Li*(3^+, 2.186) and ^{12}C*(2^+, 4.44)), at $E(^6\text{Li})$ = 210 MeV (89NA11, to ^{12}C*(2^+, 4.44)), at $E(^6\text{Li})$ = 30 MeV (89VA04, to ^{12}C*(2^+, 4.44)), at 50 MeV (90TR02, to ^{12}C*(2^+, 4.44; 0^+, 7.65; 3^-, 9.64)), at $E(^6\text{Li})$ = 30 MeV (94RE01), at $E(^6\text{Li})$ = 30, 60 MeV (96KE09, to ^{12}C*(2^+, 4.44; 0^+, 7.65; 3^-, 9.64)), to 20 MeV (96GA29, to ^{6}Li*(3^+, 2.18) and ^{12}C*(2^+, 4.44)), at $E(^6\text{Li})$ = 318 MeV (93NA01), at $E(^6\text{Li})$ = 30 MeV (94RE15 to ^{12}C*(2^+, 4.44; 3^-, 9.64)), at $E(^6\text{Li})$ = 50 MeV (95KE10). At $E(^6\text{Li})$ = 34 MeV the d-α angular correlations involve ^{6}Li*(0, 2.19) (85CU04). See also (88SE1E), and see ^{12}C in (85AJ01, 90AJ01). An experimental study of the α + d breakup in ^{6}Li + ^{12}C collision at $E(^6\text{Li})$ = 156 MeV is reported in (89JE01). For pion production see (84CH16). For the interaction cross section at $E(^6\text{Li})$ = 790 MeV/A see (85TA18). For VAP measurements at $E(^6\vec{\text{Li}})$ = 30 MeV see (88VAZY).

The elastic scattering (reaction (b)) has been studied for $E(^6\text{Li})$ = 5.8 to 40 MeV: see (84AJ01). Measurements of differential cross sections for E_{cm} = 26 MeV and observations of a nuclear quasi rainbow were reported by (94DE43). See also (87CA30, 88WO10). The elastic scattering (reaction (c)) has been measured for $E(^6\text{Li})$ = 93 MeV (87DE02). See also ^{18}F and ^{19}F in (87AJ02) and (86MC1C, 88MCZY, 83BI1A, 84HA53, 82GU1B, 83BU15, 83DE1E, 83OS03, 83SH24, 84BR08, 84GR05, 84MU1D, 84SA1B, 85CO21, 85SH1A, 86BE45, 86IO01, 86KA1B, 86MI24, 86SAZL, 86SAZK, 86SAZJ, 86SA1D, 87AR13, 87KA1I, 87SA1C, 87SA21, 88DEZU, 88DE1F, 88SA15).

Several theoretical studies relating to ^{6}Li + ^{12}C have been reported. The role of the Pauli Principle in heavy ion scattering has been studied (88GR32). The dispersive contribution to the ^{6}Li + ^{12}C real potential was estimated (90KA14). Elastic cross sections for $E(^6\text{Li}) = 30$ MeV were analyzed (90SA05). A semimicroscopic analysis of inelastic scattering at $E(^6\text{Li}) = 156$ MeV is described in (92GA17). Folding model analysis of ^{6}Li + ^{12}C scattering is discussed in (94SA10, 94NA03, 95KH03).

Other theoretical descriptions of ^{6}Li + ^{12}C scattering are discussed in (94SA33, strong absorption model), (95IS1F, multiple diffraction interaction), and (96CA01, microscopic description).

25. ^{6}Li(^{16}O, ^{16}O)^{6}Li

Elastic angular distributions have been reported at $E(^6\text{Li}) = 4.5$ to 50.6 MeV [see (84AJ01)], at $E(^6\text{Li}) = 35.3$ and $E(^{16}\text{O}) = 94.2$ MeV (84VI02) and at 50 MeV (88TRZY; prelim.; also inelastic). At $E(^6\text{Li}) = 25.7$ and $E(^{16}\text{O}) = 68.6$ MeV (85VI03, 84VI01) report some $\sigma(\theta)$ to ^{6}Li*(2.19) [and to ^{16}O*(6.13)]. See also (87PA12). See (85VI03, 86SC28) for studies of the breakup. Polarization observables have has been measured at $E(^6\text{Li}) = 25.7$ MeV, and also using ^{16}O ions (87VAZY, 89VA04). Measurements of $E(^6\text{Li}) = 50$ MeV for elastic scattering and inelastic scattering to ^{16}O*(2^+, 6.05; 3^-, 6.13; 2^+, 6.92; 1^-, 7.12) were reported (90TR02). For fusion cross sections see (86MA19). See also ^{16}O in (86AJ04), (86MO1E, 87PA12) and (83BU15, 83JO1A, 84WI08, 85CO21, 85SA13, 86SAZS). Theoretical work on this scattering reaction includes (90SA05, $E(^6\text{Li}) = 29.8$ MeV, optical model description), (88GR32, $E(^6\text{Li}) = 29.8$–30.6 MeV, Pauli Principle rule), (90SA05, $E(^6\text{Li}) = 30.6$, optical model analysis), (91BO48, projectile effects), (91HI07, $E(^6\text{Li}) = 154$ MeV, 3-body cluster model), (91HI11, $E(^6\text{Li}) = 22.8$ MeV, nonresonant breakup states), (91SA26, $E(^6\text{Li}) = 30$ MeV, double-folding model, role of Pauli Principle).

26. (a) ^{6}Li(^{24}Mg, ^{24}Mg)^{6}Li
(b) ^{6}Li(^{25}Mg, ^{25}Mg)^{6}Li
(c) ^{6}Li(^{26}Mg, ^{26}Mg)^{6}Li
(d) ^{6}Li(^{27}Al, ^{27}Al)^{6}Li

Elastic scattering for reaction (a) was studied at $E(^6\text{Li}) = 156$ MeV (95DE53). Reaction (c) has been studied at $E(^6\text{Li}) = 88$ MeV and 36 MeV (84AJ01) and at 44 MeV (89RU05, polarization observables), and $E(^6\text{Li}) = 60$ MeV (94WA20, polarization observables). Reaction (d) was studied at $E(^6\text{Li}) = 156$ MeV by (87NI04, particles and gammas from inelastic scattering). See also the measurements at $E(^6\text{Li}) = 790$ MeV/A (85TA18).

Theoretical studies for these reactions include (91BO48, analyzed non-Rutherford cross sections), (91HI11, effects of nonresonant breakup states), (94SA33, strong absorption model analysis), (91HI07, cluster folding interaction), (92HI02, coupled channels study), (94RU11, cluster-folding analysis).

27. (a) ^{6}Li(^{28}Si, ^{28}Si)^{6}Li
    (b) ^{6}Li(^{30}Si, ^{30}Si)^{6}Li

The elastic scattering has been studied at $E(^{6}\text{Li}) = 13$ to 154 MeV [see (84AJ01)], at 27 and 34 MeV (83VI03) and at 210 MeV (88NAZX). For a study of the decay see (87NI04). See also references cited in (88AJ01).

More recent measurements have been reported at $E(^{6}\text{Li}) = 210$ MeV (89NA11, inelastic $\sigma(\theta)$ to ^{28}Si*(first 2^{+} state)), (89NA02, elastic $\sigma(\theta)$, optical parameters), $E(^{6}\text{Li}) = 318$ MeV (90NAZZ, 93NA01, $\sigma(\theta)$, folding model potentials). Related analyses and other theoretical studies include (88GR32, 91SA26, Pauli Principle role), (90KU23, scattering matrix approach), (90SA05, deduced model parameters), (91BO48, non Rutherford cross section thresholds), (91HI07, cluster-folding interactions), (91TI04, energy dependence, dispersion relation), (94SA33, strong absorption model), (95EM03, $E(^{6}\text{Li}) = 210$, 318 MeV, energy approximation), (96CA01, microscopic description), (96KN02, microscopic potentials, density matrix formalism), (97SA57, $E(^{6}\text{Li}) = 35$, 53 MeV/nucleon, breakup effect), (98PI02, $E(^{6}\text{Li}) = 210$, 315 MeV, S-matrix approach).

For reaction (b) see (87AR13).

28. (a) ^{6}Li(^{39}K, ^{39}K)^{6}Li
    (b) ^{6}Li(^{40}Ca, ^{40}Ca)^{6}Li
    (c) ^{6}Li(^{44}Ca, ^{44}Ca)^{6}Li
    (d) ^{6}Li(^{48}Ca, ^{48}Ca)^{6}Li

Elastic scattering has been studied for $E(^{6}\text{Li}) = 26$ to 99 MeV: see (84AJ01, 88AJ01), and at $E(^{6}\text{Li}) = 34$ MeV (reaction (b)) by (87VA31) and at 210 MeV (88NAZX, 89NA02; reaction (b)). ^{6}Li*(2.19) has been studied at $E(^{40}\text{Ca}) = 227$ MeV (87VA31). Reaction (d) was studied at $E(^{6}\text{Li}) = 150$ MeV (90KAZH). For fusion measurements (reaction (b)) see (84BR04). For breakup measurements (reaction (b)) see (84GR20, 90YA09, 92YAZW, 93GU10, 95AR15, 96YA01).

For theoretical studies related to these reactions, see (87SA21, energy and target dependence of projectile breakup), (87VA31, sequential breakup cross sections), (88GR32, role of Pauli Principle), (88KH08, 90DA23, exchange effects), (90TA1I, imaginary part of channel-coupling potentials), (90SA05, $E(^{6}\text{Li}) = 30$ MeV, deduced optical model parameters), (91HI07, cluster folding interactions), (94SA33, strong absorption model), (95BE60, 98PI02, S-matrix approach), (96KN02, microscopic potentials). For earlier work see references cited in (88AJ01).

29. (a) ^{7}Li(γ, n)^{6}Li $\qquad Q_{\rm m} = -7.249$

(b) ^{7}Li(γ, pπ^-)^{6}Li $\qquad Q_{\rm m} = -146.035$

Transitions to ^{6}Li*(0, 2.19, 3.56) have been observed in reaction (a): see (79AJ01, 84AJ01). Differential cross sections are reported for E_γ(bremsstrahlung) = 60 to 120 MeV for the n_0+n_2 groups (85SE17). Bremsstrahlung yield for (γ, n_0) was measured for E_γ = 7–9 MeV (89KA30). Reaction (b) at 0.9 GeV involves ^{6}Li*(2.19) (85RE1A; prelim.). See also the measurements of E_γ = 350 MeV reported by (91GA26), and see ^{7}Li, (86GO1M, 85ST1A, 86BA2G).

An analysis of ^{7}Li(γ, n) data in the giant resonance energy region is described in (87VA05). Cluster effects were explored in (92VA12). Calculation with a potential two cluster model are reported in (97DU02).

30. ^{7}Li(π^+, p)^{6}Li $\qquad Q_{\rm m} = 133.101$

Differential cross sections have been measured at E_{π^+} = 75 and 175 MeV for the transitions to ^{6}Li*(0, 2.19): see (84AJ01). Proton spectra measured at momentum exchange 660 MeV/c provided evidence for an eta-meson nuclear bound state.

31. (a) ^{7}Li(p, d)^{6}Li $\qquad Q_{\rm m} = -5.025$

(b) ^{7}Li(p, pn)^{6}Li $\qquad Q_{\rm m} = -7.249$

Angular distributions of deuterons (reaction (a)) have been studied for $E_{\rm p}$ = 167 to 800 MeV [see (79AJ01, 84AJ01)] and at 18.6 MeV (86GO1N, 87GO27; d_0, d_1, d_2; see for spectroscopic factors), 200 and 400 MeV (85KR13; d_0, d_1; d_2 is weakly populated at 200 MeV) and at 800 MeV (84SM04; d_0, d_1). The ratio of the intensities of the groups to ^{6}Li*(2.19) and ^{6}Li$_{\rm g.s.}$ increases with energy. It is suggested that this can be understood in terms of a small admixture of 1f orbital in these states (85KR13). A DWBA analysis of $E_{\rm p}$ = 185 MeV data leads to C^2S = 0.87, 0.67, 0.24, (0.05), 0.14, respectively for ^{6}Li*(0, 2.19, 3.56, 4.31, 5.37). No other states were seen below $E_{\rm x} \approx 20$ MeV: see (79AJ01). The tensor analyzing power T_{20} was measured for the ^{1}H(^{7}Li, d)^{6}Li reaction at E(^{7}Li) = 70 MeV to ^{6}Li*(0, 2.186) (91DA07). Data at $E_{\rm p}$ = 33.6 MeV were analyzed by (91AB04) in a test for Cohen-Kurath wave functions. See also the analysis of data at $E_{\rm p}$ = 698 MeV by (93AL05, eta production). In reaction (b) at $E_{\rm p}$ = 1 GeV the separation energy between ≈6.5 MeV broad $1p_{3/2}$ and $1s_{1/2}$ groups is reported to be 18.0 ± 0.8 MeV (85BE30, 85DO16). See also (83LY04, 88BE1I, 88GU1D). Differential cross sections were measured at $E_{\rm p}$ = 70 MeV (88PA26) and at $E_{\rm p}$ = 2.7–3.8 MeV (88BO37, application). See also the measurements for nuclear microprobe utilization (95RI14).

32. ^{7}Li(d, t)^{6}Li $\quad Q_{\rm m} = -0.992$

A study at $E_{\rm d} = 23.6$ MeV of the relative cross sections of the analog reactions ^{7}Li(d, t)^{6}Li (to the first two $T = 1$ states at 3.56 and 5.37 MeV) and ^{7}Li(d, ^{3}He)^{6}He (to the ground and 1.80 MeV excited states) shows that ^{6}Li*(3.56, 5.37) have high isospin purity ($\alpha^2 < 0.008$): this is explained in terms of antisymmetrization effects which prevent mixing with nearby $T = 0$ states: see (79AJ01). (87BO39, 87BO39) [$E_{\rm d} = 30.7$ MeV] deduce that the branching ratio of ^{6}Li*(4.31) [2^+] into a dinucleon [$T = 1$, $S = 0$] is (85 ± 10)%: see also reactions 13 in ^{6}He and 4 in ^{6}Be. See also (87GU1F; $E_{\rm d} = 18$ MeV; angular distributions to ^{6}Li*(0, 2.19, 3.56); prelim.) and (84BL21, 86AV1C, 88GU1D). See also the analysis method discussed in (95GU22, DWBA and dispersive theory).

33. (a) ^{7}Li(^{3}He, α)^{6}Li $\quad Q_{\rm m} = 13.328$

(b) ^{7}Li(^{3}He, dα)^{4}He $\quad Q_{\rm m} = 11.853$

Angular distributions have been reported at $E(^{3}{\rm He}) = 5.1$ to 33.3 MeV [see (74AJ01, 84AJ01): the lower energy work has not been published] and more recently at $E(^{3}{\rm He}) = 60$ MeV (94BUZX). Excited states observed in this reaction are displayed in Table 6.14. No other states are reported below $E_{\rm x} = 10$ MeV: see (79AJ01). (86AN04) have analyzed unpublished data which suggest the involvement of several broad highly excited states of ^{6}Li. See also (87AL1L).

Several attempts have been made to look at the isospin decay of ^{6}Li*(5.37) [J^{π}; T = 2^+; 1] via ^{7}Li(^{3}He, α)^{6}Li*$\rightarrow$ d + α: the branching is < 1%. $\Gamma_{\rm p}/\Gamma = 0.35 \pm 0.10$ and $\Gamma_{\rm p+n}/\Gamma = 0.65 \pm 0.10$ for ^{6}Li*(5.37): see (79AJ01). ^{4}He + d spectra suggest the excitation of ^{6}Li*(4.3) [$E_{\rm x} = 4.3 \pm 0.2$ MeV, $\Gamma = 1.6 \pm 0.3$ MeV] and ^{6}Li*(5.7) [$E_{\rm x} = 5.65 \pm 0.2$ MeV, $\Gamma = 1.65 \pm 0.3$ MeV]: see (84AJ01). See also (85DA29, 88BO1Y). A more recent measurement at $E(^{3}{\rm He}) = 4$, 5, 6 MeV (95AR14) gave values for the width of of ^{6}Li*(4.31) in agreement with the adopted value $\Gamma = 1700 \pm 200$ keV and found no dependence on incident energy. Measurements of d-α coincidence spectra at $E(^{3}{\rm He}) = 11.5$ MeV (88AR20) and 5.0 MeV (91AR19) gave spectroscopic parameters for ^{6}Li*(5.65) in agreement with adopted values (88AJ01). At $E(^{3}{\rm He}) = 120$ MeV the missing mass spectra for (^{3}He, 2d) and (^{3}He, pt) reflect the population of ^{6}Li*(0, 2.19) and suggest broad structures at $E_{\rm x} = 28.5$ and 32.9 MeV (85FR01). See also ^{10}B and (88BO1J, 83KU17).

34. (a) ^{7}Li(^{6}Li, ^{7}Li)^{6}Li

(b) ^{7}Li(^{7}Li, ^{8}Li)^{6}Li $\quad Q_{\rm m} = -5.216$

At $E(^{6}{\rm Li}) = 93$ MeV a broad group ($\Gamma \approx 11$ MeV) centered at $E_{\rm x} = 20$ MeV is reported in addition to other peaks at $E_{\rm x} = 17.1 \pm 0.3$, 18.9 ± 0.3 and 21.2 ± 0.3 MeV (87GLZW). See (84KO25) for reaction (b).

35. (a) ^{9}Be(p, α)^{6}Li $\qquad Q_m = 2.126$

(b) ^{9}Be(p, 2α)^{2}H $\qquad Q_m = 0.651$

(c) ^{9}Be(p, pt)^{6}Li $\qquad Q_m = -17.688$

Angular distributions of α-particles (reaction (a)) have been measured at $E_p = 0.11$ to 45 MeV. [see (74AJ01, 79AJ01)] and at $E_p = 22.5$, 31 and 41 MeV (86HA27; α_0, α_1, α_2; see for spectroscopic factors). See also Table 6.14 and (84AJ01). ^{6}Li*(3.56) decays by γ-emission consistent with M1; $\Gamma_\alpha/\Gamma < 0.025$ [forbidden by spin and parity conservation]: see (84AJ01). At $E_p = 9$ MeV the yield of reaction (b) is dominated by FSI through ^{8}Be*(0, 2.9) and ^{6}Li*(2.19) with little or no yield from direct three-body decay: see (79AJ01). More recent measurements of cross sections and/or polarization observables have been reported at $E_p = 50$ MeV (89GU05), $E_p = 25$, 30 MeV (92PE12; determined spectroscopic strengths), $E_p = 40$ MeV (97FA17) [see also (89FA1B)], $E_p = 2$–5 MeV (88ABZW), $E_p = 16$–390 keV [deduced $S(E)$] (97ZA06), $E_p = 77$–321 keV [deduced stellar reaction rates] (98BR10). See also application-related experiments (90RE09, 95RI14). Analyses of data for this reaction have been reported for $E_p = 45$–50 MeV [DWBA] (96YA09, 97YAZV) and $E_p < 2$ MeV [analyzed reaction rates, primordial ^{6}Li] (97NO04). Reactions (b) and (c) at $E_p = 58$ MeV involve ^{6}Li*(0, 2.19) (85DE17). See also ^{10}B and (86AN26, 85MA1F, 86KA26).

36. ^{9}Be(d, ^{5}He)^{6}Li $\qquad Q_m = -0.992$

See ^{5}He.

37. ^{9}Be(t, ^{6}He)^{6}Li $\qquad Q_m = -5.382$

Angular distributions of $^6\text{He}_{\text{g.s.}}+{}^6\text{Li}_{\text{g.s.}}$ and $^6\text{He}_{\text{g.s.}}+{}^6\text{Li}^*_{3.56}$ [both listed ions were detected] have been measured at $E_t = 21.5$ and 23.5 MeV. In the latter case the final state is composed of two isobaric analog states: angular distributions are symmetric about 90° cm, within the overall experimental errors. In the reaction leading to the ground states of ^{6}He and ^{6}Li differences from symmetry of as much as 40% are observed at forward angles. Angular distributions involving $^6\text{He}_{\text{g.s.}}+$ ^{6}Li*(2.19) and $^6\text{Li}_{\text{g.s.}}+{}^6$He*(1.8) have also been measured. This reaction appears to proceed predominantly by means of the direct pickup of a triton or ^{3}He from ^{9}Be. Differential cross sections are also reported at $E_t = 17$ MeV: see (84AJ01) for references.

38. ^{9}Be(^{3}He, ^{6}Li)^{6}Li $\qquad Q_m = -1.893$

Angular distributions of ^{6}Li ions have been obtained at $E(^3\text{He}) = 6$ to 10 MeV: see (74AJ01). A study of the continuum suggests the population of ^{6}Li states at $E_x = 8$–12, ≈ 21 and 21.5 MeV: see (84AJ01). More recently, measurements at $E(^3\text{He}) = 60$ MeV of differential cross sections have been reported (90MAZG, 90MA1O, 95MA57). Spectroscopic factors were deduced. Angular distributions at $E(^3\text{He}) = 60$ MeV for transition to the ^{6}Li ground state and to ^{6}Li*(3$^+$, 2.185; 2$^+$, 5.37; 1$^+$, 5.65) were measured (96RU13) and analyzed by coupled-channels methods.

39. ^{10}B(n, ^{5}He)^{6}Li $\qquad Q_m = -5.354$

Differential cross sections are reported at $E_n = 14.4$ MeV involving ^{6}Li*(2.19) and $^5\text{He}_{\text{g.s.}}$ (84TU02).

40. ^{10}B(d, ^{6}Li)^{6}Li $\qquad Q_m = -2.985$

Angular distributions involving ^{6}Li*(0, 2.19) have been studied at $E_d = 13.6$ MeV (83DO10) and at 19.5 MeV [see (74AJ01)]. See also (84SH1E).

41. ^{10}B(^{3}He, ^{7}Be)^{6}Li $\qquad Q_m = -2.874$

Angular distributions involving ^{6}Li*(0, 2.19) have been measured at $E(^3\text{He}) = 30$ MeV: see (74AJ01).

42. ^{10}B(α, ^{8}Be)^{6}Li $\qquad Q_m = -4.551$

At $E_\alpha = 72.5$ MeV only ^{6}Li*(0, 2.19) are observed: the latter is excited much more strongly than is the ground state [S_α for the ground state is 0.4 that for ^{6}Li*(2.19)]. The angular distributions for both transitions are flat: see (79AJ01). See also (84AJ01). A more recent measurement of differential cross sections at $E_\alpha = 27.2$ MeV is reported in (95FA21). Spectroscopic factors were deduced.

43. ^{11}B(d, ^{7}Li)^{6}Li $\qquad Q_m = -7.190$

See (84AJ01).

44. ^{11}B(^{3}He, ^{8}Be)^{6}Li $\qquad Q_m = 4.572$

Angular distributions are reported at $E(^3\text{He}) = 71.8$ MeV involving several states in ^{8}Be (86JA02, 86JA14).

45. ^{12}C(p, ^{7}Be)^{6}Li $\qquad Q_m = -22.567$

Angular distributions involving ^{7}Be*(0, 0.43) have been measured at $E_p = 40.3$ MeV (85DE05). For the earlier work at $E_p = 30.6$ to 56.8 MeV see (74AJ01, 79AJ01). See also (83DE1C, 84RE1A, 87KW01, 87KW03).

46. ^{12}C(d, ^{8}Be)^{6}Li $\qquad Q_m = -5.891$

Angular distributions involving several states in ^{8}Be have been studied at $E_d = 19.5$ and 51.8 MeV [see (74AJ01)] and at 50 MeV (85GO1G, 89GO07, 89GO26), 54.2 MeV (84UM04) and 78 MeV (86JA14), as well as at $E_d = 18$ and 22 MeV (87TA07) and 51.7 MeV (86YA12). See also (84NE1A, 87GO1S) and the DWBA calculations at $E_d = 50$ MeV (88KA46) and $E_d = 15$ MeV (88RA27).

47. ^{12}C(^{3}He, ^{9}B)^{6}Li $\qquad Q_m = -11.571$

Angular distributions have been obtained at $E(^3\text{He}) = 28$ to 40.7 MeV [see (74AJ01)] and at $E(^3\text{He}) = 33$ MeV (89SI02), $E(^3\text{He}) = 33.4$ MeV (86CL1B; also A_y), $E(^3\text{He}) = 60$ MeV (90MAZG, 93MA48), $E(^3\text{He}) = 30$–60 MeV (95MA57). See also (89GL1D) and see ^{9}B.

48. (a) ^{12}C(α, ^{10}B)^{6}Li $\qquad Q_m = -23.712$

(b) ^{12}C(α, dα)^{10}B $\qquad Q_m = -25.187$

Angular distributions (reaction (a)) at $E_\alpha = 42$ MeV involve ^{6}Li*(0, 2.19): see (74AJ01). Differential cross sections were measured at $E_\alpha = 90$ MeV and cluster spectroscopic amplitudes were deduced (91GL03). At $E_\alpha = 65$ MeV reaction (b) goes via ^{6}Li*(2.19, 4.31): see (84AJ01). See also ^{10}B and (87GA20).

48.5 ^{12}C(^{6}Li, αd)^{12}C $\qquad Q_{\rm m} = -1.475$

Measurements of triple differential cross sections for elastic breakup of 156 MeV ^{6}Li were reported in (89RE1G, 89HE28, 89HE17). A diffraction dissociation model analysis was used. See also reaction 55.

49. ^{12}C(^{10}B, ^{16}O)^{6}Li $\qquad Q_{\rm m} = 2.702$

See ^{16}O in (86AJ04).

49.5 ^{12}C(^{11}B, ^{6}Li)^{17}O $\qquad Q_{\rm m} = -4.609$

Measurements of angular distributions at $E(^{11}\text{B}) = 25$, 35, 40 MeV have been reported by (96JA12). Transfer mechanisms were studied.

50. ^{12}C(^{12}C, ^{12}C)2 ^{6}Li $\qquad Q_{\rm m} = -28.172$

The fragmentation of ^{12}C into 2 ^{6}Li ions has been observed at $E(^{12}\text{C}) = 2.1$ GeV/A (86LI1D).

51. ^{12}C(^{14}N, ^{20}Ne)^{6}Li $\qquad Q_{\rm m} = -4.181$

Angular distributions of reaction products were measured for $E(^{14}\text{N}) = 50$ MeV, and multinucleon transfer mechanisms were studied (92ARZX). See also the analysis for $E(^{14}\text{N}) =$ 54 MeV (87GO12), and see ^{20}Ne in (87AJ02, 98TI06).

52. ^{13}C(p, ^{8}Be)^{6}Li $\qquad Q_{\rm m} = -8.613$

See (74AJ01).

52.3 ^{13}C(t, ^{6}Li)^{10}Be $\qquad Q_{\rm m} = -8.618$

Measurements of differential cross sections and analyzing powers were reported by (89SI02). Spectroscopic factors were extracted.

52.7 ^{13}C(^{3}He, ^{6}Li)^{10}B $\qquad Q_m = -8.081$

Differential cross sections at $E(^3\text{He}) = 60$ MeV have been reported (90MAZG, 95MA57). Cluster pick-up mechanisms were studied.

53. ^{16}O(d, ^{12}C)^{6}Li $\qquad Q_m = -5.687$

Angular distributions and polarization observables involving ^{6}Li ions and several ^{12}C states are reported at $E_d = 22$ MeV (87TA07) and 51.7 MeV (86YA12) and at $E_d = 54.2$ MeV (84UM04). See also (84NE1A), and ^{12}C in (90AJ01) for polarization studies.

53.3 ^{16}O(^{3}He, ^{6}Li)^{13}N $\qquad Q_m = -9.237$

Measurements and analyses of differential cross sections at $E(^3\text{He}) = 30$–60 MeV have been reported (95MA57).

53.7 ^{19}F(d, ^{6}Li)^{15}N $\qquad Q_m = -2.538$

Differential cross sections at $E_d = 50$ MeV were reported (90GO14).

54. ^{19}F(^{3}He, ^{16}O)^{6}Li $\qquad Q_m = 4.095$

Angular distributions have been measured at $E(^3\text{He}) = 11$ to 40.7 MeV involving ^{6}Li*(0, 3.56) and various states of ^{16}O: see (74AJ01, 77AJ02). Differential cross sections have been reported for $E(^3\text{He}) = 66$ MeV (91MA56).

55. ^{208}Pb(^{6}Li, αd)^{208}Pb $\qquad Q_m = -1.475$

Measurements of triple differential cross sections for elastic breakup of 156 MeV ^{6}Li were reported in (89RE1G, 89HE28, 89HE17). Data were analyzed on the basis of a diffractive disintegration approach. Breakup measurements at $E(^6\text{Li}) = 60$ MeV were reported in (88HE16). See also reaction 48.3, and see the theoretical study of angular correlation of breakup fragments in (89BA25).

^{6}Be

GENERAL: See Table 6.16.

1. (a) ^{3}He(^{3}He, γ)^{6}Be	$Q_\text{m} = 11.488$	
(b) ^{3}He(^{3}He, p)^{5}Li	$Q_\text{m} = 10.893$	$E_\text{b} = 11.488$
(c) ^{3}He(^{3}He, 2p)^{4}He	$Q_\text{m} = 12.859$	
(d) ^{3}He(^{3}He, ^{3}He)^{3}He		
(e) ^{3}He(^{3}He, pd)^{3}He	$Q_\text{m} = -5.494$	

The yield of γ-rays to ^{6}Be*(1.7) (reaction (a)) increases smoothly from 0.4 to 9.3 μb (assuming isotropy) for $0.86 < E(^3\text{He}) < 11.8$ MeV (90°). No transitions are observed to ^{6}Be(0) [$\sigma < 0.01$ μb at $E(^3\text{He}) = 1.4$ MeV]. This is understood in terms of a direct capture of ^{3}He by ^{3}He in the singlet spin state and with zero angular momentum: the $0^+ \rightarrow 0^+$ γ-transition is forbidden. Reaction (a) is thus of negligible astrophysical importance compared to reaction (c): see (79AJ01). The capture cross section from $E(^3\text{He}) = 12$ MeV to 27 MeV continues to increase smoothly with energy at first and then shows a broad structure centered at $E(^3\text{He}) = 23\pm1$ MeV [$E_\text{x} = 23.0\pm0.5$ MeV], $\Gamma_\text{cm} \approx 5$ MeV. This appears to be a ^{33}F cluster resonance which decays by an E1 transition to ^{6}Be*(1.7). The γ-ray angular distributions are consistent with $J^\pi = 3^-$: see (79AJ01). See also (89IS1B).

A_y has been measured for $E(^3\text{He}) = 14$ to 30 MeV [reaction (b)] by (83KI10) using a polarized target. See also ^{5}Li.

Measurements of the total cross section for reaction (c) have been carried out for $E(^3\text{He}) =$ 60 keV to 2.2 MeV [see (79AJ01)] and for 36 to 685 keV (87KR09). The measurements are consistent with a non-resonant reaction mechanism, at least down to $E_\text{cm} = 24.5$ keV. Upper limits for $\omega\gamma$ for a resonance below that energy (and with E_R (cm) as low as 16.2 keV) [which might help explain the low observed flux of solar neutrinos], are given in (87KR09). [It should be noted that a corresponding mirror state in ^{6}He has not been observed.] The best fit to the data is given by $S(0) = 5.57 \pm 0.31$ MeV $\cdot$ b (87KR09). See (79AJ01) for the earlier work. See also (66LA04, 74AJ01). For work on astrophysical considerations see (82BA1J, 82KA1E, 83FO1A, 83VO1C, 84BO1C, 84DA1H, 84HA1M, 85CA41, 85SC1A,

Table 6.16: ^{6}Be – General

Reference	Description
	Model calculations
88GU13	Correlated basis functions computation of spectra of light nuclei
89DA05	Calculation of 0^+ $T = 1$ states of $A = 6$ nuclei in $\alpha + 2$n model with local potentials
90DA22	True 3-particle decay states & method of hyperspherical functions; 0^+ state of ^{6}Be
91DA08	Dyn. multicluster model w/ hyperspherical harmonics; electroweak & charge-exch. rxns
91DA04	$A = 6$ ($J^\pi = 0^+$, 1^+) states studied in micro. $\alpha + 2$n model; hyperspherical functions
91KU1B	Multicluster models of light nuclei predict strong, EM and weak interactions
92DAZT	3-3 resonant scattering and $A = 6$ nuclei excited states
93DA07	Resonance $3 \to 3$ scattering and structure of the excited states of $A = 6$ nuclei
93PO11	Shell-model calcs. of several properties of exotic light nuclei ($Z = 2$–9; $A = 4$–30)
94CS04	3-body resonances in $A = 6$ nuclei; soft dipole mode problem of neutron halo nuclei
95KU08	3-body $\alpha + 2$N model with realistic nuclear forces; calc. Coulomb displac. of ^{6}Be levels
95KU1G	Spectra, Coulomb displacements, static characteristics using the New Dynamic Model
	Astrophysics
88CA1N	Reaction rates of astrophysically important thermonuclear reactions involving light nucl.
89BE08	Electron screening effects in low-energy fusion reactions; calc. astrophysical S-factor
	Other topics
Reviews:	
89RA16	Predictions of B(E2; $0^+_1 \to 2^+_1$ values for even-even nuclei
96DA31	Nuclei with two-particle neutron halo: theory and recent experiment
Other articles:	
88CO15	Thomas-Ehrman shift across the proton dripline; calc. masses of proton-rich nuclei
89SP01	Reduced electric-octupole transition probabilities, B(E3; $0^+_1 \to 3^-_1$), for even-even nucl.
95PU05	Quantum Monte Carlo calculations of $A \leq 6$ nuclei
97BA54	Microscopic study of ground state properties using the Skyrme Hartree Fock model
97PO12	Coulomb energies of light nuclei – an effective formula
97SH23	Isovector quadrupole term in sum rule relating scissors mode excitations to B(E2) values

Figure 3: Energy levels of ^{6}Be. For notation see introduction.

86FI1B, 87AS05, 87RO1D, 88BA1H, 88FO1A), and see (88CA1N; [thermonuclear reaction rates], 88CA1J [dynamic screening], 89BA2P [neutrino astrophysics], 89SC25 [reaction rates], 88PO1J [plasma fusion], 89VA20 [S factors, RGM], 90SC15 [cross sections, extended elastic model], 91TY01 [cross sections, microscopic study], 90KR12, [phase shifts, generator coordinate method], 94DE27 [cross sections, microscopic analysis], 89BE08 [S factor, electron screening effects], 89JI1A [nucleosynthesis around black holes]. (85SI12) report α-d correlation measurements at $E(^3\text{He}) = 13.6$ MeV, which suggest the breakup of the diproton (^{2}He) into $^2\text{H} + \text{e}^+ + \nu$.

The elastic scattering (reaction (d)) has been studied for $E(^3\text{He}) = 3$ to 32 MeV and at 120 MeV. The excitation function shows a smooth monotonic behavior except for an anomaly at $E(^3\text{He}) = 25$ MeV in the $L = 3$ partial wave corresponding to a broad state in ^{6}Be at $E_x \approx 24$ MeV. Polarization measurements have been carried out at $E(^3\vec{\text{He}}) = 17.9$ to 32.9 MeV. A two level R-matrix analysis of the phase shifts ($L \leq 5$) suggests three broad F-wave states at $E_x \approx 23.4$ (4^-), 26.2 (2^-) and 26.7 MeV (3^-), in disagreement with the capture γ-ray results described above: see (79AJ01). Calculations using the generator coordinate method have been reported for phase shifts ($E(^3\text{He}) < 5$ MeV) (90KR12), and for differential cross sections and astrophysical S factors $E(^3\text{He}) = 2$–6 MeV) (94DE27). See also (84AJ01) and (86FO04).

A kinematically complete experiment (reaction (e)) has been performed at $E(^3\text{He}) =$ 120 MeV: large peaks were observed which appear to correspond to ^{3}He-d quasi-free scattering followed by p-d FSI: see (84AJ01).

The total reaction cross sections $\sigma_R = 156.7 \pm 3.8$, 250 ± 14 and 296 ± 12 mb at $E(^3\text{He}) =$ 17.9, 21.7 and 24.0 MeV (87BR02) [see also for partial cross sections for the breakup reactions and for unpublished results for σ_R for $E(^3\text{He}) = 3.0$ to 17.9 MeV]. See also (84AJ01) and (86GO1E, 86WI1A, 83PR1A, 84HA25, 85HA14, 86OS1D, 87AS05, 88RIZW).

2. $^4\text{He}(^3\text{He, n})^6\text{Be}$ $\qquad Q_m = -9.089$

Table 6.17: Energy levels of ^{6}Be

E_x (MeV ± keV)	$J^\pi; T$	Γ_{cm}	Decay	Reactions
g.s.	$0^+; 1$	92 ± 6 keV	p, α	2, 3, 4
1.67 ± 50 [a]	$(2)^+; 1$	1.16 ± 0.06 MeV	p, α	1, 2, 3, 4
23	4^-	broad	γ, ^{3}He	1, 3
26	2^-	broad	^{3}He	1, 3
27	3^-	broad	^{3}He	1

[a] See Table 6.8 in (74AJ01).

Neutron groups to ^{6}Be*(0, 1.7) have been observed at $E(^3\text{He}) = 19.4$ to 38.61 MeV: see Table 6.8 in (74AJ01) for the parameters of the first-excited state. There is no evidence for other states of ^{6}Be with $E_x \leq 5$ MeV, nor for a state near the ^{3}He threshold at 11.5 MeV: see (79AJ01).

3. (a) ^{6}Li(p, n)^{6}Be $\qquad Q_m = -5.070$

(b) ^{6}Li(p, pn)^{5}Li $\qquad Q_m = -5.665$

Neutron groups have been observed to ^{6}Be*(0, 1.7) as has the ground-state threshold. The width of the ground state is 95 ± 28 keV. The parameters of ^{6}Be*(1.7) are displayed in Table 6.8 of (74AJ01). Angular distributions have been reported at $E_p = 8.3$ to 144 MeV [see (79AJ01, 84AJ01)] and at 800 MeV (86KI12). The transverse spin transfer coefficient, D_{NN} (0°), at $E_p = 160$ MeV for the ground-state transition is -0.37 ± 0.04 in agreement with results in other light nuclei (84TA07). See also ^{7}Be and (86SA1Q, 87SA46, 88HE08, 84TA1F, 85GO1F, 86TA1E, 87RA32, 85SH1C).

In more recent work, evidence for a proportionality between $\sigma_{pn}(0°)$ and Gamow-Teller transition strengths were examined (87TA13). See also (89RA1G). Measurements are reported at $E_p = 60$–200 MeV (90RA08 [$D_{NN}(0°)$]), $E_p = 256$, 800 MeV (93ST06 [double differential cross sections]), $E_p = 186$ MeV (93WAZX, 93YAZZ, 94RA23 [polarization observables], 94WA22 [quasifree excitations], 95YA12 [dipole excitations]), $E_p = 392$ MeV (94TO1C [$\sigma(\theta)$, $A_y(\theta)$]), $E_p = 300$, 400 MeV (94SA43 [quasifree excitations, $D_{NN}(0°)$]), $E_p = 295$ MeV (95WA16 [spin-flip strength, $D_{NN}(0°)$]), $E_p = 200$ MeV (95WAZW [$A_y(\theta)$]), $E_p = 35$ MeV (96ORZZ [$\sigma(\theta)$]), $E_p = 280$ MeV (90MI10 [$\sigma(\theta)$, isospin-symmetry test]). Calculations with a dynamical multicluster model are discussed in (91DA08, 93SH1G). See also the review of two-particle neutron halo nuclei in (96DA31).

In reaction (b) some evidence has been reported at $E_p = 47$ MeV for sequential decay via ^{6}Be*(15.5 ± 2, 24 ± 2): see (79AJ01). See also (88MIZX).

4. ^{6}Li(^{3}He, t)^{6}Be $\qquad Q_m = -4.307$

Triton groups have been observed to ^{6}Be*(0, 1.7). The width of the ground state is 89 ± 6 keV. The parameters of the excited state are displayed in Table 6.8 of (74AJ01). No other excited states have been seen with $E_x < 13$ MeV. There is no evidence for a state near 11.5 MeV: see (79AJ01). (87BO39) have studied the decay of ^{6}Be*(1.7) at $E(^3\text{He}) =$ 38.7 MeV: they report that the branching ratio for decay via the emission of ^{2}He [$T = 1$, $S = 0$] is 0.60 ± 0.15: see also reactions 13 in ^{6}He and 32 in ^{6}Li and (85BO56, 84BO49, 88BO1J). See also (84AJ01), (87DA1N; theor.) and ^{9}B.

In more recent work, kinematically complete experiments for ^{6}Li(^{3}He, t)^{6}Be*(0, 1.7) $\to$ $\alpha + p + p$ were reported in (88BO38, 89BO1N, 89BO42, 89BO25) and in (92BO25, 93BO38 [studied decay mechanism]). Measurements of differential cross sections at $E(^{3}\mathrm{He}) = 93$ MeV are described in (94DOZW).

^{6}B, ^{6}C
(Not illustrated)

Not observed: see (79AJ01, 84AJ01, 89GR06 [^{6}Li(π^{+}, π^{-}) at $E_{\pi^{+}} = 180$, 240 MeV], 93PO11 [properties of exotic light nuclei]).

Figure 4: Isobar diagram, $A = 6$. For notation see introduction.

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(Closed 1 January 1998)

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