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Nuclear Shell Structure and Beta-Decay. I. Odd *A* Nuclei

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A systematics is given of all transitions for odd A nuclei for which sufficiently reliable data are available. The allowed or forbidden characters of the transitions are correlated with the positions of the initial and final odd nucleon groups in the nuclear shell scheme. The nuclear shells show definite characteristics with respect to parity of the ground states. The latter is the same as the one obtained from known spins and magnetic moments in a one-particle interpretation.

A. INTRODUCTION

The correlation between nuclear shell structure and β-decay characteristics had been noticed in early discussions on shells models.[1,2] It is already quite customary to refer to shell considerations in the discussion of decay schemes. The present paper, together with the immediately following companion paper[3] on even A nuclei, is intended to give a comprehensive review and interpretation of β-decay data based on all available information.[4]

An excellent compilation of all nuclear data has recently been issued by the National Bureau of Standards.[5] Tabulations of f factors and ft values have been compiled by S. A. Moszkowski,[6] and by Feenberg and Trigg.[7]

In the present paper we confine our attention to the ground states and isomeric states of nuclei. It is possible in many cases to interpret also known excited states. However, the uncertainties are here much greater, and the application of shell considerations are more uncertain.

The approach of this paper is essentially an empirical one. It would seem that there are a number of results of significance for the general theory of β-decay. However, the chief interest here is in a clarification of facts.

In view of the rapidly growing information on decay schemes, it is obvious that many of the given interpretations will have to be changed in course of time. It has, however, been our experience that a clarification of facts generally tended to remove difficulties and did not add to them.

B. APPLICATION OF SHELL CONSIDERATIONS TO β-DECAY

The selection rules[8] for β-decay involve primarily the changes of spin and parity; an interpretation of the character of a given decay demands thus an assignment of these quantum numbers.

It is known (e.g., compare reference 1) that the values of the magnetic moments of odd A isotopes fall definitely into two groups, which in a fashion may be interpreted as arising from parallel or antiparallel coupling of intrinsic spin and orbital angular momentum of the last odd nucleon. These groups will be referred to as Schmidt groups because of their original discoverer. A measurement of spin and magnetic moment for a nucleus thus gives formally an angular momentum quantum number. We will call this the "orbital" for the nucleus in question, without implying that a one-particle wave function gives a close approximation to its actual wave function. The fundamental hypothesis underlying this investigation is that the parity of the ground state of the nucleus is the same as the one for a single particle with this orbital.

It is further known that there are marked regularities in the occurrence of definite spin values and associated magnetic moments, which are associated with the shell numbers 8, 20, (28), 50, 82, 126. Thus for a given number of photons or neutrons, only one or a very few orbitals, in the sense of the previous paragraph, are known to occur. In particular, parity is definitely con-

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[1] L. W. Nordheim, Phys. Rev. **75**, 1894 (1949).

[2] E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949).

[3] L. W. Nordheim, Revs. Modern Phys. **23**, 322 (1951), quoted henceforth as II.

[4] The results of this work have already been summarized by L. W. Nordheim, Phys. Rev. **78**, 294 (1950); the basic material has been presented by L. W. Nordheim, Tables for β-decay Systematics, informal distribution, 1950.

[5] NBS Circular 499: Nuclear Data, Way, Fano, Scott, and Thew, 1950.

[6] S. A. Moszkowski, "A summary of β-decay theory," Chicago, Institute for Nuclear Studies, ONR Progress Report, 1949.

[7] E. Feenberg and G. Trigg, "Tables of comparative halflives of radioactive transitions," ONR and AEC report, 1949, also Revs. Modern Phys. **22**, 399 (1950).

[8] For a comprehensive review of the theory of β-decay, see E. J. Konopinski, Revs. Modern Phys. **15**, 209 (1943).

TABLE I. Nuclear orbitals as functions of N and Z.

N or Z	Orbital		N orbital		Z orbital
3, 5	$p_{3/2}$	51–55	$d_{5/2}(g_{7/2})$	51, 53	$g_{7/2}$, $d_{5/2}$
7	$p_{1/2}$	57–61	$(d_{5/2}, g_{7/2}, s_{1/2})$	55, 57	$g_{7/2}(d_{5/2})$
9	$s_{1/2}$	63–75	$s_{1/2}(d_{3/2}, g_{7/2})$	59	$d_{5/2}$
11	$D_{3/2}(d_{5/2})$	77–81	$d_{3/2}$	61	$(d_{5/2})$
13	$d_{5/2}$	83–99	$(f_{7/2}, h_{9/2})$	63	$d_{5/2}$
15	$s_{1/2}$	101	$p_{1/2}$	65	$d_{3/2}$
17, 19	$d_{3/2}$	103	$f_{5/2}$	67	$g_{7/2}$
21, 23	$f_{7/2}$	105, 107	$p_{1/2}$, $p_{3/2}(f_{5/2}, h_{9/2})$	69	$s_{1/2}(d_{5/2})$
25	$F_{5/2}(f_{7/2})$	109, 111	$(p_{1/2}, p_{3/2}, h_{9/2})$	71, 73	$g_{7/2}$
27	$f_{7/2}$	113, 115	$p_{1/2}(p_{3/2})$	75	$d_{5/2}$
29, 31	$p_{3/2}$	117, 119	$p_{1/2}$	77, 79	$d_{3/2}$
33, 35	$p_{3/2}(f_{5/2})$	121	$p_{3/2}$	81	$s_{1/2}$
37	$p_{3/2}$, $f_{5/2}$	123	$(p_{3/2}, f_{5/2})$	83	$h_{9/2}$
39	$p_{1/2}$	125	$p_{1/2}$		
41, 43	$g_{9/2}(p_{1/2})$	127, 129	$(g_{9/2}, d_{5/2})$		
45	$(g_{9/2}, p_{1/2})$				
47	$g_{9/2}$, $p_{1/2}$				
49	$g_{9/2}(p_{1/2})$				

nected with position in the shells. The second assumption made is that the state of a nucleus, whose spin and moment has not been measured, must correspond to one of the observed orbitals in an appropriate range.

The procedure to be followed then is that for each transition possible orbitals for the initial and final nucleus are selected which give a coherent scheme of *ft* values with proper selection rules. The validity of this procedure is strongly supported by our main result, that it is indeed possible to set up such a scheme with a high degree of internal consistency.

In general, nothing more than the foregoing assumptions will be implied about nuclear structure, and our results are thus independent of any detailed model except in showing a perfect correlation with a general shell scheme. They will give information about spins and parities of radioactive nuclei, but do not do much to prove or disprove particular models. On the other hand, it is much easier to speak in terms of a definite picture. The spin orbit coupling model proposed by Haxel, Jensen, and Suess[9] and by M. G. Mayer,[10, 11] particularly with the rules formulated by the latter, gives an almost perfect description of the empirical spins and moments. It will, therefore, be used to help in the discussion.

There are a small number of anomalies in spins and moments. In Na^{23} and Mn^{55} the spin differs by 1 from the expected values. The allowed character of the β-transition of Ne^{23} proves that the parity of Na^{23} corresponds to the shell scheme. It supports, therefore, the customary explanation that in these cases the odd particles outside a closed shell couple to a different configuration from those in the neighboring nuclei but with preservation of the parity. This assumption is made here throughout. The evidence from β-decay data makes it likely that the spins of such configurations differ from those of the single particle orbitals by not more than one unit, in which case the characters of the transitions are in general not affected.

In the two cases of anomalous magnetic moments, Eu^{153} and Yb^{173}, no β-decay data are available to decide whether the shell-parity correlation is violated. In view of such anomalies one would expect occasional discrepancies between shell scheme and characteristics. It is only surprising that there seem to be so few of them.

TABLE I

Table I gives the observed orbitals[12, 13] for odd A nuclei as functions of the number of particles (Z = number of protons, N = number of neutrons). The usual spectroscopic notation for single particle orbits is used. The already mentioned cases with anomalous spins are distinguished by capital letters, indicating a configuration which cannot result from a single particle model. The values in brackets are those which were inferred from β-decay data though they have not been directly observed. Not listed are $g_{9/2}$ for 39 and $h_{11/2}$ for 63 to 81, which may occur in isomeric states.

The alternatives are few below 50 and one can make assignments with considerable confidence. The selection becomes more and more ambiguous at higher numbers, particularly for $N > 82$, where only a few spins have been measured.

The parities can be predicted with considerably more confidence than the spins. In the oxygen shell, 3 to 7 particles, the parity is odd; for 9 to 19 it is even. From 21 to 49 the parity is odd except for $g_{9/2}$ orbits, which compete with $p_{1/2}$ orbits between 41 and 49 and which seem to occur for 39 in isomeric states. From 51 to 81 the parity is even, except again for $h_{11/2}$ orbits which are inferred from isomeric states above 63. The states of 83 to 125 neutrons should again be odd. This alternating behavior excludes, in general, the occurrence of allowed transitions when the odd proton and neutron involved in it belong to different shells.

C. INTERPRETATION

The entire material on β-decay data for odd A nuclei is given in Table III, Sec. D. It contains all isotopes (except the mirror nuclei) for which we believe our knowledge is sufficient to obtain an *ft* value and to decide whether the transition (or part of it) goes to the ground state or an excited state.

The mirror nuclei in which the number of initial protons are equal with those of final neutrons are omitted for shortness since we have nothing new to add to their discussions. As is well known, they form a very distinct group of superallowed transitions with log *ft* values in the narrow range from 3.3 to 3.7 and with no over-all trend from H^3 to Ti^{43}.

While the master Table III, Sec. D, contains all available material, it is instructive to group the transi-

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[9] Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949).

[10] Maria G. Mayer, Phys. Rev. **75**, 1969 (1949).

[11] Maria G. Mayer, Phys. Rev. **78**, 16, 22 (1950).

[12] H. L. Poss, Brookhaven National Laboratory 26 (T-10) (1949).

[13] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).

TABLE II. Classification of β-decays to ground state of odd A nuclei according to changes in spin (ΔI) and parity (no, yes). Column 1: Initial isotope Z-Element-A. Column 2: Sign of emitted charge, maximum energy in Mev. Column 3: Initial and final odd nucleon number in this order. Column 4: Assignment of orbitals to initial and final odd nucleon group in this order. Column 5: Log ft. Column 6: Log$(W_0^2-1)ft$ for $\Delta I=2$, Yes. W_0=energy of β-transition in units mc^2.

1	2	3	4[a]	5	6
(a) $\Delta I=0$, 1. No (allowed)					
10 Ne 23	−4.1	13–11	$d_{5/2}-D_{3/2}^{*}$	4.9	
11 Na 25	−3.7	11–13	$D_{3/2}-d_{5/2}^{*}$	5.2	
16 S 35	−0.17	19–17	$d_{3/2}-d_{3/2}^{*}$	5.0	
20 Ca 45	−0.22	25–21	$f_{7/2}-f_{7/2}^{*}$	5.6	
21 Sc 43	+1.13	21–23	$f_{7/2}-f_{7/2}$	4.8+	
21 Sc 47	−0.61	21–25	$f_{7/2}-f_{7/2}$	5.6+	
21 Sc 49	−1.8	21–27	$f_{7/2}-f_{7/2}$	5.5	
22 Ti 45	+1.2	23–21	$f_{7/2}-f_{7/2}$	4.7+	
23 V 47	+1.65	23–25	$f_{7/2}-f_{7/2}$	4.7+	
24 Cr 49	+1.45	25–23	$f_{7/2}-f_{7/2}$	4.5+	
25 Mn 51	+2.0	25–27	$F_{5/2}-f_{7/2}$	5.1+	
26 Fe 53	+2.8	27–25	$f_{7/2}-F_{5/2}$	5.0+	
27 Co 61	−1.3	27–33	$f_{7/2}-f_{5/2}$	5.2	
30 Zn 63	+2.36	33–29	$p_{3/2}-p_{3/2}^{*}$	5.4	
30 Zn 69	−1.0	39–31	$p_{1/2}-p_{3/2}^{*}$	4.6	
30 Zn 71	−2.1	41–31	$p_{1/2}-p_{3/2}^{*}$	4.5+	
31 Ga 73	−1.4	31–41	$p_{3/2}-p_{1/2}$	5.9	
32 Ge 75	−1.1	43–33	$p_{1/2}-p_{3/2}^{*}$	5.0	
32 Ge^m 77	−2.8	45–33	$p_{1/2}-p_{3/2}$	4.8+	
33 As 71	+0.6	33–39	$p_{3/2}-p_{1/2}$	5.1	
33 As 77	−0.7	33–43	$p_{3/2}-p_{1/2}$	5.7	
34 Se 73	+1.29	39–33	$p_{1/2}-p_{3/2}$	5.3	
34 Se 81	−1.5	47–35	$p_{1/2}-p_{3/2}^{*}$	4.8	
34 Se^m 83	−3.4	49–35	$p_{1/2}-p_{3/2}$	5.2+	
35 Br 75	+1.6	35–41	$p_{3/2}-p_{1/2}$	5.6	
35 Br 77	+0.36	35–43	$p_{3/2}-p_{1/2}$	5.0	
35 Br 83	−1.05	35–47	$p_{3/2}-p_{1/2}$	5.3	
35 Br 85	−2.5	35–49	$p_{3/2}-p_{1/2}$	5.1	
36 Kr 77	+1.7	41–35	$p_{1/2}-p_{3/2}$	5.4+	
40 Zr^m 89	+1.07	49–39	$p_{1/2}-p_{1/2}^{*}$	5.8+	
42 Mo 91	+3.7	49–41	$g_{9/2}-g_{9/2}$	5.8+	
45 Rh 105	−0.57	45–59	$g_{9/2}-g_{7/2}$	5.5	
48 Cd 107	+0.32	59–47	$g_{7/2}-G_{7/2}$	4.9	
50 Sn 121	−0.38	71–51	$d_{3/2}-d_{5/2}^{*}$	5.0	
52 Te 127	−0.76	75–53	$d_{3/2}-d_{5/2}^{*}$	5.6	
55 Cs 127	+1.2	55–73	$d_{5/2}-d_{3/2}$	4.7+	
60 Nd 141	+0.7	81–59	$d_{3/2}-d_{5/2}^{*}$	5.2	
(b) $\Delta I=0$, 1. Yes (first forbidden)					
35 Br 87	−8.0	35–51	$p_{3/2}-d_{5/2}$	7.3	
36 Kr 87	−3.2	51–37	$d_{5/2}-p_{3/2}^{*}$	7.0	
37 Rb 89	−3.8	37–51	$p_{3/2}-d_{5/2}$	6.6	
46 Pd 111	−3.5	65–47	$s_{1/2}-p_{1/2}$	6.8	
47 Ag 111	−1.0	47–63	$p_{1/2}-s_{1/2}^{*}$	7.2	
47 Ag 113	−2.2	47–65	$p_{1/2}-s_{1/2}^{*}$	7.0	
47 Ag 115	−3.0	47–67	$p_{1/2}-s_{1/2}$	6.4	
48 Cd 115	−1.13	67–49	$s_{1/2}-p_{1/2}$	6.8+	
48 Cd 117	−1.5	69–49	$s_{1/2}-p_{1/2}$	6.1	
49 In^m 115	−0.83	49–65	$p_{1/2}-s_{1/2}^{*}$	6.6	
49 In 117	−1.73	49–67	$p_{1/2}-s_{1/2}^{*}$	6.2	
49 In 119	−2.7	49–69	$p_{1/2}-s_{1/2}^{*}$	6.2	
54 Xe 137	−4.0	83–55	$f_{7/2}-g_{7/2}^{*}$	6.3	
56 Ba 139	−2.27	83–57	$f_{7/2}-g_{7/2}^{*}$	6.7+	
57 La 141	−2.9	57–83	$g_{7/2}-f_{7/2}$	7.6	
58 Ce 141	−0.56	83–59	$f_{7/2}-d_{5/2}^{*}$	7.7	
59 Pr 143	−0.93	59–83	$d_{5/2}-f_{7/2}$	7.6	
60 Nd 147	−0.7	87–61	$f_{7/2}-d_{5/2}^{*}$	7.0+	
61 Pm 147	−0.23	61–85	$d_{5/2}-f_{7/2}$	7.6	
62 Sm 151	−0.076	89–63	$f_{7/2}-d_{5/2}^{*}$	6.9	
66 Dy 165	−1.28	99–67	$f_{7/2}-g_{7/2}^{*}$	6.1+	
67 Er 169	−0.33	101–69	$p_{1/2}-s_{1/2}^{*}$	6.1	
68 Er 171	−1.49	103–69	$f_{5/2}-d_{5/2}$	7.0	
71 Lu 177	−0.49	71–105	$g_{7/2}-f_{5/2}$	6.8	
72 Hf 181	−0.40	109–73	$p_{1/2}-s_{1/2}$	7.2	
74 W 185	−0.43	111–75	$p_{3/2}-d_{5/2}^{*}$	7.5	
74 W 187	−1.33	113–75	$p_{3/2}-d_{5/2}$	7.8	
78 Pt 199	−1.8	121–79	$p_{1/2}-d_{3/2}$	6.3	
80 Hg 205	−1.6	125–81	$p_{1/2}-s_{1/2}$	5.4	
82 Pb 209	−0.68	127–83	$g_{9/2}-h_{9/2}^{*}$	5.6	
83 Bi 213	−1.3	83–129	$h_{9/2}-g_{9/2}$	6.0	
(c) $\Delta I=2$. Yes (first forbidden)					
16 S 37	−4.3	21–17	$f_{7/2}-d_{3/2}^{*}$	7.1	9.1
18 A 41	−2.55	23–19	$f_{7/2}-d_{3/2}^{*}$	8.6	10.1
36 Kr 85	−0.74	49–37	$g_{9/2}-f_{5/2}^{*}$	9.2	9.9
38 Sr 89	−1.46	51–39	$d_{5/2}-p_{1/2}^{*}$	8.5	9.7
38 Sr 91	−3.2	53–39	$d_{5/2}-p_{1/2}$	8.0	9.7
39 Y 91	−1.56	39–51	$p_{1/2}-d_{5/2}^{*}$	8.7	9.9
40 Zr 95	−1.0	55–41	$d_{5/2}-p_{1/2}$	9.8	10.7
43 Tc^m 95	+0.4	43–53	$p_{1/2}-d_{5/2}^{*}$	8.3	8.6
44 Ru 103	−0.8	59–45	$d_{5/2}-p_{1/2}$	8.5	9.3
50 Sn^m 123	−1.42	73–51	$h_{11/2}-g_{7/2}^{*}$	9.1	10.3
51 Sb 123	−0.62	51–73	$g_{7/2}-h_{11/2}$	9.4	10.0
55 Cs 137	−0.53	55–81	$g_{7/2}^{*}-h_{11/2}$	9.6	10.1
69 Tm 171	−1.0	69–101	$d_{5/2}-p_{1/2}^{*}$	9.5	10.4
(d) $\Delta I=1$. No $\Delta l=2$ (l-forbidden)					
8 O 19	−4.5	11–9	$D_{3/2}-s_{1/2}^{*}$	5.5	
14 Si 31	−1.8	17–15	$d_{3/2}-s_{1/2}^{*}$	5.9	
28 Ni 63	−0.05	35–29	$f_{5/2}-p_{3/2}^{*}$	6.8	
28 Ni 65	−2.10	37–29	$f_{5/2}-p_{3/2}^{*}$	6.6	
29 Cu 61	+1.22	29–33	$p_{3/2}-f_{5/2}$	4.9	
29 Cu 67	−0.65	29–37	$p_{3/2}-f_{5/2}^{*}$	5.5	
30 Zn 65	+0.32	35–29	$f_{5/2}-p_{3/2}^{*}$	7.0	
32 Ge 69	+1.0	37–31	$f_{5/2}-p_{3/2}^{*}$	6.0	
46 Pd 109	−1.0	63–47	$d_{5/2}-G_{7/2}$	6.2	
(e) $\Delta I=2$. No and $\Delta I>2$ (second and higher forbidden)					
37 Rb 87	−0.13	37–49	$p_{3/2}^{*}-g_{9/2}^{*}$	16.5	
43 Tc 99	−0.30	43–55	$g_{9/2}^{*}-d_{5/2}$	13.0	
49 In 115	−0.63	49–65	$g_{9/2}^{*}-s_{1/2}^{*}$	23.2	
52 I 129	−0.12	53–75	$g_{7/2}^{*}-s_{1/2}^{*}$	13.5	
55 Cs 135	−0.21	55–79	$g_{7/2}^{*}-d_{3/2}^{*}$	13.1	
55 Cs 137	−1.19	55–81	$g_{7/2}^{*}-d_{3/2}^{*}$	12.2	
75 Re 187	−0.043	75–111	$d_{5/2}^{*}-h_{9/2}$	17.7	

[a] Asterisk signifies that the spin has been measured.

tions according to type. This is done in Table II for all those decays which go at least partially to the ground state of the final nucleus and where the empirical evidence seems to be sufficiently clear. The table gives the isotope as identified by its charge, chemical symbol and mass number, the type and energy of its transition, the number of the initial and final odd nucleons in this order (the larger numbers refer always to the neutron), the assignment of orbitals, and the value of log ft. Further details can be obtained by reference to the master Table III, Sec. D.

TABLE II

The main result of an inspection of Table II is the close correlation of type of transition and shell structure and comparatively small amount of straggling of log ft values within each group.

The members of the allowed group with the assignments $\Delta l=0$, $\Delta I=0$, 1 have, without exception, the initial and final odd nucleon group in the same shell. There is no trend in ft values with atomic number up to Nd^{141} (which occurs at the highest place where allowed transitions to the ground state can be expected). The absence of a trend, which will be found also in all other groups, is in marked contrast to previous expectations. The largest log ft value found is 6 with a few examples near this number. The majority, however, is contained in the band 5.0 ± 0.3. There is no recognizable distinction between transitions with $\Delta I=0$ and $\Delta I=1$; that is, one has to postulate Gamow-Teller selection rules.

The members of the group with the assignment $\Delta l=1$, $\Delta I=0$, 1 (first forbidden) leave without exception initial and final odd nucleon group in a different shell. No log ft value below[14] 6 or above 8 is found with a clustering around about 6.2 and 7.2 (compare Feenberg and Trigg, reference 7). The distinction between the allowed and first-forbidden groups, which formerly seemed to be somewhat vague, has now become quite clear. The dividing line at log ft 6 seems never to be violated by either group, but a more reliable criterion is given by the numbers of the odd nucleon groups in relation to shell structure.

There is again no clear distinction between transitions with $\Delta I=0$ and $\Delta I=1$. In this connection it should be pointed out that inferences from transitions with $N>83$ have to be taken with caution, owing to the ambiguities in interpretation in this range.

The next group with the assignments $\Delta l=1$, $\Delta I=2$ (also first forbidden) was first recognized by Feenberg.[7,15] It is of particular interest since its spectra show a uniquely defined shape different from the allowed type.[16] Since the f factors for such transitions should also be different from that of allowed transitions approximately by a factor (W^2-1), we have added in Table II of $\log(W_0^2-1)ft$, where W_0 is the energy of the transition inclusive of the rest of the mass of the electron in units mc^2. The resultant values are remarkably homogeneous except for the very light and energetic nucleus S^{37} and for the positron decay of the Tc^{95} isomeric state. Again the initial and final odd nucleon configurations belong always to different shells except those involving the orbital $h_{11/2}$ of isomeric states. The occurrence of this well-defined and easily recognized group constitutes a very valuable check on spins and parity assignments in the shell scheme.

There is a small and perhaps not too well-defined group for which the formal assignment of orbitals gives $\Delta l=2$ and $\Delta I=1$. According to the formal selection rules these transitions should be allowed since there is no change of parity. The ft values for these transitions, however, seem to be larger than expected, and there may be the remnant of a selection rule pertaining to orbital angular momentum. The discussion of this group will be deferred to Paper II, where a few more examples will be available.

The last group contains the second and higher forbidden transitions which involve spin changes of at least 2. The most important remark is that there is no example with a log ft value[17] below 12. This is true for even the second-forbidden ones ($\Delta I=2$, 3, no change in parity) as shown most clearly by the two Cs isotopes, where the spins in both the initial and the final state have been measured. The ratio of the probabilities of allowed to second-forbidden transition seems to be thus at least of the order of 10^6, if not higher, in place of 10^4 as has been frequently assumed. This low probability of high forbidden transitions explains the small number of examples found and the failure to find many spectral shapes different from the allowed or unique first-forbidden forms.

There is a considerable number of transitions which go to an excited state with subsequent γ-radiation in series. The validity of an interpretation demands then that the ft value for the observed β-ray be much lower than that for a transition between the expected ground states. This is fulfilled in all cases listed in Table III of Sec. D. The actual ft values observed classify most of these transitions as allowed or first forbidden with $\Delta I=0$, 1, while most of the assignments predict an at least second-forbidden transition between the ground states. This gives a margin in the square of the matrix elements of order 10^5–10^7 which is ample to explain the absence of observation of high energy β-rays.

There are still quite a few ambiguities in the interpretation as noted in the footnotes in Table III. There are also a considerable number of cases where the facts are not well known. However, no outstanding difficulties occur whenever the characteristics of the transitions are definitely established. There can thus be little doubt as to the correctness of the scheme presented here.

As the main results we may summarize: The Schmidt groups give definite indication of the parities of the nuclear states which in turn are closely correlated with the shell numbers. The character of the ground states of a nucleus with one odd nucleon group is essentially determined by the number of nucleons in this group in formal agreement with the rules of the spin-orbit coupling model.

The success of the scheme, however, does not give support to an extreme one-particle model. On the contrary, the clear distinction between the super-allowed transitions of the mirror nuclei and the normal allowed group (unfavored allowed in Wigner's terminology) shows clearly the inadequacy of the one-particle model.

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[14] Exceptions are the two very heavy nuclei Hg^{205} and Pb^{209}, where Z-dependent factors in the matrix elements may have become of importance. (Compare the discussion by Konopinski, reference 8.)

[15] F. B. Shull and E. Feenberg, Phys. Rev. **75**, 1768 (1949).

[16] Compare the recent review by Chien Shiung Wu, Revs. Modern Phys. **22**, 386 (1950).

[17] Again the f function for these transitions will show a different energy dependence from that for allowed ones, but a qualitative comparison remains useful.

The difference in *ft* values for these two groups is of the order of 30 to 40, that is, a difference in the matrix elements of the order of 5 to 6. It will be the task of future theories of nuclear structure and β-decay, especially the establishing of the form of the interaction Hamiltonian, to explain this ratio and other ratios between the probabilities of the various types of transitions.

The authors wish to thank Dr. Henry Brysk for his valuable assistance in preparing the tables.

D. TABLES FOR β-DECAY SYSTEMATICS: ODD *A*

TABLE III. β-decay data and orbital assignments for odd-*A* nuclei.

Column 1: Class of transition: A. isotope certain; B. isotope probable; C. isotope doubtful. Class C. nuclei are only included if the β-decay data contribute to the identification. a. decay data well established; b. decay data probably correct; c. decay data uncertain and possibly incorrect; α. configuration assignment well established; β. configuration assignment probable; γ. configuration assignment uncertain and possibly incorrect. Column 2: Initial isotope: *Z*-Element-*A*. The *m* denotes a metastable state. Column 3: Sign of emitted charge, maximum energy in Mev of the most energetic observed β-ray. The energy is given in brackets, if the transition is believed to go to an excited state. Column 4: Half-life. Column 5: *g*, *e*, *m*, mean, respectively, transition is believed to go to the ground, an excited, or a metastable state of the final nucleus. The figure following gives the branching percentage to the specified state when known. The <100 means that there is a branching, but of unknown percentage. Omission of a figure means that most of the transitions go to the specified state. Column 6: Initial and final odd nucleon number in this order. The larger number is always the odd neutron. Column 7: Assignment of orbitals to initial and final nucleon in this order. Capitalized letters signify that a configuration has to be invoked. The $D_{3/2}$ for 11 nucleons means, for instance, a configuration with orbital angular momentum 2 which results from $d_{5/2}$ orbits of the last 3 nucleons. Asterisk signifies that the spin has been measured. Column 8: Log *ft* value calculated with the *f* function for allowed transitions. The values are given in brackets if the transition goes to an excited state. A plus sign is added if branching of unknown percentage is known to occur. Column 9: Reference to bibliography. No authors are quoted if all references are given in the compilations by Seaborg and Perlman (S1), Mitchell (M1), or Natl. Bur. Standards (N1). Column 10: References to footnotes for table.

Class 1	Z-Element-A 2	Sign Energy 3	Half-life 4	Final state 5	Numbers 6	Configuration 7[a]	Log *ft* 8	Ref. 9	Foot-notes 10
Abβ	6–C–15	−(8.8)	2.4 sec	e	9–7	$s_{1/2}-p_{1/2}$*	(5.3)	H1	
Aaβ	7–N–17	−(3.7)	4.2 sec	e	7–9	$p_{1/2}-s_{1/2}$	(3.8)	A1	
Aaβ	8–O–19	− 4.5	27.0 sec	g30	11–9	$D_{3/2}-s_{1/2}$*	5.5	S1	
Abα	10–Ne–23	− 4.1	40.7 sec	g	13–11	$d_{5/2}-D_{3/2}$*	4.9	S1	
Baα	11–Na–25	− 3.7	61 sec	g55	11–13	$D_{3/2}-d_{5/2}$*	5.2	B1	b
Aaα	12–Mg–27	−(1.8)	10 min	e80	15–13	$s_{1/2}-d_{5/2}$*	(4.7)	M1	
Aaα	13–Al–29	−(2.5)	6.6 min	e70	13–15	$d_{5/2}-s_{1/2}$*	(5.2)	S2	
Aaα	14–Si–31	− 1.8	170 min	g	17–15	$d_{3/2}-s_{1/2}$*	5.9	S1	
Abα	16–S–35	− 0.17	87.1 days	g	19–17	$d_{3/2}-d_{3/2}$*	5.0	S1	
Aaα	16–S–37	− 4.3	5.0 min	g10	21–17	$f_{7/2}-d_{3/2}$*	7.1	N1	
Aaα	18–A–41	− 2.55	109 min	g0.7	23–19	$f_{7/2}-d_{3/2}$*	8.6	S1	
Aaβ	20–Ca–45	− 0.22	152 days	g	25–21	$f_{7/2}-f_{7/2}$*	5.6	M2	c
Abβ	21–Sc–43	+ 1.13	3.92 hr	$g<80$	21–23	$f_{7/2}-f_{7/2}$	4.8+	H2	
Bbβ	21–Sc–47	− 0.61	3.43 days	$g<100$	21–25	$f_{7/2}-f_{7/2}$	5.6+	K1	c, d
Aaα	21–Sc–49	− 1.8	57 min	g	21–27	$f_{7/2}-f_{7/2}$	5.5	S1	
Abβ	22–Ti–45	+ 1.2	3.08 hr	$g<100$	23–21	$f_{7/2}-f_{7/2}$	4.7+	S1	
Bbβ	23–V–47	+ 1.65	33 min	$g<100$	23–25	$f_{7/2}-f_{7/2}$	4.7+	K1	c, d
Acβ	24–Cr–49	+ 1.45	41.9 min	$g<100$	25–23	$f_{7/2}-f_{7/2}$	4.5+	S1	c, d
Abβ	25–Mn–51	+ 2.0	46 min	$g<100$	25–27	$F_{5/2}-f_{7/2}$	5.1+	S1	c
Aaα	26–Fe–53	+ 2.8	8.9 min	$g<100$	27–25	$f_{7/2}-F_{5/2}$	5.0+	N2	c
Aaα	26–Fe–59	−(0.46)	47 days	e50	33–27	$p_{3/2}-f_{7/2}$	(6.7)	M1	
Aaα	27–Co–55	+(1.5)	18.2 hr	$e<50$	27–29	$f_{7\ 2}-p_{3/2}$	(6.2)	D1	
Abα	27–Co–57	+(0.26)	270 days	$e<100$	27–31	$f_{7/2}-p_{3/2}$	(5.3)	S1	
Abγ	27–Co–61	− 1.3	1.75 hr	g	27–33	$f_{7/2}-f_{5/2}$	5.2	P1	e
Aaα	28–Ni–57	+(0.73)	35.7 hr	$e<100$	29–27	$p_{3/2}-f_{7/2}$	(5.0+)	M3	
Baβ	28–Ni–63	− 0.05	300 yr	g	35–29	$f_{5/2}-p_{3/2}$	6.8	S1	
Aaβ	28–Ni–65	− 2.10	2.6 hr	g57	37–29	$f_{5/2}-p_{3/2}$*	6.6	M1	
Bbβ	29–Cu–61	+ 1.22	3.4 hr	g65	29–33	$p_{3/2}-f_{5/2}$	4.9	B2	e
Abβ	29–Cu–67	− 0.65	61 hr	g	29–37	$p_{3/2}-f_{5/2}$*	5.5	S1	
Aaα	30–Zn–63	+ 2.36	38 min	g85	33–29	$p_{3/2}-p_{3/2}$*	5.4	S1	
Abβ	30–Zn–65	+ 0.32	250 days	g3	35–29	$f_{5/2}-p_{3/2}$*	7.0	N1	f
Aaα	30–Zn–69	− 1.0	57 min	g	39–31	$p_{1/2}-p_{3/2}$*	4.6	S1	
Bbα	30–Zn–71	− 2.1	2.2 min	$g<100$	41–31	$p_{1/2}-p_{3/2}$*	4.5+	S1	
Bbα	31–Ga–73	− 1.4	5 hr	m	31–41	$p_{3/2}-p_{1/2}$	5.9	S1	g
Abα	32–Ge–69	+ 1.0	1.65 days	g33	37–31	$f_{5/2}-p_{3/2}$*	6.0	M4	
Aaα	32–Ge–75	− 1.1	1.37 hr	g	43–33	$p_{1/2}-p_{3/2}$*	5.0	M4	
Aaβ	32–Ge–77	−(1.74)	12 hr	e	45–33	$g_{9/2}-p_{3/2}$	(6.8)	M5	
Aaβ	32–Ge^{m}–77	− 2.8	59 sec	$g<100$	45–33	$p_{1/2}-p_{3/2}$	4.8+	S1	
Abα	33–As–71	+ 0.6	55 hr	g33	33–39	$p_{3/2}-p_{1/2}$	5.1	N1	
Abβ	33–As–77	− 0.7	40 hr	m	33–43	$p_{3/2}-p_{1/2}$	5.7	N1	h
Bbα	34–Se–73	+ 1.29	7.1 hr	g50	39–33	$p_{1/2}-p_{3/2}$	5.3	C1	
Baα	34–Se–81	− 1.5	17 min	g	47–35	$p_{1/2}-p_{3/2}$*	4.8	S1	
Abβ	34–Se–83	−(1.5)	25 min	e	49–35	$g_{9/2}-p_{3/2}$	(5.0)	S1	
Abβ	34–Se^{m}–83	− 3.4	67 sec	$g<100$	49–35	$p_{1/2}-p_{3/2}$	5.2+	S1	
Abβ	35–Br–75	+ 1.6	1.7 min	m18	35–41	$p_{3/2}-p_{1/2}$	5.6	W1	i
Bbα	35–Br–77	+ 0.36	2.4 days	m5	35–43	$p_{3/2}-p_{1/2}$	5.0	W1	h
Aaα	35–Br–83	− 1.05	2.4 hr	m	35–47	$p_{3/2}-p_{1/2}$	5.3	S1	

TABLE III—*Continued.*

Class 1	Z-Element-A 2	Sign Energy 3	Half-life 4	Final state 5	Numbers 6	Configuration 7^a	Log *ft* 8	Ref. 9	Foot-notes 10
Abα	35–Br–85	− 2.5	3.0 min	m	35–49	$p_{3/2}-p_{1/2}$	5.1	S1	
Bbβ	35–Br–87	− 8.0	55.6 sec	g	35–51	$p_{3/2}-d_{5/2}$	7.3	S3	
Baα	36–Kr–77	+ 1.7	1.1 hr	$g<30$	41–35	$p_{1/2}-p_{3/2}$	5.4+	S1	
Abα	36–Kr–79	+(0.9)	34 hr	$e0.6$	43–35	$g_{9/2}-p_{3/2}*$	(7.5)	S1	
Aaα	36–Kr–85	− 0.74	9.4 yr	g	49–37	$g_{9/2}-f_{5/2}*$	9.2	S1	
Acβ	36–Kr^m–85	−(0.75)	4.36 min	$e<100$	49–37	$p_{1/2}-f_{5/2}*$	(5.1+)	K2	
Abα	36–Kr–87	− 3.2	1.3 hr	g	51–37	$d_{5/2}-p_{3/2}*$	7.0	K2	
Abα	37–Rb–87	− 0.13	6×10^{10} yr	g	37–49	$p_{3/2}-g_{9/2}*$	16.5	S1	
Abβ	37–Rb–89	− 3.8	15 min	g	37–51	$p_{3/2}-d_{5/2}$	6.6	S1	
Aaα	38–Sr–89	− 1.46	53 days	g	51–39	$d_{5/2}-p_{1/2}*$	8.5	L1	
Aaα	38–Sr–91	− 3.2	9.7 hr	$g60$	53–39	$d_{5/2}-p_{1/2}$	8.0	S1	
Aaβ	38–Sr–91	−(1.3)	9.7 hr	$e40$	53–39	$d_{5/2}-g_{9/2}$	(6.6)	N1	j
Aaα	39–Y–91	− 1.56	61 days	g	39–51	$p_{1/2}-d_{5/2}*$	8.7	A2	
Abβ	40–Zr^m–89	+ 1.07	78 hr	$g<100$	49–39	$p_{1/2}-p_{1/2}*$	5.8+	S1	k
Acβ	40–Zr–95	− 1.0	65 days	$m2$	55–41	$d_{5/2}-p_{1/2}$	9.8	S1	l
Abβ	41–Nb–95	−(0.15)	37 days	e	41–53	$g_{9/2}-d_{5/2}$	(5.0)	S1	l
Bcβ	41–Nb–97	−(1.4)	68 min	e	41–55	$g_{9/2}-d_{5/2}$	(5.4)	S1	l
Aaβ	42–Mo–91	+ 3.7	15.5 min	g	49–41	$g_{9/2}-g_{9/2}$	5.8+	D2	
Acβ	42–Mo–99	−(1.03)	67 hr	e	57–43	$d_{5/2}-g_{9/2}*$	(6.8+)	M6	
Abβ	42–Mo–101	−(2.2)	14.6 min	e	59–43	$d_{5/2}-g_{9/2}$	(5.6+)	S1	m
Abβ	43–Tc–93	+(0.83)	2.7 hr	$e7$	43–51	$g_{9/2}-d_{5/2}$	(7.5+)	K3	m
Bbβ	43–Tc^m–95	+ 0.4	62 days	$g0.4$	43–53	$p_{1/2}-d_{5/2}*$	8.3	M7	n
Aaα	43–Tc–99	− 0.30	10^6 yr	g	43–55	$g_{9/2}*-d_{5/2}$	13.0	K4	
Abγ	43–Tc–101	−(1.3)	16 min	e	43–57	$g_{9/2}-d_{5/2}$	(4.7)	S1	m
Abβ	44–Ru–95	+(1.1)	1.65 hr	$e<100$	51–43	$d_{5/2}-g_{9/2}$	(4.1+)	S1	m
Abα	44–Ru–103	− 0.8	42 days	$m3$	59–45	$d_{5/2}-p_{1/2}$	8.5	N1	
Abβ	44–Ru–105	−(1.15)	4.5 hr	$e<100$	61–45	$d_{5/2}-g_{9/2}$	(5.6)	D3	
Abβ	45–Rh–105	− 0.57	36 hr	g	45–59	$g_{9/2}-g_{7/2}$	5.5	D3	o
Bcγ	46–Pd–101	−(0.53)	9 hr	e	55–45	$d_{5/2}-g_{9/2}$	(5.2)	S1	p
Abγ	46–Pd–109	− 1.0	14 hr	m	63–47	$d_{5/2}-G_{7/2}$	6.2	S1	q
Abα	46–Pd–111	− 3.5	26 min	g	65–47	$s_{1/2}-p_{1/2}$	6.8	S1	
Aaα	47–Ag–111	− 1.0	7.5 days	g	47–63	$p_{1/2}-s_{1/2}*$	7.2	S1	
Aaα	47–Ag–113	− 2.2	5.3 hr	g	47–65	$p_{1/2}-s_{1/2}*$	6.0	S1	
Abα	47–Ag–115	− 3.0	20 min	g	47–67	$p_{1/2}-s_{1/2}$	6.4	D4	
Aaγ	48–Cd–107	+ 0.32	6.7 hr	$m0.31$	59–47	$g_{7/2}-G_{7/2}$	4.9	N1	q
Abβ	48–Cd–115	− 1.13	56 hr	$m<100$	67–49	$s_{1/2}-p_{1/2}$	6.8+	M1	
Abβ	48–Cd–117	− 1.5	170 min	g	69–49	$s_{1/2}-p_{1/2}$	6.1	S1	
Aaα	49–In–115	− 0.63	6×10^{14} yr	g	49–65	$g_{9/2}*-s_{1/2}*$	23.2	M8	
Aaα	49–In^m–115	− 0.83	4.5 hr	$g6$	49–65	$p_{1/2}-s_{1/2}*$	6.6	B3	
Aaα	49–In–117	− 1.73	117 min	g	49–67	$p_{1/2}-s_{1/2}*$	6.2	S1	
Aaα	49–In–119	− 2.7	17.5 min	g	49–69	$p_{1/2}-s_{1/2}*$	5.2	D5	
Aaα	50–Sn–121	− 0.38	28 hr	g	71–51	$d_{3/2}-d_{5/2}*$	5.0	D6	
Abβ	50–Sn–123	−(1.26)	39.5 min	e	73–51	$d_{3/2}-g_{7/2}*$	(5.2)	D6	
Abβ	50–Sn^m–123	− 1.42	136 days	g	73–51	$h_{11/2}-g_{7/2}*$	9.1	N1	
Aaα	51–Sb–125	− 0.62	2.7 yr	$m18$	51–73	$g_{7/2}-h_{11/2}$	9.4	M1	
Aaα	52–Te–127	− 0.76	9.3 hr	g	75–53	$d_{3/2}-d_{5/2}*$	5.6	S1	
Acβ	52–Te–129	−(1.8)	70 min	e	77–53	$d_{3/2}-g_{7/2}*$	(6.1)	S1	
Abα	53–I–129	− 0.12	3×10^7 yr	g	53–75	$g_{7/2}*-s_{1/2}*$	13.5	N1	
Aaα	53–I–131	−(0.61)	8.0 days	$e86$	53–77	$g_{7/2}-d_{3/2}*$	(6.6)	S1	
Acβ	53–I–133	−(1.4)	22 hr	e	53–79	$g_{7/2}-d_{3/2}$	(6.9)	S1	
Abβ	53–I–135	−(1.40)	6.7 hr	$e25$	53–81	$g_{7/2}-d_{3/2}$	(7.0)	S1	
Acβ	54–Xe–133	−(0.42)	5.3 days	e	79–55	$d_{3/2}-g_{7/2}$	(5.9)	S1	
Abβ	54–Xe–135	−(0.93)	9.2 hr	e	81–55	$d_{3/2}-g_{7/2}*$	(5.0)	S1	
Abβ	54–Xe–137	− 4.0	3.8 min	g	83–55	$f_{7/2}-g_{7/2}*$	6.3	S1	r
Abβ	55–Cs–127	+ 1.2	5.5 hr	$g<100$	55–73	$d_{5/2}-d_{3/2}$	4.7+	F1	s
Aaα	55–Cs–135	− 0.21	2.1×10^6 yr	g	55–79	$g_{7/2}*-d_{3/2}*$	13.1	S4	
Aaα	55–Cs–137	− 0.53	33 yr	$m95$	55–81	$g_{7/2}*-h_{11/2}$	9.6	M1	
Aaα	55–Cs–137	− 1.19	33 yr	$g5$	55–81	$g_{7/2}*-d_{3/2}*$	12.2	M1	
Abβ	56–Ba–139	− 2.27	84 min	$g<100$	83–57	$f_{7/2}-g_{7/2}*$	6.7+	N1	r
Abβ	57–La–141	− 2.9	3.7 hr	g	57–83	$g_{7/2}-f_{7/2}$	7.6	S1	r
Aaβ	58–Ce–141	− 0.56	28 days	$g30$	83–59	$f_{7/2}-d_{5/2}*$	7.7	N1	r
Aaβ	59–Pr–143	− 0.93	13.7 days	g	59–83	$d_{5/2}-f_{7/2}$	7.6	F2	t
Bbα	60–Nd–141	+ 0.7	145 min	$g2$	81–59	$d_{3/2}-d_{5/2}*$	5.2	W2	
Abβ	60–Nd–147	− 0.7	11 days	$g<100$	87–61	$f_{7/2}-d_{5/2}$	7.0+	M9	t
Aaβ	61–Pm–147	− 0.23	3.7 yr	g	61–85	$d_{5/2}-f_{7/2}$	7.6	A2	t
Aaβ	62–Sm–151	− 0.076	20 yr	g	89–63	$f_{7/2}-d_{5/2}*$	6.9	A2	u
Abβ	66–Dy–165	− 1.28	2.5 hr	$g<100$	99–67	$f_{7/2}-g_{7/2}*$	6.1+	M1	v
Bbβ	68–Er–169	− 0.33	9.4 days	g	101–69	$p_{1/2}-s_{1/2}*$	5.1	S1	
Baγ	68–Er–171	− 1.49	7.5 hr	$g6$	103–69	$f_{5/2}-d_{5/2}$	8.1	S1	w
Bbβ	69–Tm–171	− 1.0	500 days	g	69–101	$d_{5/2}-p_{1/2}*$	9.5	S1	
Abγ	71–Lu–177	− 0.49	7.0 days	$g65$	71–105	$g_{7/2}-f_{5/2}$	6.8	D7	w
Abβ	72–Hf–181	− 0.40	47 days	m	109–73	$p_{1/2}-s_{1/2}$	7.2	M1	x

TABLE III—*Continued.*

Class 1	Z-Element-A 2	Sign Energy 3	Half-life 4	Final state 5	Numbers 6	Configuration 7[a]	Log *ft* 8	Ref. 9	Foot-notes 10
Aaβ	74–W–185	− 0.43	73.2 days	*g*	111–75	$p_{3/2}-d_{5/2}^*$	7.5	S1	y
Abβ	74–W–187	− 1.33	24.1 hr	*g*30	113–75	$p_{3/2}-d_{5/2}$	7.8	M1	y
Aaγ	75–Re–187	− 0.043	4×10^{12} yr	*g*	75–111	$d_{5/2}^*-h_{9/2}$	17.7	S1	z
Abγ	78–Pt–199	− 1.8	31 min	*g*	121–79	$p_{3/2}-d_{3/2}$	6.3	S1	
Aaβ	79–Au–199	−(0.32)	3.3 days	*e*	79–119	$d_{3/2}-p_{1/2}^*$	(5.8)	M1	
Aaγ	80–Hg–203	−(0.21)	43.5 days	*e*	123–81	$f_{5/2}-s_{1/2}$	(6.4)	M1	aa
Abβ	80–Hg–205	− 1.62	55 min	*g*	125–81	$p_{1/2}-s_{1/2}$	5.4	S1	bb
Aaβ	82–Pb–209	− 0.68	3.32 hr	*g*	127–83	$g_{9/2}-h_{9/2}^*$	5.6	S1	bb
Abβ	83–Bi–213	− 1.3	46 min	*g*96	83–129	$h_{9/2}-g_{9/2}$	6.0	S1	bb

[a] Asterisk signifies that the spin has been measured.

[b] It cannot be decided whether the 11 protons in Na^{25} are in a $D_{3/2}$ or $d_{5/2}$ configuragion.

[c] It cannot be decided whether the 25 nucleon configurations in Ca^{45}, Ti^{47}, Cr^{49}, Mn^{51}, Mn^{53} are of the type $F_{5/2}$ or $f_{7/2}$.

[d] There is no experimental evidence that the γ-rays in Sc^{47}, V^{47}, and Cr^{49} are in series with the β-rays.

[e] Co^{61} and Cu^{61} both go to Ni^{61} with no γ-rays reported and with *ft* values corresponding to allowed transitions. It is suggested that the facts are not completely known in this case. The table assigns an $f_{5/2}$ orbit to the 33 neutrons in Ni^{61} so as to make the Co^{61} transition an allowed one; Cu^{61} would then be *l*-forbidden with abnormally low *ft* value.

[f] The series γ-ray reported for Zn^{65} does not fit with the shell scheme. If it really exists it would constitute a serious difficulty.

[g] The transition goes to the meta state of Ge^{73}. The spin of the ground state is measured to be 9/2.

[h] The transition goes to the meta state of Se^{77}, the ground state of which is reported to have a spin $7/2\pm1$ (J. E. Mack, Revs. Modern Phys. **22**, 64 (1950)).

[i] The ground state of Se^{74} is likely to be $g_{9/2}$ since it exhibits a very complex γ-spectrum.

[j] This is the transition to the metal state of Y^{91}, which goes over an excited state with series γ-ray.

[k] This transition could also go from the ground state of Zr^{89} to a *meta* state of Y^{89} in which case the interpretation would be $g_{9/2}-g_{9/2}$. The *ft* value is high for an allowed transition, but no other assignments seem possible.

[l] The experimental evidence on Zr^{95} and the Nb isotopes is not clear enough to prove the given assignments.

[m] The interpretation of this transition is not unique owing to lack of sufficient evidence.

[n] The *ft* value is rather low for this type of transition. An alternative would be to ascribe to the 43 protons of Tc^{95} a $g_{7/2}$ configuration, which would make the transition an *l*-forbidden one.

[o] $g_{7/2}$ for 59 neutrons gives the only possibility for an allowed transition for the Rh^{105} decay.

[p] Experimental evidence on decay data conflicting.

[q] The lifetimes of the isomeric states of Ag^{107} and Ag^{109} make it likely that their configuration is $G_{7/2}$ in place of $g_{9/2}$.

[r] An alternative for the $f_{7/2}$ configuration of the 83 neutrons is $h_{9/2}$.

[s] The expected configuration for 73 neutrons is $s_{1/2}$. In this case a series γ-ray has to be assumed.

[t] In place of $d_{5/2}$ also $g_{7/2}$ is possible, while there may be an $h_{9/2}$ configuration instead of $f_{7/2}$.

[u] In place of $f_{7/2}$ also $p_{3/2}$ is possible.

[v] $f_{5/2}$ is possible in place of $f_{7/2}$.

[w] The interpretation of this transition is highly ambiguous, and several alternatives are possible.

[x] The ground state of Ta^{181} is $g_{7/2}$.

[y] In place of $p_{3/2}$ also $f_{5/2}$ is possible.

[z] To explain the high forbiddenness of this transition a spin of at least 9/2 has to be assumed for Os^{187}. The assumption of the table makes it third order *l*-forbidden. Another possibility is $i_{13/2}$, which would make it fourth forbidden.

[aa] $p_{3/2}$ in place of $f_{5/2}$ would not exclude the direct transition to the ground state.

[bb] There is no possibility for an allowed transition for these nucleon numbers. The low *ft* value for these first-forbidden transitions may be due to the importance of the *Z*-dependent factors in the matrix elements, which reduce the ratio of the transition probabilities of allowed to forbidden transitions at high *Z* values$_2$ compare Konopinski, Revs. Modern Phys. **15**, 209 (1943).

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