SYSTEMATICS OF SOME LEVELS IN EVEN-EVEN NUCLEI

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Abstract

Morinaga's study of the lowest odd-parity states in even-even nuclei has been extended to even-parity odd-spin and odd-parity even-spin states. These states show good agreement with the curve $E = 67\ A^{-3/4}$ Mev.

1. Introduction

The first excited states of many even-even nuclei are found to be systematically ordered in a manner suggestive of collective motion.[1] Nuclei in the mass ranges $150 < A < 190$ and $A > 214$ have spectra of the kind expected from rotation of a deformed nucleus with axial symmetry.[2] Many nuclei outside these ranges have spectra of a vibrational kind.[3] These spectra have been interpreted in various ways,[4, 5] but the most widely held view is that they are due to quadrupole surface vibrations about a spherical equilibrium state.[3] Successive bands of levels in the spectra correspond to the excitation of 0, 1, 2, 3, ... quadrupole vibration quanta, each quantum carrying angular momentum 2. Accepting this picture one may inquire about the existence of any other modes of collective vibration.[1]

The vibrational model of the nucleus[3] predicts a 2^+ one-phonon first-excited state, a 0^+, 2^+, 4^+ two-phonon triplet for the second-excited state, and a 0^+, 2^+, 3^+, 4^+, 6^+ three-phonon quintet[6] for the third-excited state. Furthermore, the simple hormonic oscillator predicts that the energies of these states are $n\hbar w$, where n is the number of phonons, and $\hbar w$ is the energy of the first-excited state. However, in nuclei the presumed two-phonon states do not lie at exactly $2\,\hbar\,w$ and are not degenerate.

In order to see if there is any general trend in the lowest odd-parity states in even-even nuclei, Morinaga[7] has collected the lowest experimentally identified odd-parity states and plotted their energies against A, the atomic weight. His results indicate that these states appear not too far from the line $E = 67\ A^{-3/4}$ Mev, except for two kinds of exceptions—anomalies at around

Pb isotopes (also at N = 82), and the low-lying 1^- states in very heavy nuclei which are considered to be due to collective odd-parity states. This fact indicates that in general the lowest odd-parity states lie on the odd-odd mass parabola.

The present article deals with a study of even-parity, odd-spin and odd-parity, even-spin states, in order to see if these states show a general trend.

2. (*a*) ANALYSIS OF DATA

The excitation energies of 2^-, 4^-, 6^- and 1^+, 3^+, 5^+ levels of the nuclei outside the ranges $150 < A < 190$ and $A > 214$ are collected in Table I and plotted against the atomic weight, in Figs. 1 and 2. The curves obtained are compared with the curve $E = 67\,A^{-3/4}$ Mev. The first column represents the nuclei. The spin and parity of the levels are given in the second column. The uncertain spins and parities are put in parentheses. The energies of excitation in Mev. are listed in the third column. The fourth column gives the remarks on spins and parities.

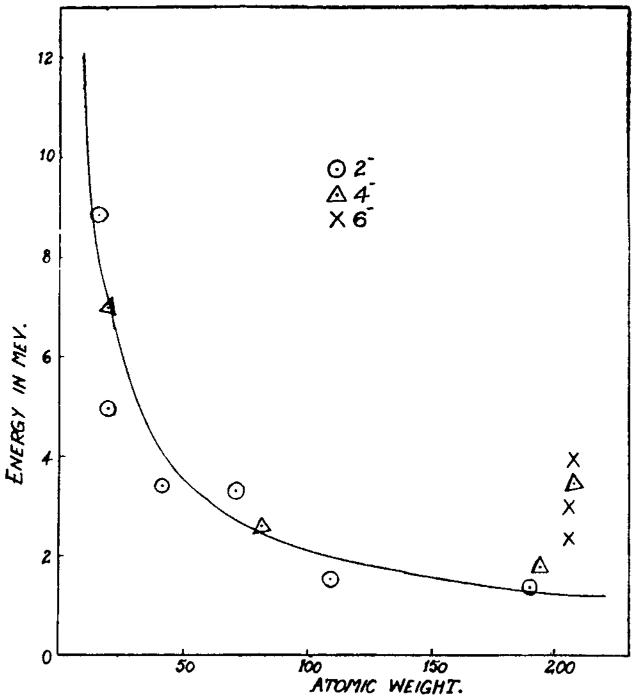

FIG. 1. Plot of energy *vs.* atomic weight for even-spin, odd-parity states in even-even nuclei. Solid line represents the curve $E = 67\,A^{-3/4}$ Mev.

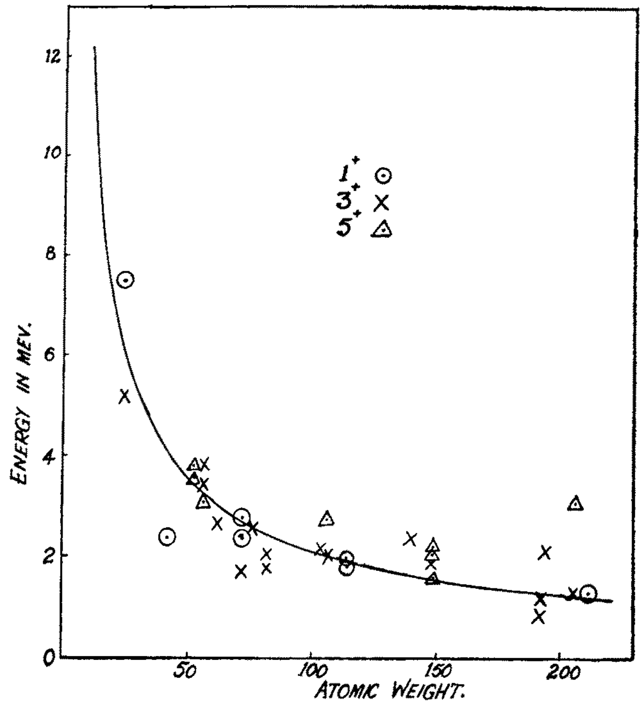

FIG. 2. Plot of energy *vs.* aomic weight for odd-spin, even-parity states in even-even nuclei. Solid line represents the curve Et $=67\,A^{-3/4}$ Mev.

2. (*b*) SPIN ASSIGNMENTS

(*a*) In the case of Ca^{42} (Ref. 3 of Table I), the 0·60 and 2·42 Mev. transitions from the 2·42 Mev. level to known 0^+ states require that the spin of that level be 1^+ or 2^+. The 1^+ assignment cannot be excluded experimentally, but systematics of other even-even nuclei in this region strongly points to a 2^+ state. Since 1^+ assignment is experimentally possible, the 2·42 Mev. level is plotted as an 1^+ level. The low log *ft* value (5·1) for the 3·44 Mev. state indicates an allowed transition to it. This coupled with the absence of any 3·44 Mev. gamma-ray indicates a 2^- or 3^- assignment. We have plotted this as a 2^- state and the 3^- assignment considered as less probable.

(*b*) For the 3·832 Mev. level in Cr^{52} (Ref. 4 of Table I), a log *ft* of 6·2 for electron capture is obtained for a net feeding of 3·3%. For the level at 3·614 Mev. with a net feeding of about 8·4%, a log *ft* value of electron capture 6·0 is obtained. It is felt that the log *ft* values of 6·2 and 6·0 are more representative of allowed rather than the first forbidden transitions

TABLE I

Nucleus	References	Spin and Parity	Energy in Mev.	Remarks
${}_{8}O^{16}{}_{8}$	1	2⁻	8·87	..
${}_{10}Ne_{10}{}^{20}$	2	2⁻	4·97	..
		(4⁻)	7·02	..
${}_{12}Mg_{12}{}^{24}$	1	3⁺	5·23	..
		(1⁺)	7·50	..
${}_{20}Ca_{22}{}^{42}$	3	2′⁺ (1⁺)	2·42	*a*
		(2⁻, 3⁻)	3·44	..
${}_{24}Cr_{28}{}^{52}$	4	(5⁺, 6⁺)	3·614	*b*
		(5′⁺, 6′⁺)	3·832	..
${}_{26}Fe_{30}{}^{56}$	5	(5⁺)	3·12	..
		3⁺	3·45	..
		(3′⁺)	3·84	..
${}_{28}Ni_{34}{}^{62}$	1	(2″⁺, 3⁺)	2·66	*c*
${}_{32}Ge_{40}{}^{72}$	6	2″⁺, 3⁺	1·73	*d*
		1⁺, 2⁺	2·39	..
		1⁺, 2⁺	2·82	..
		2⁻	3·34	..
${}_{34}Se_{42}{}^{76}$	1	3⁺	2·63	..
${}_{36}Kr_{46}{}^{82}$	1	(4⁺, 3⁺)	1·80	*e*
		3⁺	2·07	..
		4⁻	2·62	..
${}_{46}Pd_{58}{}^{104}$	7	3⁺	2·178	..
${}_{46}Pd_{60}{}^{106}$	8	(3⁺)	2·0832	*f*
		(5⁺)	2·7569	..
${}_{48}Cd_{62}{}^{110}$	1	2±	1·540	*g*
${}_{48}Cd_{66}{}^{114}$	9	(1⁺) (2⁺)	1·8399	*h*
		(1⁻) (1⁺) (2⁺)	1·95834	..
${}_{58}Ce_{82}{}^{140}$	1	3⁺	2·412	..
${}_{62}Sm_{86}{}^{148}$	10	(5±, 3⁻)	1·595	*i*
		3⁺	1·887	..
		(5⁺, 4, 3⁺)	2·097	..
		(5, 3⁺)	2·202	..
${}_{76}Os^{190}{}_{114}$	1	(2⁻)	~1·380	..
${}_{78}Pt^{192}{}_{114}$	1	3⁺	0·921	..
		3′⁺	1·201	..
${}_{78}Pt^{194}{}_{116}$	1	(4⁻)	1·794	*j*
		(3⁺)	2·150	..
${}_{82}Pb^{206}{}_{124}$	1	3⁺	1·3408	..
		6⁻	2·384	..
		(6′⁻)	3·017	..
		(5⁺)	3·124	..
${}_{82}Pb^{208}{}_{126}$	1	4⁻	3·475	..
		6⁻	3·961	..
${}_{84}Po^{212}{}_{128}$	1	1⁺, 2′⁺	1·34	*k*

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This calls for spins of 5^+, 6^+ or 7^+ for the 3·614 and 3·832 Mev. levels. Because both of these levels depopulate by transitions to 4^+ states rather than 6^+ states, it is assumed that the 7^+ assignment should be excluded for the upper two levels. Hence the 3·614 and 3·832 Mev. levels are considered to be 5^+ states for the present purpose.

(*c*) 2·66 Mev. level in Ni^{62} is assumed to be a 3^+ level.

(*d*) An assignment of 3^+ is preferable for the 1·73 Mev. level in Ge^{72}.

The level at 2·39 Mev. which is mainly responsible for the feeding of the isomeric state could have either a 1^+ or 2^+ assignment as could the level at 2·82 Mev. (Ref. 6 of Table I). Both these levels are plotted as 1^+ levels.

(*e*) 1·80 Mev. level in Kr^{82} is assumed to be a 3^+ state.

(*f*) In case of Pd^{106} (Ref. 8 of Table I), the levels other than 2·0832 and 2·7569 Mev. are not considered since they are not definitely known to be odd-spin, even-parity states.

(*g*) The 1·54 Mev. level in Cd^{110} can either be 2^+ or 2^-. We have chosen the 2^- assignment as the more probable one.

(*h*) The spins of 1 and 2 are suggested for the 1·84 Mev. level in Cd^{114} (Ref. 9 of Table I), by the γ-ray transitions from it to 2^+ and 0^+ levels. The compton spectrometer work of Motz and Carter[8] and the work of Groshev[9] are in support of the 1^+ or 2^+ spin assignment. Cohen[10] observes a proton group in the Cd^{113} (d, p) Cd^{114} reaction which corresponds to a level at 1·86 Mev. From relative cross-section measurements at 8° and 14° he conculdes that $ln = 0$ for the captured neutron which forms this level. This indicates a spin of 0^+ or 1^+ for this state. Since the 0^+, 3^+ and 4^+ assignments have been ruled out, the most likely spin assignment is 1^+.

Four γ-rays are found to connect the 1·95834 Mev. level with the lower states. The spins of these lower states (only 0^+ and 2^+) suggest a 1^+, 2^+ or 1^- assignment for this level. The 0^+, 3^+ and 4^+ assignments are eliminated by the presence of two transitions to 0^+ states. The 2^+ assignment might be ruled out by the absence of a transition to the 4^+ state at 1·28222 Mev. If the 1·9583 Mev. level is not connected with the collective motion of the nucleons, then there is no reason to assume that the E2 transitions would be enhanced to compete with the M1 transitions. If the spin of the 1·9583 Mev. level is 2, then it must be 2^+ if transitions to 0^+ states are to compete with the transitions to 2^+ states. The error in the energy match of the 1·4003 Mev. cross-over transition to the 2^+ state at 0·55778 Mev. is $0{\cdot}00023 \pm 0{\cdot}0007$ Mev.

This cross-over is forbidden in the collective model if the 1·9583 Mev. level is considered as a member of the three-phonon vibrational quintet. Although this model is inadequate for this case, the intensity of the 1·4003 Mev. transition is large for a collective model interpretation of this level. The 1^- assignment for this level may be ruled out by the absence of a strong gamma-ray transition to the ground state.

(*i*) The nature of the level at 1·595 Mev. in Sm^{148} (Ref. 10 of Table I), is not quite clear. Directional correlation measurements and the experimental value for the internal conversion coefficient for the 414 Kev. transition are consistent with an assignment of 3^- or $5^\pm$ for this state. If it is 3^- it is difficult to explain the absence of an allowed β-transition from the 2^- Pm^{148} graund state, as well as the absence of an E1 transition of 1·044 Mev. to the 2^+ first-excited state. On the other hand if it is a 5^- state, it is difficult to explain the absence of direct transitions from either of the high spin states of Pm^{148} or Eu^{148}. The least objectionable assignment is 5^+, although an almost pure E2 (0·414 Mev.) transition, is then required between the 5^+ and 4^+ levels.

The I.C.C. for the 0·915 Mev. transition and the directional correlation data are consistent with a 3^+, 4^+ or 5^+ assignment for the state at 2·097 Mev. The absence of a transition to the 2^+ state at 0·551 Mev. would indicate that 5^+ is the most likely value.

With regard to the level at 2·202 Mev., the I.C.C. for the 1·020 Mev. transition and 1·020–0·631 Mev. directional correlation are consistent with an assignment of 3^+ or 5^+. Again the absence of a cross-over to the 2^+ level at 0·551 Mev. makes the higher spin value preferable.

(*j*) 4^- and 3^+ assignments for the 1·794 and 2·150 Mev. levels in Pt^{194} are not certain.

(*k*) 1·34 Mev. level in Po^{212} is considered as an 1^+ state.

3. CONCLUSIONS

1. Odd-spin, even-parity states (1^+, 3^+, 5^+) fit the curve $E = 67\ A^{-3/4}$ Mev. better than the even-spin, odd-parity states (2^-, 4^-, 6^-).

2. 1^+, 3^+ and 5^+ states almost lie on the $E = 67\ A^{-3/4}$ Mev. curve except for some deviations at the magic numbers and for the uncertain 3^+ states in Ge^{72}, Kr^{82} and Pt^{194}. Deviations are observed for the 5^+ state in Pd^{106} and 3^+, 1^+ states in Mg^{24} even though they correspond to non-magic numbers. The deviations are not of the same order of magnitude for all the magic numbers.

3. In spite of the insufficient data on 2^- and 4^- states it can be remarked that they lie not too far from the curve $E = 67\ A^{-3/4}$ Mev., 2^- state for the doubly-magic nucleus O^{16} almost lies on the curve whereas it lies far below the curve for the non-magic nucleus Ne^{20}.

4. The deviations of 6^- states in heavy nuclei can be probably attributed to the influence of magic numbers. One wishes one had more states available for medium mass nuclei.

5. 2^-, 4^-, 1^+ and 5^+ states show a general trend same as that of 3^+ state whose occurrence is predicted either by the harmonic oscillator model or by the asymmetric rotor model.

6. The curve $E = 67\ A^{-3/4}$ Mev. seems to be independent of the excitation mechanism of the various states.

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