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Measurement of Reduced Electric Octupole Transition Probabilities, $B(E3; 0_1^+ \rightarrow 3_1^-)$, for $^{118,120,122}Sn$

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Abstract

Values of reduced electric octupole transition probabilities, $B(E3; 0_1^+ \rightarrow 3_1^-)$, for the nuclides $^{118,120,122}Sn$ have been determined using Coulomb excitation with ^{12}C projectiles. The results are in good agreement with shell-model calculations made without introducing effective charges but involving core excitations. Values for $B(E2; 0_1^+ \rightarrow 2_1^+)$ are also presented.

The chief purpose of this brief communication is to present the results of some new measurements of reduced electric octupole transition probabilities, $B(E3; 0_1^+ \rightarrow 3_1^-)$, for transitions from the 0^+ ground state to the first 3^- state of the nuclides $^{118,120,122}Sn$. Apart from the value of such information in contributing to the overall systematics of E3 excitations, which are much more poorly established than the corresponding E2 systematics (Spear 1989), the results may be compared with specific theoretical predictions made on the basis of various refinements of the shell model (Veje 1966; Lombard and Campi-Benet 1966; Gillet *et al.* 1969). Values are also presented for electric quadrupole transition probabilities, $B(E2; 0_1^+ \rightarrow 2_1^+)$, for transitions to the first 2^+ states, although the measurement of these was subordinate to the main objective of the work.

The measurements were performed using Coulomb excitation by 37-MeV and 38-MeV ^{12}C projectiles obtained from the 14UD accelerator at the ANU. Targets, typically of thickness $10\,\mu g\,cm^{-2}$, were prepared by evaporating isotopically enriched tin onto thin carbon foils. The isotopic enrichments of ^{118}Sn, ^{120}Sn and ^{122}Sn were 96·0%, 98·4% and 92·3% respectively. Scattered particles were detected at a laboratory angle of 90° using an Enge split-pole magnetic spectrometer with a position-sensitive multi-electrode gas-filled proportional counter at its focal plane.

A typical position spectrum is shown in Fig. 1. The major peaks correspond to scattering to the 0_1^+, 2_1^+ and 3_1^- states of the target nucleus (^{122}Sn). The structure on the low-energy side of the 0_1^+ ('elastic') peak is due to elastic scattering from other isotopes of tin present at low concentrations in the target material ('isotopic impurities'). The spectrum shown is for ^{12}C ions in the 6^+ atomic charge state; some 5^+ ions were also observed, but they were

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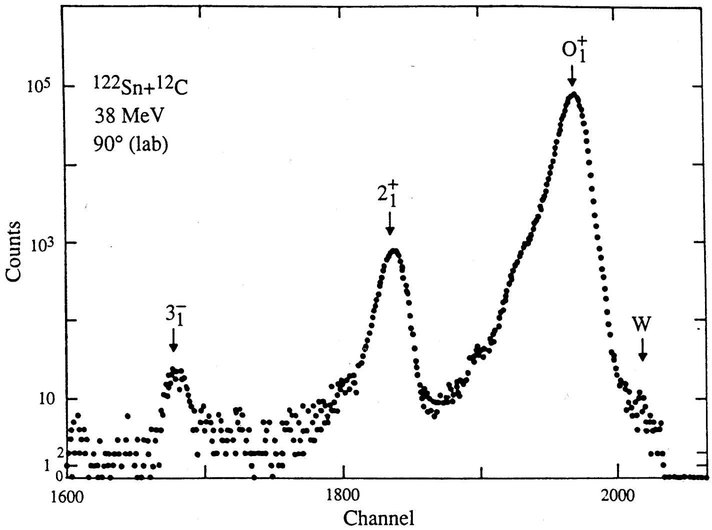

Fig. 1. Spectrum of $^{12}C^{6+}$ ions obtained in the detector at the focal plane of the magnetic spectrometer at 90° using a ^{122}Sn target and 38-MeV ^{12}C projectiles. Peaks corresponding to states in ^{122}Sn are indicated. Also shown is a small peak due to elastic scattering from tungsten contaminant in the target.

too few to be usefully analysed, and their inclusion would have negligible effect on the results of the experiment.

Excitation probabilities P, defined for the present purposes as the ratio of the area of the appropriate inelastic peak to the area of the elastic peak, were extracted for the 2_1^+ and 3_1^- states from each of the six spectra obtained. Allowance was made for contributions to the spectra due to scattering from isotopic impurities, assuming relative isotopic abundances derived either from the supplier's assay or, in the case of ^{118}Sn, from direct measurement using Rutherford scattering of 16-MeV ^7Li ions. Well established lineshape-fitting procedures (Esat *et al.* 1976; Fewell *et al.* 1979) were used to establish the magnitude of the elastic-peak tail underneath the inelastic peaks.

The multiple-Coulomb-excitation program of Winther and de Boer (1966) was used to calculate $B(E2; 0_1^+ \to 2_1^+)$ and $B(E3; 0_1^+ \to 3_1^-)$ from the measured excitation probabilities. For each nucleus, the 0_1^+, 2_1^+, 2_2^+ and 3_1^- states were included in the analysis; other states were found to have negligible effects. Relevant matrix elements were obtained from the literature (Stelson *et al.* 1970; Graetzer *et al.* 1975; Jonsson *et al.* 1981). Results obtained are listed, together with excitation probabilities, in Table 1. The uncertainties shown for the $B(E2; 0_1^+ \to 2_1^+)$ values include contributions from the uncertainty in the scattering angle, statistical uncertainties, the uncertainty in the quadrupole moment of the 2_1^+ state, and the ambiguity in the sign of the interference term due to virtual excitation of the 2_2^+ state. Effects of the usual small corrections for electron screening, vacuum polarisation, nuclear polarisation and the use of the semi-classical approximation (Fewell *et al.* 1979) were

Table 1. Excitation probabilities $P(2_1^+)$ and $P(3_1^-)$ and values of $B(E2;0_1^+\rightarrow 2_1^+)$ and $B(E3;0_1^+\rightarrow 3_1^-)$

Excitation energies $E_x(2_1^+)$ and $E_x(3_1^-)$ are taken from Tamura *et al.* (1987), Hashizume *et al.* (1987) and Kitao *et al.* (1986)

Nucleus	$E(^{12}C)$[A] (MeV)	$E_x(2_1^+)$ (keV)	$P(2_1^+)$ ($\times 10^{-3}$)	$B(E2; 0_1^+\rightarrow 2_1^+)$ (e^2 b^2)	$E_x(3_1^-)$ (keV)	$P(3_1^-)$ ($\times 10^{-4}$)	$B(E3; 0_1^+\rightarrow 3_1^-)$ (e^2 b^3)
^{118}Sn	36·98	1230	8·45(15)	0·207(6)	2328	2·79(21)	0·118(9)
	37·98	1230	9·58(17)	0·202(6)	2328	3·88(23)	0·125(8)
^{120}Sn	36·98	1171	8·99(9)	0·194(4)	2400	3·07(21)	0·149(11)
	37·98	1171	10·43(11)	0·194(4)	2400	3·08(22)	0·113(12)
^{122}Sn	36·98	1140	8·89(9)	0·182(4)	2492	1·96(18)	0·082(8)
	37·98	1140	10·19(9)	0·181(4)	2492	2·87(19)	0·091(7)

[A] Uncertainties in bombarding energies $E(^{12}C)$ were ±0·04 MeV.

Table 3. Values of $B(E3;0_1^+\rightarrow 3_1^-)$ (in e^2 b^3) for isotopes of tin

Experimental results are presented in the upper part of the table, and calculated values in the lower part

Reference	Method	^{112}Sn	^{114}Sn	^{116}Sn	^{118}Sn	^{120}Sn	^{122}Sn	^{124}Sn
Present work	Coulex				0·122(6)	0·131(10)	0·087(6)	
Jonsson (1981)	Coulex	0·087(12)	0·100(12)	0·127(17)	0·097(14)	0·090(17)	0·110(17)	0·073(10)
Curtis (1969)	(e, e′)			0·074	0·112	0·103		
Barreau (1967)	(e, e′)			0·120(15)		0·113(14)		0·076(11)
Lightbody (1976)	(e, e′)			0·163(13)				
Veje (1966)	Theory		0·062	0·069	0·077	0·084	0·091	0·098
Lombard (1966)	Theory	0·085	0·088	0·097	0·107	0·118	0·132	0·137
Gillet (1969)	Theory		0·111	0·113	0·122	0·118	0·097	0·063

found to be negligible. The correction for virtual excitation of states in the giant dipole resonance was approximately 0·5%. The uncertainties in the $B(\mathrm{E3};\, 0_1^+ \to 3_1^-)$ values are almost entirely statistical. In the determination of these $B(\mathrm{E3};\, 0_1^+ \to 3_1^-)$ values, the most significant second-order effect is potentially that involving the unknown static quadrupole moment $Q(3_1^-)$. The results given were obtained assuming $Q(3_1^-) = 0$. If the magnitude of $Q(3_1^-)$ were as large as 0·3 *e*b [cf. $Q(3_1^-) = -0{\cdot}34 \pm 0{\cdot}15$ *e*b for ^{208}Pb (Spear *et al.* 1983)], the value of $B(\mathrm{E3};\, 0_1^+ \to 3_1^-)$ would change by less than 3%, i.e. no more than about half the statistical uncertainty.

Data used for Coulomb-excitation analysis should be obtained at bombarding energies sufficiently low for Coulomb–nuclear interference effects to be negligible. If possible, the maximum safe bombarding energy should be determined for each experimental configuration by taking data at a number of bombarding energies and checking that the energy dependence of the excitation probabilities obtained is consistent with pure Coulomb excitation (Spear *et al.* 1978*a*). Low count rates and time constraints restricted the present work to two bombarding energies. However, for ^{12}C projectiles and ^{118,120,122}Sn targets, the distances of closest approach of the nuclear surfaces (Fewell *et al.* 1979) are approximately 6·5 and 6·1 fm for bombarding energies of 37 and 38 MeV respectively; in the light of previous experience (Spear *et al.* 1978*a*, 1978*b*), nuclear contributions under these conditions should be negligible, particularly at the level of precision pertaining to the $B(\mathrm{E3};\, 0_1^+ \to 3_1^-)$ determinations. This expectation is supported by the overall consistency of the results obtained at the two bombarding energies.

Table 2. Experimental values of $B(\mathrm{E2};\, 0_1^+ \to 2_1^+)$ (in $e^2\,\mathrm{b}^2$) for ^{118,120,122}Sn

Authors	^{118}Sn	^{120}Sn	^{122}Sn
Present work	0·204(4)	0·194(3)	0·182(3)
Raman *et al.* (1987)[A]	0·209(8)	0·202(4)	0·192(4)
Graetzer *et al.* (1975)	0·199(6)	0·197(4)	0·188(4)

[A] Adopted values.

The numerous previous determinations of $B(\mathrm{E2};\, 0_1^+ \to 2_1^+)$ for the tin isotopes have been compiled by Raman *et al.* (1987). As may be seen from Table 2, the present results are near the lower limits of the 'adopted values' of those authors. They are, however, in excellent agreement with the Coulomb-excitation results of Graetzer *et al.* (1975).

The values of $B(\mathrm{E3};\, 0_1^+ \to 3_1^-)$ determined in the present work are compared with those of previous experiments, and calculations, in Table 3. Results for some isotopes not studied in the present work are included. The present results are substantially more precise than those of the previous Coulomb-excitation work of Jonsson *et al.* (1981), which used the gamma–gamma coincidence technique. The accuracy of the inelastic-electron-scattering data is limited by the model dependence of the analyses; Curtis *et al.* (1969), for example, did not assign conventional errors for this reason. The three theoretical calculations are all based upon the spherical shell model, all allow for core excitations, and none of them introduces effective charges. They differ from each other in their assumptions about the residual interaction and their choice of single-particle energies. The calculation of Gillet *et al.* (1969) is more sophisticated than the other two; a more realistic finite-range interaction is used, and the input data are taken from neighbouring odd-mass nuclei, with no adjustable parameters.

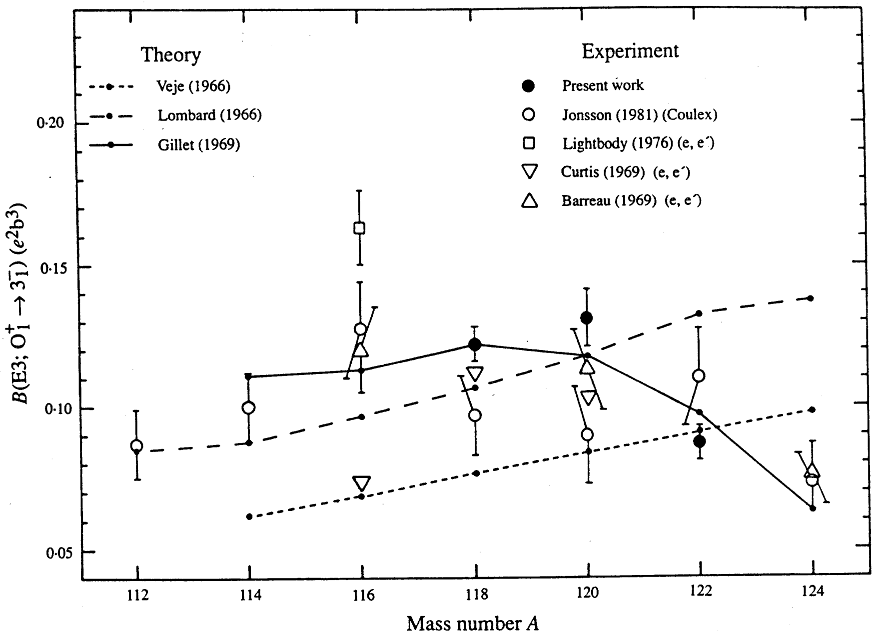

Fig. 2. Comparison of experimental and theoretical values of $B(\mathrm{E3}; 0_1^+ \rightarrow 3_1^-)$ for the tin isotopes.

The experimental and theoretical values are further compared in Fig. 2. The overall agreement between theory and experiment is impressive, given that the calculations do not resort to the use of effective charges, and are generally not expected to provide a precise fit to experiment. If some discrimination between the three calculations is sought, it appears that the mass dependence of the present data favours the work of Gillet *et al.* (1969). This preference is supported by the available data for ^{124}Sn. It is of interest that if core excitations were excluded the calculations of Gillet *et al.* would underestimate $B(\mathrm{E3}; 0_1^+ \rightarrow 3_1^-)$ values by factors of approximately 3 to 10, even if the neutron were allowed to have an effective charge of *e*.

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