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Nuclear Isomerism and Shell Structure*

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INTRODUCTION

IN the last few years a number of spectacular advances have been made in our knowledge of nuclear isomerism. There is little doubt that these advances can be traced primarily to an understanding of isomeric levels in terms of nuclear shell structure. Alongside this development, however, there have been other significantly contributing factors, which include (1) considerable progress in experimental techniques and a rapid accumulation of pertinent data, such as conversion coefficients and K/L ratios, (2) a highly satisfactory calculation of theoretical K shell conversion coefficients, and (3) an improved approach to a theory of radiative transition probabilities in nuclei.

Though many questions remain unanswered (e.g., the detailed understanding of electric and magnetic transitions in relation to nuclear models, the value of the internal conversion coefficients in the various L shells, etc.), a considerable degree of success has been achieved empirically, and it is possible at present to bring together isomerism and shell structure in a very satisfactory manner.

The suggestion that there is a correlation between shell structure and isomerism was first put forward by Feenberg.[1] Feenberg and Hammack[2] and Nordheim[3] discussed in detail the possibility of accounting on the shell model for the "islands of isomerism" which correlate with the existence of adjacent nuclear levels of considerably different total angular momenta. The more rigid level assignments of the strong spin orbit coupling model developed by Mayer[4] and Haxel, Jensen, and Suess[5] have been found in agreement with the spins deduced from experiments on isomeric transitions in nuclei belonging to the various shells. It is not an aim of this review to consider the relative merits of the different shell models, but in order to state our case for the close correlation between nuclear isomerism and shell structure we have chosen to hold to one variant, the strong spin-orbit coupling model, and to make level assignments as far as possible in terms of this "theory." This does not imply that the one particle model should be taken as literally true. It appears to be an idealization which successfully restricts to a few the number of possible assignments of spin and parity of low-lying nuclear states. At present, the shell model is incapable of giving exactly the empirically observed relative order of levels and their distance from each other. For this purpose the empirical regularities, such as those brought out by the study of the Te isomers[6] and first noticed by Hill,[7] must at present supplement the theory. They are developed further and discussed in detail at the end of this review.

Although accurate theoretical K conversion coefficients have long been available[8] for some transitions (high Z, low multipole order radiation) only approximate nonrelativistic estimates could be made until recently for the majority of the elements and energies encountered.[9] For the K conversion coefficients this deficiency has now been removed, and accurate relativistic values due to Rose and collaborators[10] and Reitz[11] are now available for practically all the radiations that occur in the study of isomers. (Values of the K conversion coefficients for radiations approaching the K-shell binding energies have been calculated recently.)[11a]

In classifying nuclear isomeric transitions according to energies and lifetimes it was evident from the work of many authors, as reviewed by Segrè and Helmholz[12] and Axel and Dancoff,[13] that the transitions could be grouped according to the angular momentum differences between the states or the multipolarity of the isomeric transitions. Although considerable success was achieved in this direction, especially for M4 transitions, it was evident that many classifications were ambiguous, e.g., the M3 and E4 classes.[13] Other transitions were anomalously absent, particularly the E5 class.[14] A

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[1] E. Feenberg, Phys. Rev. **75**, 320 (1949).

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

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

[4] M. G. Mayer, Phys. Rev. **78**, 16, 22 (1950).

[5] Haxel, Jensen, and Suess, Z. Physik **128**, 301 (1950).

[6] R. D. Hill, Phys. Rev. **76**, 186 (1949); J. C. Bowe and G. Scharff-Goldhaber, Phys. Rev. **76**, 437 (1949); Katz, Hill, and Goldhaber, Phys. Rev. **78**, 9 (1950); J. W. Mihelich and R. D. Hill, Phys. Rev. **79**, 781 (1950).

[7] R. D. Hill, Phys. Rev. **79**, 1021 (1950); **80**, 906 (1950); Brookhaven National Laboratory (S-11), 18 (1951).

[8] H. R. Hulme, Proc. Roy. Soc. (London) **A138**, 643 (1932); H. M. Taylor and N. F. Mott, Proc. Roy. Soc. (London) **A138**, 665 (1932).

[9] M. H. Hebb and E. Nelson, Phys. Rev. **58**, 486 (1940); S. M. Dancoff and P. Morrison, Phys. Rev. **55**, 122 (1939); S. D. Drell, Phys. Rev. **75**, 132 (1949); N. Tralli and I. S. Lowen, Phys. Rev. **76**, 1541 (1949).

[10] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).

[11] J. R. Reitz, Phys. Rev. **77**, 10 (1950).

[11a] B. I. Spinrad and L. B. Keller, Phys. Rev. **84**, 1056 (1951).

[12] E. Segrè and A. C. Helmholz, Revs. Modern Phys. **21**, 271 (1949).

[13] P. Axel and S. M. Dancoff, Phys. Rev. **76**, 892 (1949).

[14] R. D. Hill, Phys. Rev. **81**, 470 (1951).

considerable step forward was made when Weisskopf[15] derived theoretical relations for radiation probabilities that distinguished between magnetic and electric multipole transitions. It is evident, however, that this theory is still incomplete, and the classification has now been taken further empirically by Goldhaber and Sunyar.[16] They have been able to identify multipole transitions on the basis of K conversion coefficients and empirical K/L ratios and have shown that the resulting classification of isomers is in excellent agreement with shell theoretical level assignments. Of special interest here is the identification by Goldhaber and Sunyar[16] and by Moszkowski[17] of $7/2+$ states that arise from the coupling of several odd nucleons in $g_{9/2}$ orbits. These are often more stable than the $g_{9/2}$ states expected on the simple-one-nucleon model. This fact is probably connected with the finite range of nuclear forces (Racah,[18] Kurath,[19] Talmi[20]).

Parallel with the association of isomerism and nuclear shell theory, a similar development took place with respect to β-decay.[2,3,21] Because many metastable states decay, or are formed, by β-ray emission, we have used, wherever possible, the information yielded by β-ray studies to assist in assignments of isomeric levels.

While it would seem worthwhile to review the whole subject of isomerism in the light of all these developments, we have confined ourselves in the main to the one purpose of constructing level schemes consistent with the empirical evidence.

The level assignments are on the whole consistent with the possible choices (restricted to one or a few) given by the strong spin-orbit coupling model. In so far as they do not depend on this model, they may be taken as symbolic only. For example, an $h_{11/2}$ assignment need not imply that all the angular momentum is carried by a single particle with 5 units of orbital angular momentum and its spin parallel to the orbit. However, it is probable that a good portion of the wave function can be represented by an $h_{11/2}$ component of a single particle in the "field" of an even-even core. Whatever may be the fate of the single particle model, we expect the implication of an $h_{11/2}$ assignment—that the nucleus has a spin of 11/2 and odd parity—to stand the test of time.

Many of our assignments are tentative, partly because the experimental information is still incomplete. However, in the main the level assignments are internally consistent and can be considered as reasonably correct (in the sense just discussed). These assignments bring out certain clear regularities with regard to the shifts of levels from nucleus to nucleus as the numbers of protons and neutrons are varied. It is interesting to point out that there exists so far no example in which the spins of the initial and final states in an isomeric transition have been directly measured. However, a number of nuclei are known in which the study of isomeric transitions has led to predictions about the spin of a nuclear ground state which subsequent direct measurements have confirmed.

CORRELATION OF ISOMERS WITH THE MAGIC NUMBERS

In Fig. 1 all the known long-lived isomers ($T_{1/2}\gtrsim 1$ sec) of odd mass number A are plotted against their odd proton or odd neutron number (Z or N). It is clear that there are abundant groupings of isomers just below the magic numbers 50, 82, and 126. The states of high spin appearing in the islands of isomers below magic numbers 50, 82, and 126 are found to be those connected with $g_{9/2}$, $h_{11/2}$, and $i_{13/2}$ orbits, respectively, in agreement with the strong spin-orbit coupling model.

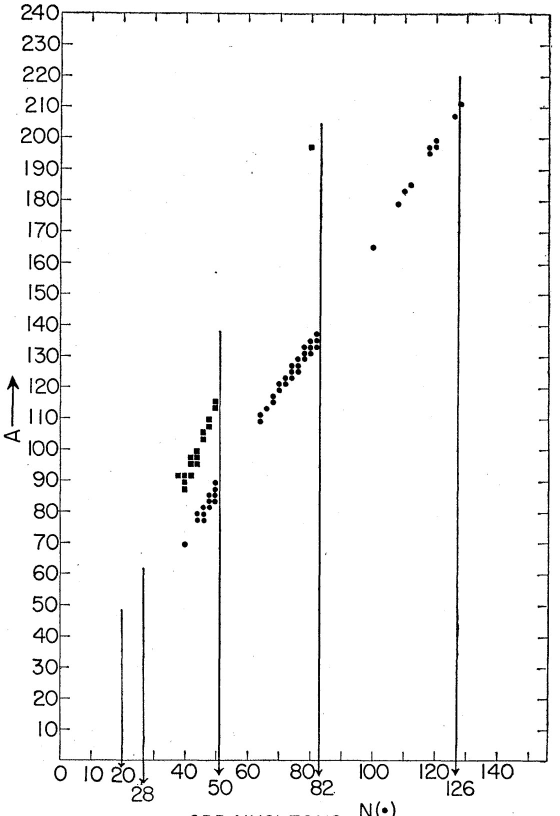

FIG. 1. Distribution of long-lived nuclear isomers of odd A.

It is rather striking that only one odd proton isomer (Au^{197}) appears between $Z=50$ and $Z=82$, whereas more than 20 examples of odd neutron isomers are known. The absence of long-lived odd Z isomers in this region may be connected with the fact that the first excited state of an even-even nucleus is quite low in this region (e.g., 80–100 kev for some of the rare earths).

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[15] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).
[16] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[17] S. A. Moszkowski, Phys. Rev. **83**, 1071 (1951).
[18] G. Racah, Phys. Rev. **78**, 622 (1950).
[19] D. Kurath, Phys. Rev. **80**, 98 (1950).
[20] I. Talmi, Phys. Rev. **82**, 101 (1951).
[21] C. S. Wu, Revs. Modern Phys. **22**, 386 (1950).

The simple one-particle model may be expected to break down for odd A nuclei with such an even-even core. It is possible then, that several states intermediate in spin between the ground state and the expected $h_{11/2}$ state may be formed, thus destroying the "metastability" of the $h_{11/2}$ state.

SUMMARY OF ISOMERS

The grouping of isomers in "islands" as in Fig. 1, does not illustrate very well the levels involved in the isomeric transitions, nor does it indicate whether they take place in one or more steps. This information is given in Table I, for all isomers of odd as well as of even A, and also including the short-lived isomers.§ In order to exhibit more clearly the similarities between the levels involved, the isomers are arranged in order of increasing A and in four groups: (1) odd $Z-$even N; (2) even $Z-$odd N; (3) odd $Z-$odd N; and (4) even $Z-$even N.

POINTS CONCERNING DECAY SCHEMES

The isomers summarized in Table I are discussed in detail in the following section in order of mass number. Where possible a decay scheme is given. As a rule, only disintegrations leading to or from isomeric nuclei, and those contributing to information about isomeric levels, are represented in the figures.

Ground states and metastable states are indicated by heavy horizontal lines.

Level assignments in parentheses are considered tentative. Where orbital angular momenta are given, the nuclear shell model with strong spin-orbit coupling has been used. The spin and parity of an even-even nuclear ground state have been assumed to be zero and even (+), respectively. Spins assigned to metastable and ground states that form possible pairs, compatible with present evidence, are written immediately above and below one another. The symbol ϵ is introduced to indicate orbital electron capture (K, L, etc. capture, sometimes referred to as ϵ-capture).

POINTS CONCERNING REFERENCES

References in the first place are given to "Nuclear Data" (ND)‖ and "Nuclear Data, Supplement 1 or 2" (NDS 1 or 2). Detailed references are not given as a rule when they are contained in this reference work.

Assignments of the character of isomeric transitions follow closely those given by Goldhaber and Sunyar (G10).¶ A number of these assignments are, of course, identical with many already given by earlier reviewers, including Axel and Dancoff (A8) and Segrè and Helmholz (S7), as well as by many original investigators of the isomeric transitions.

The table of log ft values for beta-transitions given by Feingold (F4) has been used extensively in referring to beta-disintegrations leading to isomeric states. Here again, however, a number of log ft values are often taken from the original sources. Other information has also been used from sources such as the reviews of Feenberg and Trigg (F3) and Mayer, Moszkowski, and Nordheim (M7).

References:

(G10) M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
(A8) P. Axel and S. M. Dancoff, Phys. Rev. **76**, 892 (1949).
(S7) E. Segrè and A. C. Helmholz, Revs. Modern Phys. **21**, 271 (1949).
(F4) A. M. Feingold, Revs. Modern Phys. **23**, 10 (1951).
(F3) E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).
(M7) M. G. Mayer, S. R. Moszkowski, and L. W. Nordheim, Argonne National Laboratory ANL-4626 (1951); Revs. Modern Phys. **23**, 315 (1951).
(D2) J. P. Davidson, Jr., Phys. Rev. **82**, 48 (1951).

A=39

$$_{18}\mathrm{A}_{21} \quad \begin{array}{ll} T_1 > 15 \text{ yr} & \beta^- \; 0.565, \\ T_2 = 160 \text{ sec} & \beta^- \; 2.1. \end{array}$$

I. The log ft value of the >15 yr $_{18}\mathrm{A}^{39}$ decay is >8.7 [log $f_1t > 7.6$, (D2)], and the transition has been identified from the spectrum shape (B30) as 1st forbidden, $\Delta I=2$, yes. Since the measured ground-state spin and magnetic moment of $_{19}\mathrm{K}^{39}$ are compatible with a $d_{3/2}$ assignment, the assignment of $f_{7/2}$ can be made to the >15 yr $_{18}\mathrm{A}^{39}$ state in agreement with shell theory.

II. The log ft value of the 160-sec $_{18}\mathrm{A}^{39}$ $2.1\beta^-$ decay is 4.4, and if the allowed transition goes to the $d_{3/2}$ ground state of $_{19}\mathrm{K}^{39}$, the $_{18}\mathrm{A}^{39}$ state in this case would be identified as 1/2, 3/2, or 5/2, with even parity. The longest-lived isomeric transition between the 160-sec and >15-yr states in $_{18}\mathrm{A}^{39}$ would therefore occur when the 160-sec state had spin 1/2, and the I.T. would be of E3 character. However, an E3 transition of ~ 1.5-Mev energy would live $<10^{-4}$ sec, and such a level assignment seems therefore improbable. If the "$2.1\beta^-$ radiation," which has only been identified by Al absorption, should turn out to be a low energy photon radiation, these difficulties might be resolved.

III. The A^{39} 160-sec activity has also been produced by an A^{40} (γ, n) reaction (I1).

IV. Recently, however, Hälg (H1) has been unable to produce the 160-sec activity by fast neutron bombardment of K. This throws considerable doubt on the existence of isomerism in A^{39}. Anderson *et al.* (A11) come to the same conclusion.

References:

$_{17}\mathrm{Cl}^{39}$, NDS2 p. 10; $_{18}\mathrm{A}^{39}$, NDS2 p. 10.
(H4) R. N. H. Haslam, L. Katz, H. E. Johns, and H. J. Moody, Phys. Rev. **76**, 704 (1949).
(B30) A. R. Brosi, H. Zeldes, and B. H. Ketelle, Phys. Rev. **79**, 902 (1950).
(Z3) A. Zucker and W. W. Watson, Phys. Rev. **80**, 966 (1950).

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§ We have left out here the few examples in the light elements (e.g., Li^7) where the lifetimes of nuclear excited states have been measured. These are discussed by Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 291 (1950).

‖ K. Way *et al.*, "Nuclear Data," National Bureau of Standards Circular 499.

¶ References in parentheses also will be found listed alphabetically in the Bibliography at the end of the paper.

TABLE I. Summary of known isomers. Isomers are arranged according to mass numbers (A) and divided into four classes: odd Z—even N, even Z—odd N, odd Z—odd N, and even Z—even N. (Z=number of protons, N=number of neutrons). The table does not include those isomers whose mass assignments are as yet uncertain. For a few nuclei there are three isomers known. These cases are not here distinguished from the normal binary cases. The level assignments in parentheses are those corresponding in order to the energetically upper state, the intermediate states (if any), and the lower energy (final) state of the isomeric nucleus. Even parity is indicated by + and odd parity by −.

A	Odd Z−Even N	Even Z−Odd N	Odd Z−Odd N	Even Z−Even N
39		$_{18}\mathrm{A}_{21}(?)$		
41	$_{19}\mathrm{K}_{22}(f_{7/2}, d_{3/2})$			
44			$_{21}\mathrm{Sc}_{23}(7+, 3+)$ or $(6+, 2+)$	
46			$_{21}\mathrm{Sc}_{25}(7+, 4+)$	
52			$_{25}\mathrm{Mn}_{27}(1+, 5+)$	
57		$_{26}\mathrm{Fe}_{31}(?, p_{3/2})$		
58			$_{27}\mathrm{Co}_{31}(5+, 2+)$	
60			$_{27}\mathrm{Co}_{33}(2+, 5+)$	
62			$_{27}\mathrm{Co}_{35}$	
69		$_{30}\mathrm{Zn}_{39}(g_{9/2}, p_{1/2})$		
72				$_{32}\mathrm{Ge}_{40}(0+, 0+)$
77		$_{32}\mathrm{Ge}_{45}(p_{1/2}, 7/2+)$		
77		$_{34}\mathrm{Se}_{43}(7/2+, p_{1/2})$		
79		$_{34}\mathrm{Se}_{45}(p_{1/2}, 7/2+)$		
79		$_{36}\mathrm{Kr}_{43}(p_{1/2}, 7/2+)$		
80			$_{35}\mathrm{Br}_{45}(5-, 2-, 1+)$	
81		$_{34}\mathrm{Se}_{47}(7/2+, p_{1/2})$		
81		$_{36}\mathrm{Kr}_{45}(p_{1/2}, 7/2+)$		
83		$_{34}\mathrm{Se}_{49}$		
83		$_{36}\mathrm{Kr}_{47}(p_{1/2}, 7/2+, g_{9/2})$		
84	$_{37}\mathrm{Rb}_{47}$			
85		$_{36}\mathrm{Kr}_{49}(p_{1/2}, g_{9/2})$		
85	$_{37}\mathrm{Rb}_{48}(g_{9/2}, f_{5/2})$			
85		$_{38}\mathrm{Sr}_{47}(p_{1/2}, 7/2+, g_{9/2})$		
86	$_{37}\mathrm{Rb}_{49}$			
87		$_{38}\mathrm{Sr}_{49}(p_{1/2}, g_{9/2})$		
87	$_{39}\mathrm{Y}_{48}(g_{9/2}, p_{1/2})$			
89	$_{39}\mathrm{Y}_{50}(g_{9/2}, p_{1/2})$			
89		$_{40}\mathrm{Zr}_{49}(p_{1/2}, g_{9/2})$		
91	$_{37}\mathrm{Rb}_{54}$			
91	$_{39}\mathrm{Y}_{52}(g_{9/2}, p_{1/2})$			
91	$_{41}\mathrm{Nb}_{50}(g_{9/2}, p_{1/2})$			
91		$_{42}\mathrm{Mo}_{49}$		
93			$_{43}\mathrm{Tc}_{50}$	
94			$_{41}\mathrm{Nb}_{53}(4-, 7+)$ or $(3-, 6+)$	
95	$_{41}\mathrm{Nb}_{54}(p_{1/2}, g_{9/2})$			
95	$_{43}\mathrm{Tc}_{52}(p_{1/2}, g_{9/2})$			
96			$_{43}\mathrm{Tc}_{53}(4+, 7+)$	
97	$_{41}\mathrm{Nb}_{56}(p_{1/2}, g_{9/2})$			
97	$_{43}\mathrm{Tc}_{54}(p_{1/2}, g_{9/2})$			
98			$_{43}\mathrm{Tc}_{55}$	
99	$_{43}\mathrm{Tc}_{56}(p_{1/2}, 7/2+, g_{9/2})$			
103	$_{45}\mathrm{Rh}_{58}(7/2+, p_{1/2})$			
104			$_{45}\mathrm{Rh}_{59}(4-, 1+)$	
105	$_{45}\mathrm{Rh}_{60}(p_{1/2}, 7/2+)$			
106			$_{47}\mathrm{Ag}_{59}$	
107	$_{47}\mathrm{Ag}_{60}(7/2+, p_{1/2})$			
109		$_{46}\mathrm{Pd}_{63}(h_{11/2}, d_{5/2})$		
109	$_{47}\mathrm{Ag}_{62}(7/2+, p_{1/2})$			
110			$_{47}\mathrm{Ag}_{63}(5-, 1+)$	
110			$_{49}\mathrm{In}_{61}(5-, 1+)$	
111		$_{48}\mathrm{Cd}_{63}(h_{11/2}, d_{5/2}, s_{1/2})$		
112			$_{49}\mathrm{In}_{63}(4\pm, 1+)$	
113		$_{48}\mathrm{Cd}_{65}(h_{11/2}, s_{1/2})$		
113	$_{49}\mathrm{In}_{64}(p_{1/2}, g_{9/2})$			
114			$_{49}\mathrm{In}_{65}(5+, 1+)$	
115		$_{48}\mathrm{Cd}_{67}(h_{11/2}, s_{1/2})$		
115	$_{49}\mathrm{In}_{66}(p_{1/2}, g_{9/2})$			
116			$_{49}\mathrm{In}_{67}(?, 1+)$	
117		$_{50}\mathrm{Sn}_{67}(h_{11/2}, d_{3/2}, s_{1/2})$		
118			$_{51}\mathrm{Sb}_{67}(?)$	
119		$_{50}\mathrm{Sn}_{69}(h_{11/2}, d_{3/2}, s_{1/2})$		
(120)			$(_{51}\mathrm{Sb}_{69}(?))$	

TABLE I.—*Continued.*

A	Odd *Z*−Even *N*	Even *Z*−Odd *N*	Odd *Z*−Odd *N*	Even *Z*−Even *N*
121		$_{50}\mathrm{Sn}_{71}(h_{11/2}, d_{3/2})$		
121		$_{52}\mathrm{Te}_{69}(h_{11/2}, d_{3/2}, s_{1/2})$		
122			$_{51}\mathrm{Sb}_{71}(?, 2-)$	
123		$_{50}\mathrm{Sn}_{73}(h_{11/2}, d_{3/2})$		
123		$_{52}\mathrm{Te}_{71}(h_{11/2}, d_{3/2}, s_{1/2})$		
124			$_{51}\mathrm{Sb}_{73}((0+), (1+), 3-)$	
125		$_{50}\mathrm{Sn}_{75}(d_{3/2}, h_{11/2})$		
125		$_{52}\mathrm{Te}_{73}(h_{11/2}, d_{3/2}, s_{1/2})$		
127		$_{52}\mathrm{Te}_{75}(h_{11/2}, d_{3/2})$		
127		$_{54}\mathrm{Xe}_{73}(h_{11/2}, d_{5/2}, s_{1/2})$		
129		$_{52}\mathrm{Te}_{77}(h_{11/2}, d_{3/2})$		
129		$_{54}\mathrm{Xe}_{75}(h_{11/2}, d_{3/2}, s_{1/2})$		
131		$_{52}\mathrm{Te}_{79}(h_{11/2}, d_{3/2})$		
131		$_{54}\mathrm{Xe}_{77}(h_{11/2}, s_{1/2}, d_{3/2})$		
133		$_{52}\mathrm{Te}_{81}(h_{11/2}, d_{3/2})$		
133		$_{54}\mathrm{Xe}_{79}(h_{11/2}, d_{3/2})$		
133		$_{56}\mathrm{Ba}_{77}(h_{11/2}, d_{3/2}, s_{1/2})$		
134			$_{55}\mathrm{Cs}_{79}(7\mp, 4\pm)$	
135		$_{54}\mathrm{Xe}_{81}(h_{11/2}, d_{3/2})$		
135		$_{56}\mathrm{Ba}_{79}(h_{11/2}, d_{3/2})$		
137		$_{56}\mathrm{Ba}_{81}(h_{11/2}, d_{3/2})$		
152			$_{63}\mathrm{Eu}_{89}$	
153	$_{63}\mathrm{Eu}_{90}(?+, ?+, 5/2+)$			
160				$_{66}\mathrm{Dy}_{94}(2+, 0+)$
165		$_{66}\mathrm{Dy}_{99}(?, f_{7/2})$		
166				$_{68}\mathrm{Er}_{98}(2+, 0+)$
169	$_{69}\mathrm{Tm}_{100}(?, s_{1/2})$			
170				$_{70}\mathrm{Yb}_{100}(2+, 0+)$
171	$_{69}\mathrm{Tm}_{102}$			
176			$_{71}\mathrm{Lu}_{105}(1\pm, \geq 7)$	
177	$_{71}\mathrm{Lu}_{106}$			
179		$_{72}\mathrm{Hf}_{107}(h_{9/2}, p_{3/2}, p_{1/2})$		
179		$_{74}\mathrm{W}_{105}(?)$		
180				$_{72}\mathrm{Hf}_{108}(?, ?, ?, 2+, 0+)$
181	$_{73}\mathrm{Ta}_{108}(1/2+, 3/2+, 7/2+, g_{7/2})$			
182			$_{73}\mathrm{Ta}_{109}$	
182			$_{75}\mathrm{Re}_{107}(?)$	
183		$_{74}\mathrm{W}_{109}(7/2+, p_{1/2})$		
183	$_{75}\mathrm{Re}_{108}(?)$			
184			$_{75}\mathrm{Re}_{109}(?)$	
185		$_{74}\mathrm{W}_{111}(7/2+, p_{1/2})$		
186				$_{76}\mathrm{Os}_{110}(2+, 0+)$
187	$_{75}\mathrm{Re}_{112}(?, d_{5/2})$			
190			$_{77}\mathrm{Ir}_{113}(?)$	
192			$_{77}\mathrm{Ir}_{115}$	
193	$_{77}\mathrm{Ir}_{114}(?, d_{3/2})$			
195		$_{78}\mathrm{Pt}_{117}(i_{13/2}, f_{5/2}, p_{3/2}, p_{1/2})$		
196			$_{79}\mathrm{Au}_{117}(?)$	
197		$_{78}\mathrm{Pt}_{119}(i_{13/2}, f_{5/2}, ?)$		
197	$_{79}\mathrm{Au}_{118}(h_{11/2}, d_{5/2}, 3/2+, d_{3/2})$			
197		$_{80}\mathrm{Hg}_{117}(i_{13/2}, f_{5/2}, p_{1/2})$		
199		$_{80}\mathrm{Hg}_{119}(i_{13/2}, p_{3/2}, f_{5/2}, p_{1/2})$		
204				$_{82}\mathrm{Pb}_{122}(7-, 2+, 0+)$
207		$_{82}\mathrm{Pb}_{125}(i_{13/2}, f_{5/2}, p_{1/2})$		
210			$_{83}\mathrm{Bi}_{127}$	
211		$_{84}\mathrm{Po}_{127}$		
234			$_{91}\mathrm{Pa}_{143}(1+, 5+)$	
242			$_{95}\mathrm{Am}_{147}$	

The following isomers are of uncertain mass number:

$_{42}\mathrm{Mo}^{93\pm1}$ (6.75 hr); $_{49}\mathrm{In}^{113\pm1}$ (2.5 sec); $_{68}\mathrm{Er}$ (2.5 sec); $_{70}\mathrm{Yb}$ (0.5 sec and 6 sec).

Note added in proof.—A number of other isomers have been reported recently:
$_{22}\mathrm{V}^{52}$ (2.6 min) (G. A. Renard, Ann. phys. **5**, 385 (1950)).
$_{31}\mathrm{Ga}^{67}$ ($\sim\mu$ sec) [Fultz, Nash, Woodward, and Pool, Bull. Am. Phys. Soc. **27**, No. 4, 19 (1952)].
$_{32}\mathrm{Ge}^{75}$ (42 sec) (A. Flammersfeld, Z. Naturforsch. **79**, 295 (1952)).
Other isomers, added in the text but not included in Table I are:
$_{46}\mathrm{Pd}^{105}$, $_{46}\mathrm{Pd}^{107,109}$, $_{46}\mathrm{Pd}^{111}$, $_{47}\mathrm{Ag}^{111}$, $_{48}\mathrm{Cd}^{117}$, $_{67}\mathrm{Ho}^{166}$, $_{72}\mathrm{Hf}^{176}$, $_{76}\mathrm{Os}^{191}$.

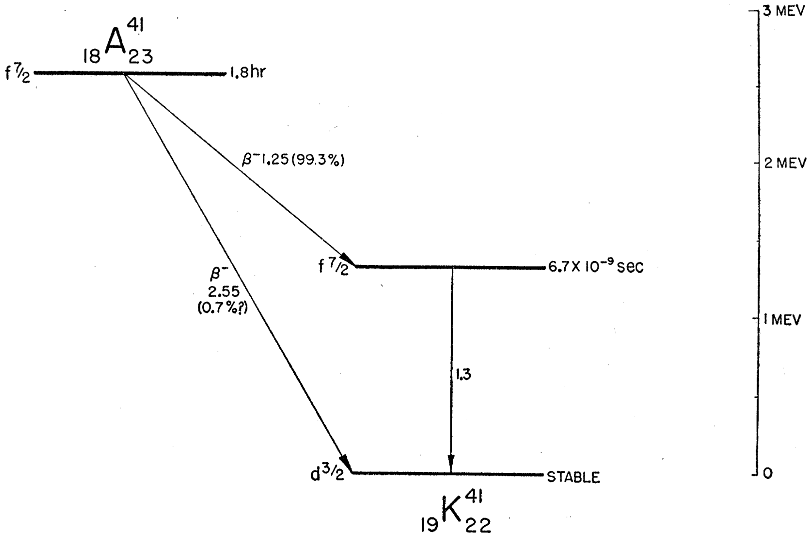

FIG. 2. $A=41$.

(H14) M. Hoffman, Phys. Rev. **83**, 215A (1951).
(I1) Iowa State College Report No. 175, G. W. Fox, *et al.* (1951).
(H1) W. Hälg, Helv. Phys. Acta **24**, 641 (1951).
(A11) C. E. Anderson, G. W. Wheeler, and W. W. Watson, Phys. Rev. **87**, 195A (1952).

A=41

I. The 6.7×10^{-9} sec half-life of the 1.3-Mev excited state in $_{19}K^{41}$ is consistent with an M2 transition (E2).

II. The log *ft* values of the 1.25 and 2.55 β^- components of the 1.8-hr $_{18}A^{41}$ decay are 5.11 and 8.56, respectively (F4). These transitions are allowed and $\Delta I=2$, yes, respectively, and are consistent with the shell structure assignments shown above (log f_1t for the 2.55 β^- component is ~ 8.7).

References:

$_{18}A^{41}$, ND p. 33; $_{19}K^{41}$, ND p. 36.
(E2) L. G. Elliott, private communication; Phys. Rev. **85**, 942 (1952).

A=44

I. The lifetime of 58.6-hr $_{21}Sc^{44m}$ is in best accord with an E4 transition (G10). The spins shown in the

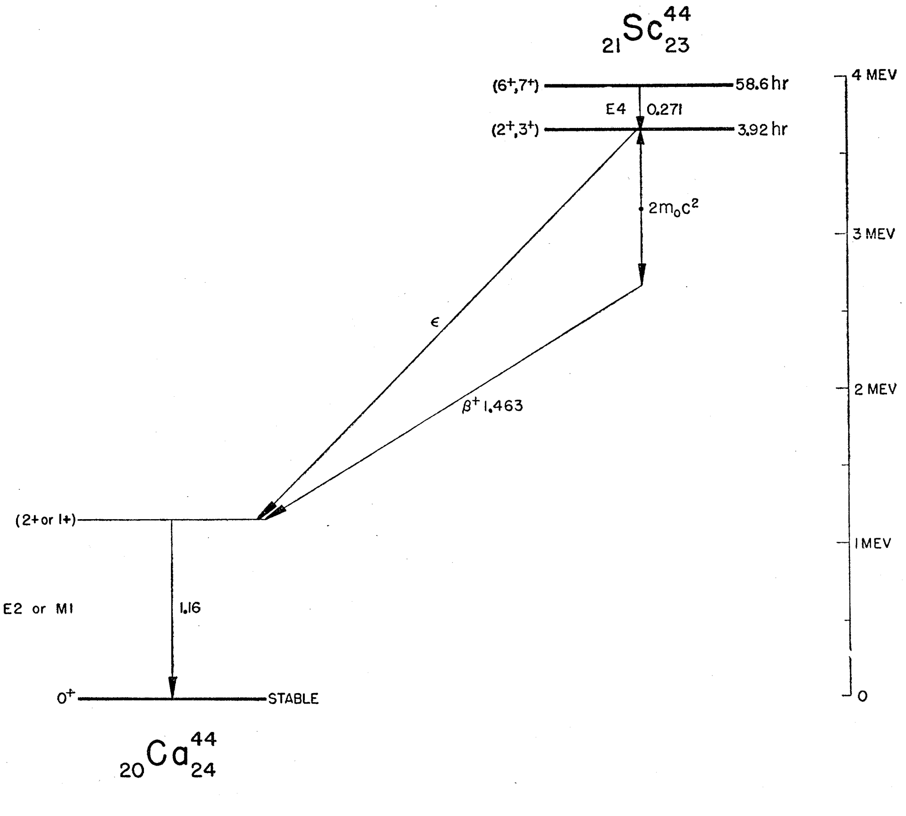

FIG. 3. $A=44$.

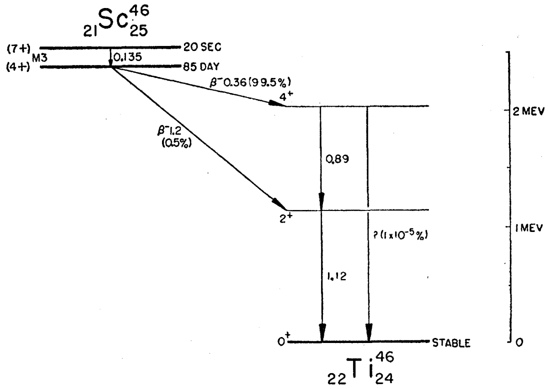

FIG. 4. $A=46$.

diagram are possible assignments built up from the $_{20}$Ca^{44} ground state. The 7+ spin for the 58.6-hr $_{21}$Sc^{44} state would fit shell theory (odd proton $f_{7/2}$ and odd neutron $f_{7/2}$) and Nordheim's rule.

II. The $\log(f_+ + f_k)t$ value for the 3.92-hr $_{21}$Sc^{44} activity is >5.27 (F4). The Fermi plot of the β^+ spectrum has an allowed shape (B31). According to theory (F3), $f_k/f_+ = 1/25$. Experiment (B31), however, indicates $f_k/f_+ = 2$. The cause of this discrepancy is at present unknown.

III. No activity, <100 *y* or >1 *m*, has been observed for $_{22}$Ti^{44}.

References:

Sc^{44}, ND p. 41, NDS p. 10, NDS2 p. 12.
(B31) J. A. Bruner and L. M. Langer, Phys. Rev. **79**, 606 (1950).

A=46

I. The isomeric transition of 135-kev (D9) in $_{21}$Sc^{46} is identified as either E3 or M3 (G10). The 85-day state of $_{21}$Sc^{46} has probably a high spin, 4+ judging from *ft* values. The spins of $_{21}$Sc^{46} shown in the diagram are tentative. Shell theory supports 7+ for the 20-sec state.

II. The log*ft* values for the 0.36 and 1.2 β^- spectra are 6.2 and 10.3, respectively. The latter value is consistent with a $\Delta I = 2$, no, transition for the higher energy β-ray. The latest beta-energy values and branching ratio are given (P7). No ϵ-capture to stable $_{20}$Ca^{46} is known.

III. Spin and parity assignments to levels in $_{22}$Ti^{46} are based mainly on $\gamma - \gamma$ angular and polarization correlation experiments (B27) (M25) and are consistent with conversion coefficients (M33). Evidence for a cross-over transition is indirect (F9).

IV. No β-transition from the 20-sec state to any of the known Ti states has been observed (G7).

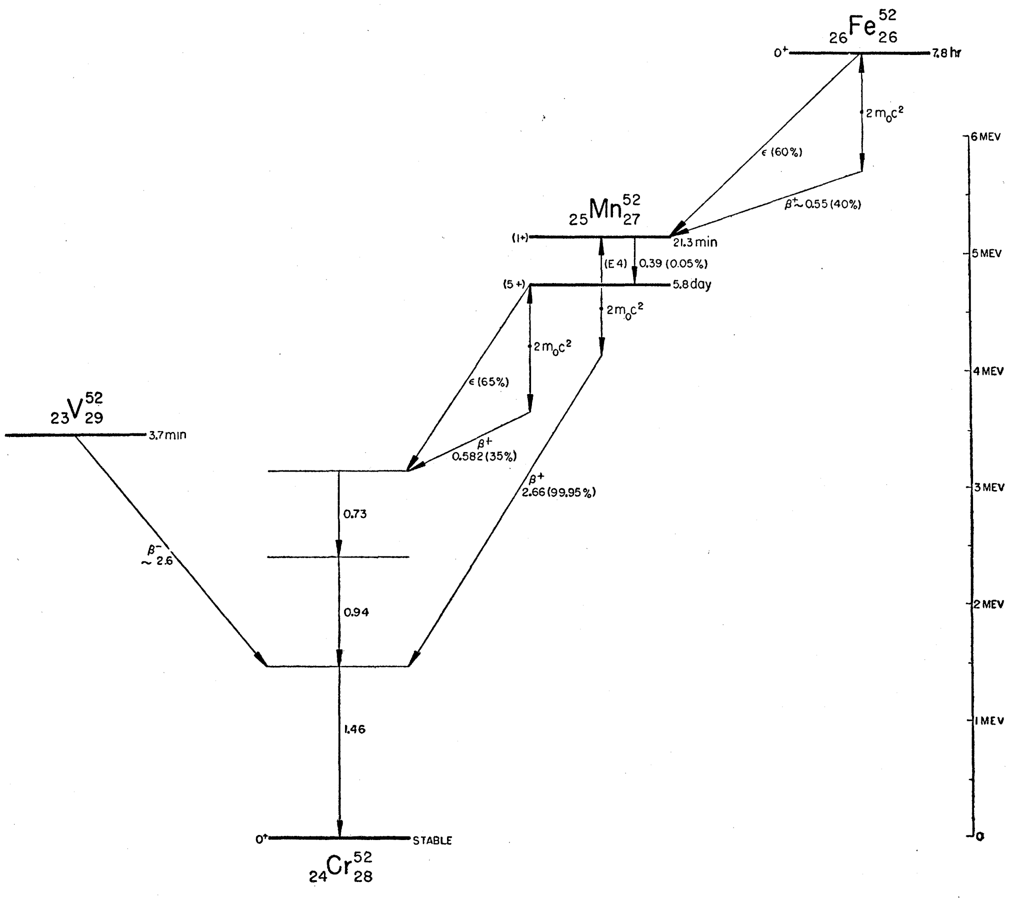

FIG. 5. $A=52$.

V. More recently the 20-sec I.T. has been found to have an energy of 140 kev and a K/L ratio of 10 ± 3 (B38).

References:

$_{21}Sc^{46}$, ND p. 41, NDS p. 10, NDS2 p. 12.
(P7) F. T. Porter and C. S. Cook, Phys. Rev. **81**, 640 (1951).
(B27) E. L. Brady and M. Deutsch, Phys. Rev. **78**, 558 (1950); **74**, 1541 (1948).
(M25) F. Metzger and M. Deutsch, Phys. Rev. **74**, 1640 (1948).
(F9) R. G. Fluharty and M. Deutsch, Phys. Rev. **76**, 182 (1949).
(G7) M. Goldhaber and C. O. Muehlhause, Phys. Rev. **74**, 1877 (1948).
(M33) M. L. Moon, M. A. Waggoner, and A. Roberts, Phys. Rev. **79**, 905 (1950).
(D9) E. der Mateosian and M. Goldhaber, Phys. Rev. **82**, 115 (1951).
(B38) S. B. Burson and W. C. Rutledge, Phys. Rev. **86**, 633A (1952).

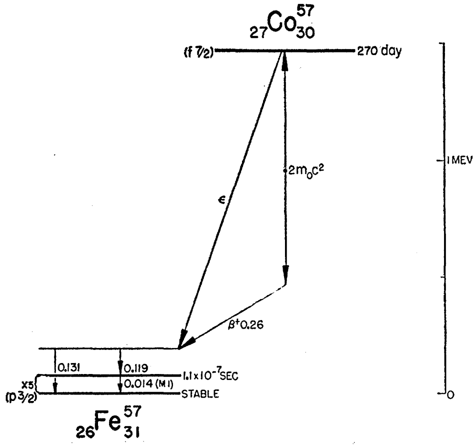

FIG. 6. $A=57$.

A = 52

I. The lifetime of the 21.3-min $_{25}Mn^{52}$ isomer indicates an M4 transition (G10), but an E4 transition is not excluded. The tentative spin assignments for $_{25}Mn^{52}$ are linked to the level assignment for $_{26}Fe^{52}$.

II. The logft value of 4.3 for the β^+ transition of Fe^{52} indicates an allowed transition to the 21.3-min state of Mn^{52m}. There is 61 percent of ϵ-capture in this transition (F15).

III. On the above spin assignments the absence of a β^+ transition from the 21.3-min state of Mn^{52} to the ground state of Cr^{52} is puzzling. A 5− assignment for the ground state of Mn^{52} would contradict spin-orbit shell theory, since an $(f_{7/2})^5\ (f_{7/2})^{-1}$ arrangement would give even parity; the assumption of an E4 transition would therefore seem preferable (S6).

IV. Two activities of 3.74-min and 2.6-min half-lives have been reported recently in $_{23}V^{52}$ (R3).

References:

$_{25}Mn^{52}$, ND p. 49; $_{23}V^{52}$, NDS2 p. 13.
(F15) G. Friedlander and J. Miller, Phys. Rev. **84**, 588 (1951).
(S6) J. M. C. Scott, Cavendish Laboratory, unpublished manuscript (1951).
(R3) G. A. Renard, Ann. phys. **5**, 385 (1950).

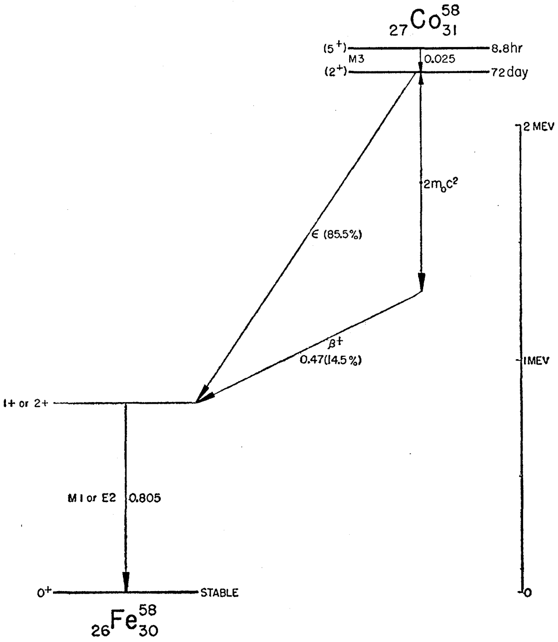

FIG. 7. $A=58$.

A = 57

I. The lifetime of the 1.1×10^{-7} sec $_{26}Fe^{57}$ isomeric state probably indicates an M1 transition (G10).

II. Assuming a value of $f_k/f_+=100$, the logft of the $_{27}Co^{57}$ beta-transition is ~7.

III. No $_{25}Mn^{57}$ activity is known.

Reference:

$_{26}Fe^{57}$, ND p. 53.

A = 58

I. The lifetime of the 8.8-hr $_{27}Co^{58m}$ is consistent either with an M3 or E3 transition. The observed K/L ratio of 1.9 for this transition lies above the empirical E3 curve (G10) which speaks for an M3 transition.

II. The $\log(f_++f_k)t$ value for the 72-day decay is 6.6, which indicates that the transition is allowed or 1st forbidden. The spins shown are consistent assignments. An assignment of 2− to the 72-day ground state would imply a small percentage (~2 percent) of β^+ transitions to the ground state of $_{26}Fe^{58}$. The most probable parities are + for both states of Co^{58} (see discussion of Co^{60}).

III. The experimental value of $\epsilon_k=2.5\times10^{-4}$ (S25) for the 0.805 transition in $_{26}Fe^{58}$ is consistent with either an M1 or E2 transition.

References:

$_{27}Co^{58}$, ND p. 54; NDS2 p. 15.
(S25) K. Strauch, Phys. Rev. **79**, 487 (1950).

A = 60

I. The 59-kev isomeric transition of 10.7-min $_{27}Co^{60}$ is identified as either E3 or M3 from lifetime (G10), with M3 favored (K/L ratio, shell theory).

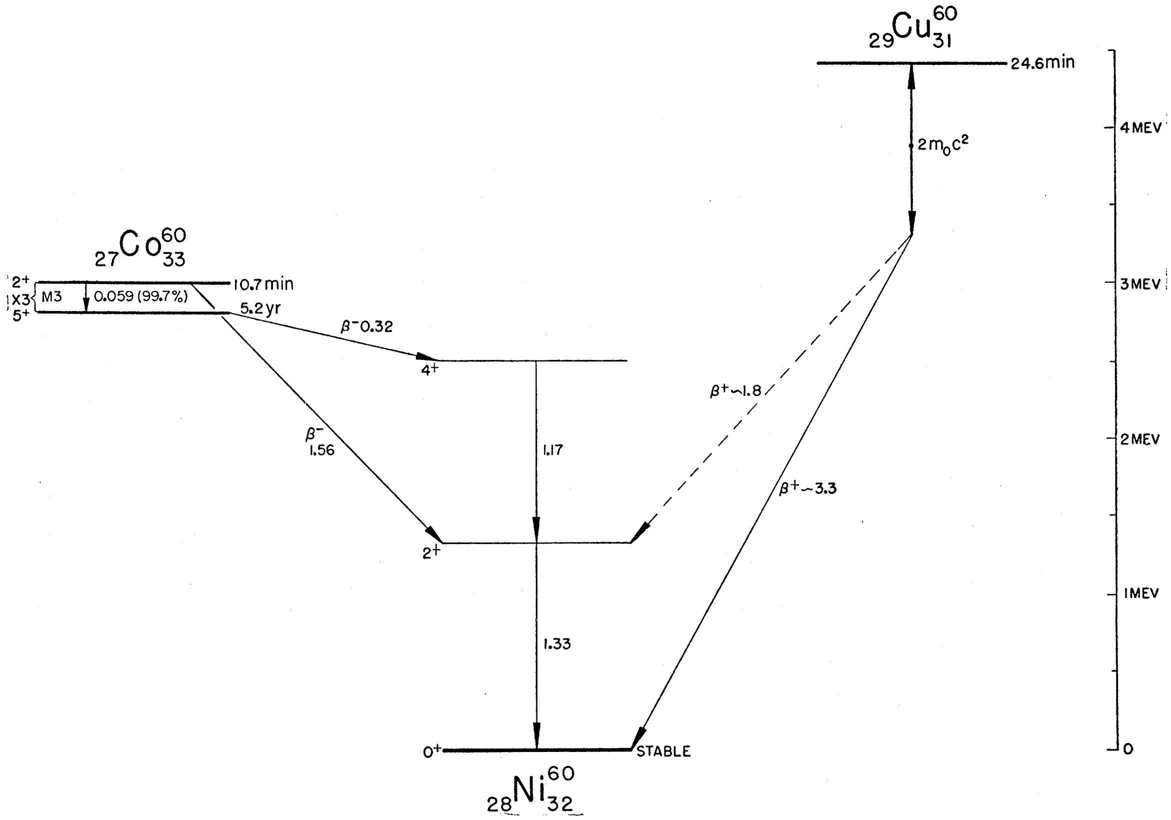

FIG. 8. $A=60$.

II. The spins and parities of the levels of ${}_{28}\text{Ni}^{60}$ are well described by $0+$, $2+$, and $4+$. Both $\gamma-\gamma$ angular and polarization correlation experiments and conversion coefficients of the 1.17 and 1.33 γ-transitions strongly support these assignments.

III. The log*ft* values of the 0.32 and 1.56 β^- transitions from the 5.2-yr and 10.7-min ${}_{27}\text{Co}^{60}$ states are 7.46 and 7.15, respectively (compatible with allowed or first forbidden transitions).

IV. No β^- branching from the 10.7-min state to the ground state of Ni^{60} is found ($<10^{-4}$ percent of the 59-kev isomeric transition) (D18). This fact speaks against a negative parity assignment for Co^{60m}. The spins and parities of the ${}_{27}\text{Co}^{60m}$ states given here are consistent with those given in reference (D18).

References:

${}_{27}\text{Co}^{60}$, ND p. 54, NDS p. 13, NDS2 p. 15; ${}_{29}\text{Cu}^{60}$, ND p. 58.
(D18) M. Deutsch and G. Scharff-Goldhaber, Phys. Rev. **83**, 1059 (1951).

$A=62$

${}_{27}\text{Co}_{35}$ $T_1=13.9$ min, β^- 2.3, γ 1.3,
$T_2=1.6$ min, β, γ.

Reference:

${}_{27}\text{Co}^{62}$, ND p. 55.

$A=69$

I. The M4 character of the isomeric transition, the allowed transition (log$ft=4.4$) of the beta-decay, and the measured spin of 3/2 for the ground state of ${}_{31}\text{Ga}^{69}$ are all consistent with the above level assignments from shell structure theory.

Reference:

${}_{30}\text{Zn}^{69}$, ND p. 63.

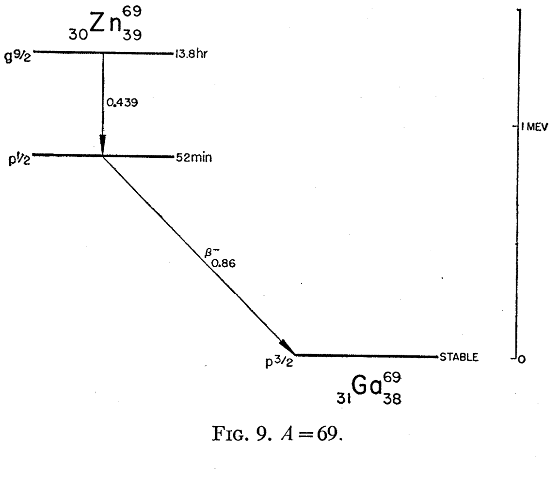

FIG. 9. $A=69$.

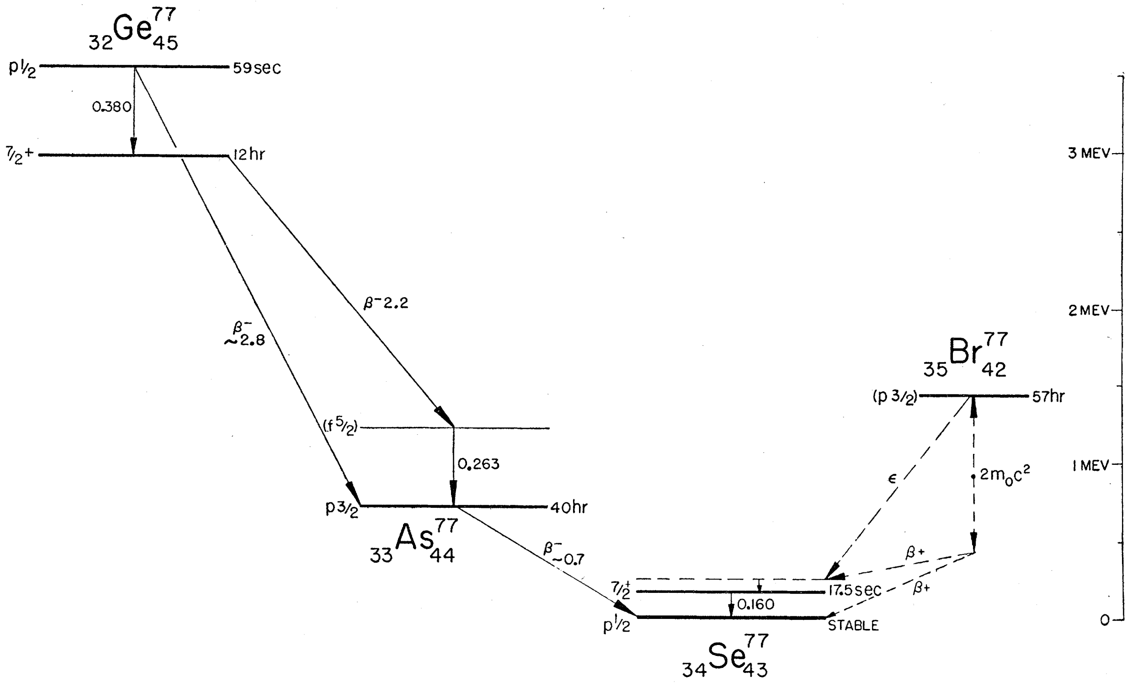

FIG. 10. $A=77$.

A=72

$_{32}Ge^{72m}$ $T_1=0.3$ μsec, I.T.=0.68,
$_{32}Ge^{72}$ T_2 (stable).

I. Alternative disintegration schemes of 14.25-hr $_{31}Ga^{72}$ are given in ND p. 66. The lifetime of the weak, but highly converted, 0.68 transition has been observed as 0.29 (M17) and 0.33 μsec (F12). Since the isomeric transition does not show detectable unconverted γ-rays, it has been attributed (B20) to a $0+\rightarrow 0+$ transition to the ground state of $_{32}Ge^{72}$.

References:

$_{31}Ga^{72}$, ND p. 66.
(B20) J. C. Bowe, M. Goldhaber, R. D. Hill, W. E. Meyerhof, and O. Sala, Phys. Rev. **73**, 1219A (1948).
(M17) F. K. McGowan, S. DeBenedetti, and J. E. Francis, Jr., Phys. Rev. **75**, 1761 (1949).
(F12) S. Frankel, Ph.D. thesis, Illinois (1949).

A=77

I. The 0.16-Mev isomeric transition of 17.5-sec $_{34}Se^{77}$ is assigned an E3 character on the basis of lifetime considerations (G10). The ground-state spin of $_{34}Se^{77}$ is probably 1/2 as no quadrupole interaction could be observed (G1). An isomeric transition between the 59-sec and 12-hr states of $_{32}Ge^{77}$ has been observed recently by Mitchell and Smith (M36) who reported a (380±20) kev γ-ray from the 59-sec state which they interpreted as an E3 isomeric transition, favoring 7/2+ for the ground state. The 12-hr decay they find to be accompanied by a very complex γ-ray spectrum. Only the highest energy β-ray component is shown here.

II. The following logft values are given for the β^- transitions shown:

59 sec, Ge^{77m}, >4.72 (F4),
12 hr, Ge^{77}, 7.21 (K19),
40 hr, As^{77}, 5.75 (K19).

III. The decay of $_{35}Br^{77}$ shows a complex γ-spectrum and proceeds partially through $_{34}Se^{77m}$ (C5).

References:

$_{32}Ge^{77}$, ND p. 69, NDS2 p. 18; $_{34}Se^{77}$, ND p. 74, NDS2 p. 19.
(G1) S. Geschwind, H. Minden, C. H. Townes, Phys. Rev. **78**, 174 (1950).
(C5) R. Canada, W. H. Cuffey, A. E. Lessor, and A. C. G. Mitchell, Phys. Rev. **82**, 750 (1951); **83**, 955 (1951).
(M36) A. C. G. Mitchell and A. B. Smith, Phys. Rev. **85**, 153 (1952).
(K19) R. W. King, private communication.

A=79

I. Both the 3.9-min $_{34}Se^{79}$ and 55-sec $_{36}Kr^{79}$ isomeric transitions are identified on the basis of lifetimes as E3 transitions (G10).

II. The long-lived β^- transition from the $_{34}Se^{79}$ ground state (G5) had not been observed until recently. The half-life of the $_{34}Se^{79}$ ground state is 6.5×10^4 years and the β^- upper energy limit is ~0.150 Mev (P2).

III. The positron activity from the 34.5-hr $_{36}Kr^{79}$ level has a logft value of 5.3 (B12). Two γ-rays follow the β^+, ε decay, although their order has not yet been determined (B12). The spin of the ground state of Se^{79} has been measured and found to be 7/2 (H2), in agreement with the regular displacements of levels, which are discussed at the end of this article.

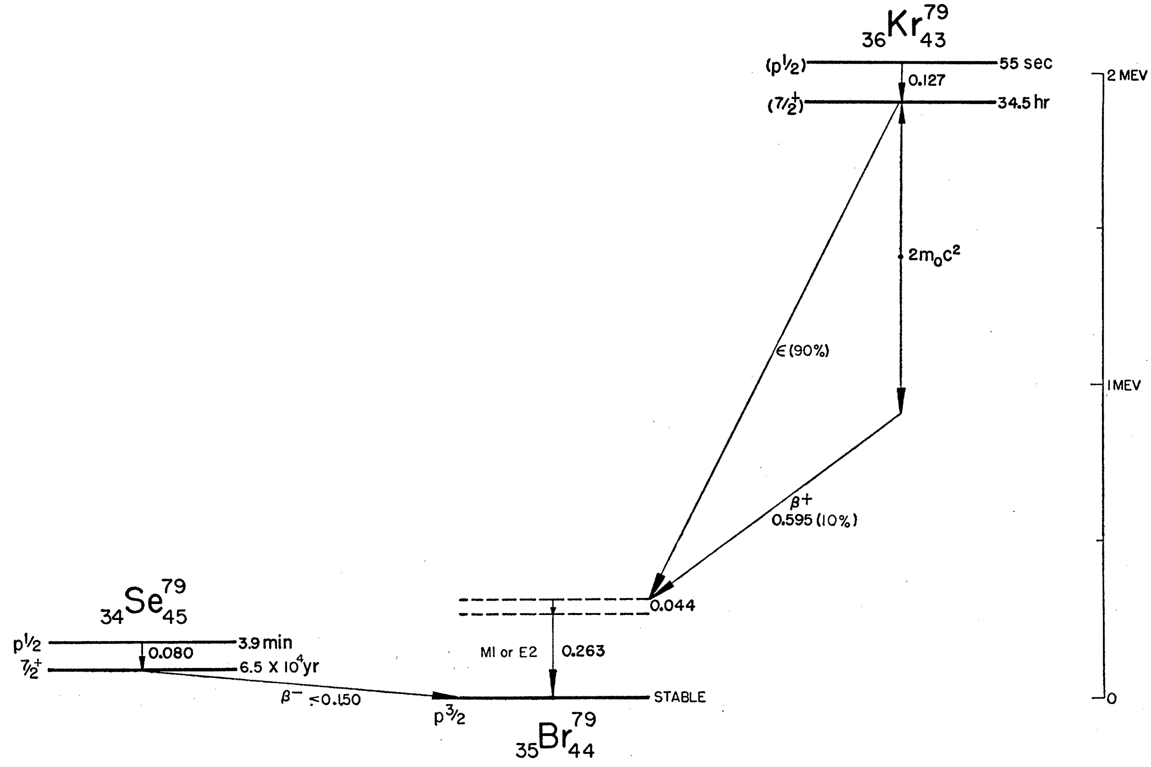

FIG. 11. $A=79$.

References:

$_{36}Kr^{79,81}$, ND pp. 81, 82; $_{34}Se^{79}$, NDS2 p. 20.
(F6) A. Flammersfeld, Z. Naturforsch. **5a**, 569 (1950).
(G5) L. E. Glendenin, National Nuclear Energy Series **9**, paper 61, page 596.
(W8) L. Winsberg, National Nuclear Energy Series **9**, paper 60, page 593.
(B12) I. Bergstrom, Phys. Rev. **82**, 112 (1951).
(H2) W. A. Hardy, G. Silvey, and C. H. Townes, Phys. Rev. **85**, 494 (1952).
(P2) G. W. Parker, National Nuclear Energy Series **9**, appendix C, page 2020.

A = 80

I. From lifetime and conversion coefficient, the 49-kev transition of 4.4-hr $_{35}Br^{80}$ is very probably M3 (B15) (R8) (L10).

II. From its conversion coefficient, the second transition of 0.37 is identified as E1 (L10) (R8).

III. The β^- spectrum of $_{35}Br^{80}$ has an allowed shape (L10) and $\log ft=5.56$. The β^+ spectrum has $\log ft=4.62$. On this basis the spin of the 18.5-min $_{35}Br^{80}$ is assigned a value 1+.

IV. Angular correlation between conversion electrons of the 49- and 37-kev transitions has been observed, indicating thus far that the spin of the intermediate state is different from zero (R10).

V. The spin of 5− for the 4.4-hr $_{35}Br^{80m}$ state may arise from the configurations $p_{3/2}$ proton-7/2+ neutron (S6).

References:

$_{35}Br^{80}$, ND p. 78, NDS p. 19.
(B15) A. Berthelot, Ann. phys. **19**, 219 (1944).
(R8) P. Rothwell and D. West, Proc. Phys. Soc. (London) **63A**, 539 (1950).
(L10) I. J. Lidofsky, P. A. Macklin, and C. S. Wu, Phys. Rev. **78**, 318A (1950).
(R10) L. I. Rusinov and E. I. Chutkin, Nuc. Sci. Abstracts **4**, No. 1827, 291 (1950).
(S6) J. M. C. Scott, Cavendish Laboratory, unpublished manuscript (1951).

A = 81

I. Both isomeric transitions: the 0.098 Mev of $_{34}Se^{81}$ and the 0.187 Mev of $_{36}Kr^{81}$ are characterized as E3 (G10).

II. The energy of the β^- decay of $_{34}Se^{81}$ is observed to be 1.38 (B13) and is probably an allowed transition since $\log ft=4.6$. The measured spin of Br^{81} is 3/2, and the 17-min $_{34}Se^{81}$ level assignment is therefore probably $p_{1/2}$.

III. The 4.7-hr $_{37}Rb^{81}$ has been found to feed the 13-sec isomer $_{36}Kr^{81}$ (K2). There are γ-rays following the Rb^{81} decay and the 0.2 e^- may be the same as the 0.187 I.T. of the Kr^{81} isomer (R4).

IV. The long life of the $_{36}Kr^{81}$ ground state may be

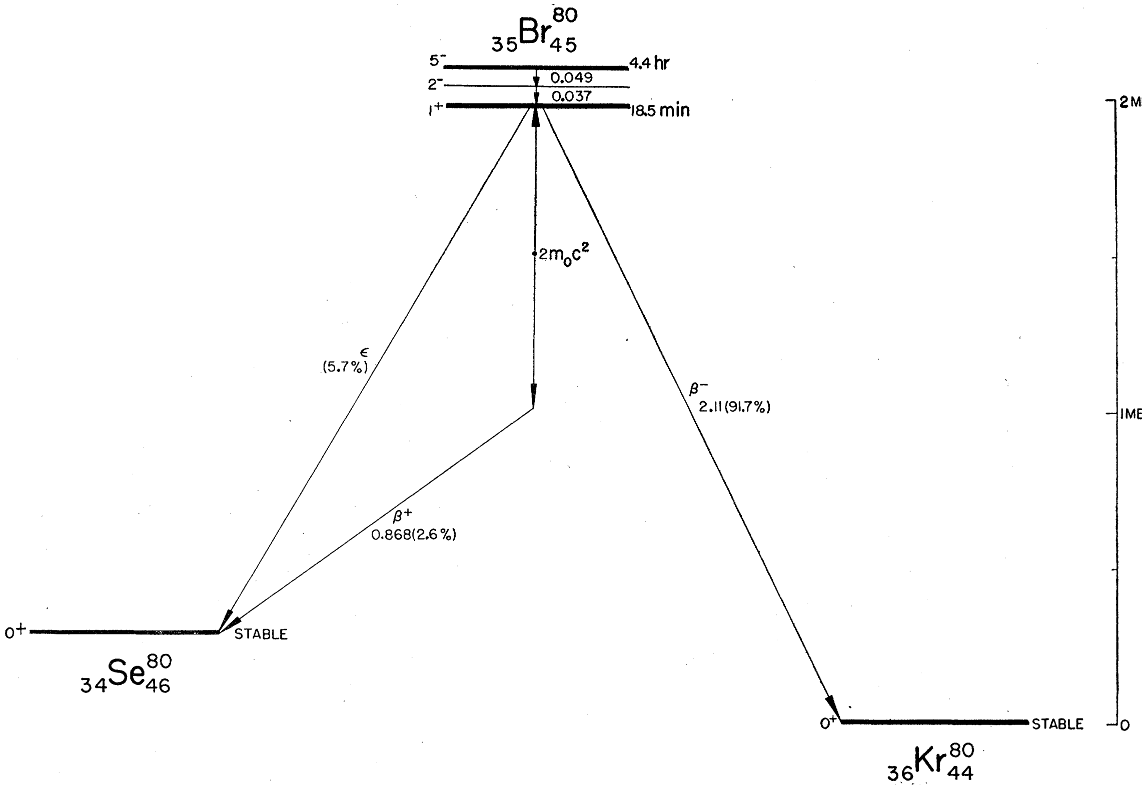

FIG. 12. $A=80$.

associated either with a forbidden transition ($\Delta I=2$, yes) ($7/2+\rightarrow p_{3/2}$) or a small energy difference.

References:

$_{34}Se^{81}$, ND p. 75, NDS p. 18, NDS2 p. 20; $_{36}Kr^{81}$, NDS p. 19, NDS2 p. 21; $_{37}Rb^{81}$, ND p. 85, NDS p. 20, NDS2 p. 22.

(B13) L. Bergstrom and S. Thulin, Phys. Rev. **76**, 1718 (1949).

(K2) D. G. Karraker *et al.*, University of California Radiation Laboratory, UCRL-46 (1950).

(R4) F. L. Reynolds, D. G. Karraker, and D. H. Templeton, Phys. Rev. **75**, 313 (1949).

A = 83

I. The 114-min isomeric level of $_{36}Kr^{83}$ and the intermediate 9-kev excited level have been assigned spins $p_{1/2}$ and $7/2+$ (B10). The 32-kev and 9-kev transitions have been classified as E3 and M1, respectively (G10). The measured ground state spin is 9/2. No cross-over transition from the $p_{1/2}$ level has yet been observed. It should be negligibly weak from semi-empirical lifetime formulas.

II. The $\log ft$ value of the 1.0 β^- transition from $_{35}Br^{83}$ is 5.13, and the transition is identified as allowed.

III. The data concerning the decay of the 67-sec and 25-min $_{34}Se^{83}$ isomers are insufficient to describe a level system for $_{34}Se^{83}$.

References:

$_{34}Se^{83}$, ND p. 76; $_{36}Kr^{83}$, ND p. 82.

(B10) I. Bergstrom, Phys. Rev. **81**, 638 (1951).

A = 84

$_{37}Rb_{47}$ $T_1=34$ days 1.55 β^+; ϵ; 0.85 γ; e^-,
$T_2=23$ min 0.32 e^-; ϵ (F7).

References:

$_{37}Rb_{47}$, ND p. 86, NDS p. 20, NDS2 p. 22.

(F7) A. Flammersfeld, Z. Naturforsch. **5a**, 687 (1950).

A = 85

I. The 300-kev I.T. from 4.4-hr $_{36}Kr^{85}$ has been classified as M4 (G10) (B14). The 513-kev transition from 9×10^{-7} sec $_{37}Rb^{85}$ has a lifetime and conversion coefficient consistent with an M2 transition (S32). The 70-min $_{38}Sr^{85m}$ activity decays by electron capture (14 percent) and by two γ-transitions: a 7.5-kev E3 transition ($\sim$84.7 percent) and a 232.5-kev M4 transition ($\sim$1.3 percent) (S32).

II. The measured spin of $_{37}Rb^{85}$ is 5/2, and the shell theory assignment is $f_{5/2}$. The 150-kev γ-transition in $_{37}Rb^{85}$ has been identified from conversion data as probably a mixture of an M1 and E2 transition (B14). The shell structure assignment for the 150-kev excited level is probably $p_{3/2}$.

III. The $\log ft$ values of the 0.695 and 0.15 β^- transitions from 9.4-yr $_{36}Kr^{85}$ are 9.2 and 9.15, respectively. The shape of the 0.695 β^- spectrum is consistent with the type $\Delta I=2$, yes, and $\log f_1t=8.3$ (Z2). On this basis, the assignment for the 9.4-yr $_{36}Kr^{85}$ state is $g_{9/2}$. The

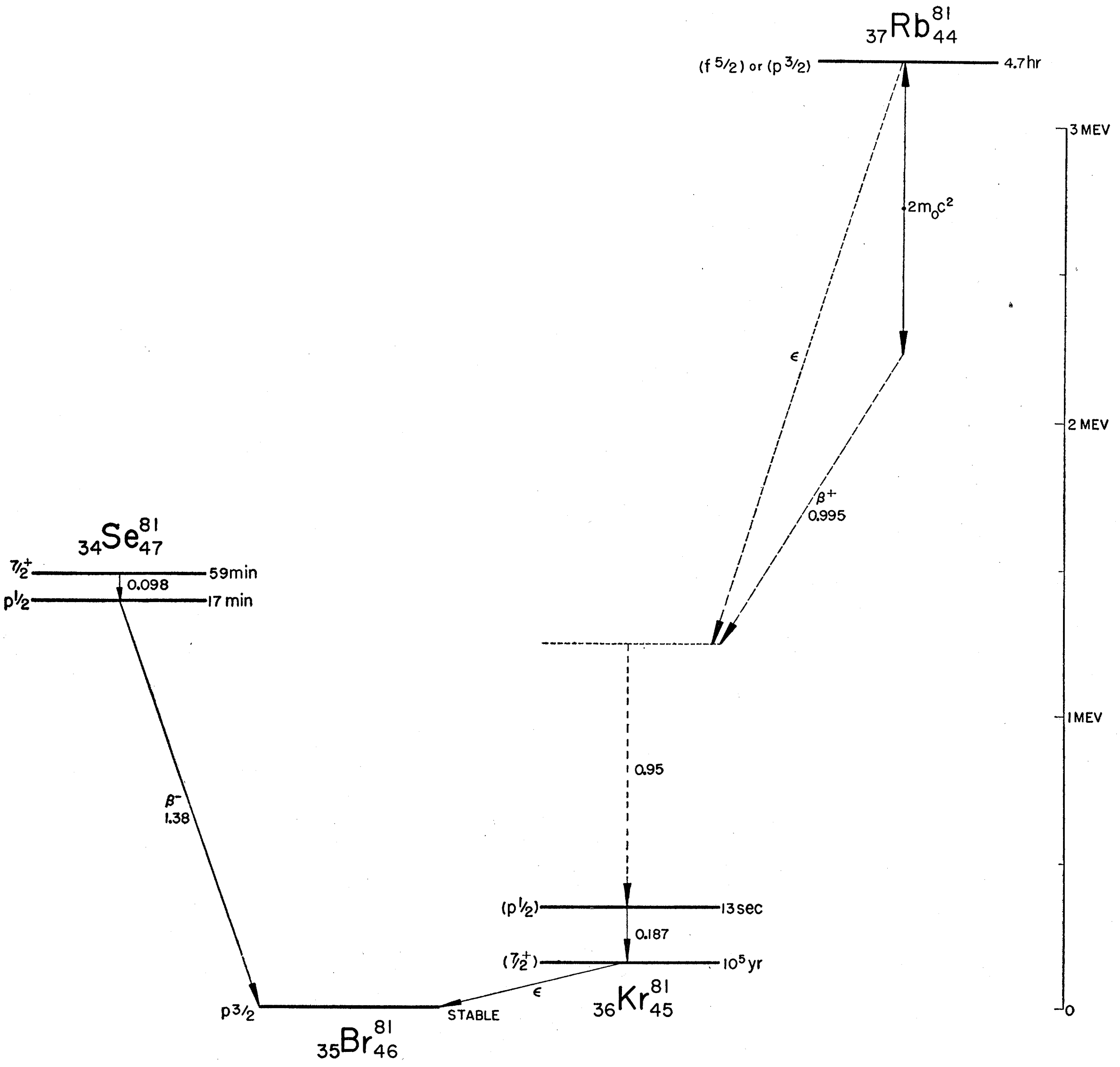

FIG. 13. $A=81$.

high log*ft* of the 0.15 β^- transition between states of equal spin has been interpreted as due to a re-arrangement of nucleons in the even-even core of $_{37}$Rb^{85m} (S30).

IV. The log*ft* value of the 0.817 β^- transition from 4.4-hr $_{36}$Kr^{85} is 5.0. An assignment of $p_{1/2}$ for the 4.4-hr $_{36}$Kr^{85} isomeric state is therefore consistent both with the M4 isomeric transition and the allowed β-transition from this state.

V. From the similarity of the ε-capture transitions from $_{38}$Sr^{85} and the β^- transitions of $_{36}$Kr^{85} we may assign the following character to the $_{38}$Sr^{85} level: ground state, $g_{9/2}$; 225-kev excited state, 7/2+; and 232.5-kev excited state, $p_{1/2}$ (S30).

VI. The recently measured improved energies and branching ratios of $_{36}$Kr^{85m} reported by Bergstrom (B40) are shown in the drawing.

References:

$_{36}$Kr^{85}, ND p. 83, NDS p. 19, NDS2 p. 21; $_{37}$Rb^{85}, ND p. 86; $_{38}$Sr^{85}, ND p. 89, NDS p. 20.
(B14) I. Bergstrom and S. Thulin, Phys. Rev. **79**, 537 (1950).
(S32) A. W. Sunyar, J. W. Mihelich, G. Scharff-Goldhaber, M. Deutsch, and M. Goldhaber, Phys. Rev. **85**, 734A (1952).
(Z2) H. Zeldes, B. H. Ketelle, and A. R. Brosi, Phys. Rev. **79**, 901 (1950).
(S30) A. W. Sunyar, J. W. Mihelich, G. Scharff-Goldhaber, M. Goldhaber, N. S. Wall, and M. Deutsch, Phys. Rev. **86**, 1023 (1952).
(E6) W. S. Emmerich and J. D. Kurbatov, Phys. Rev. **85**, 149 (1952).
(B40) I. Bergstrom, M. Siegbahn Commemorative Volume, Uppsala (1951).

A = 86

$_{37}$Rb$_{49}$ $T_1 = 19.5$ day 1.82, 0.72 β^-; 1.08 γ,
$T_2 = 1.06$ min ε or I.T., 0.78 γ, x-rays (F8).

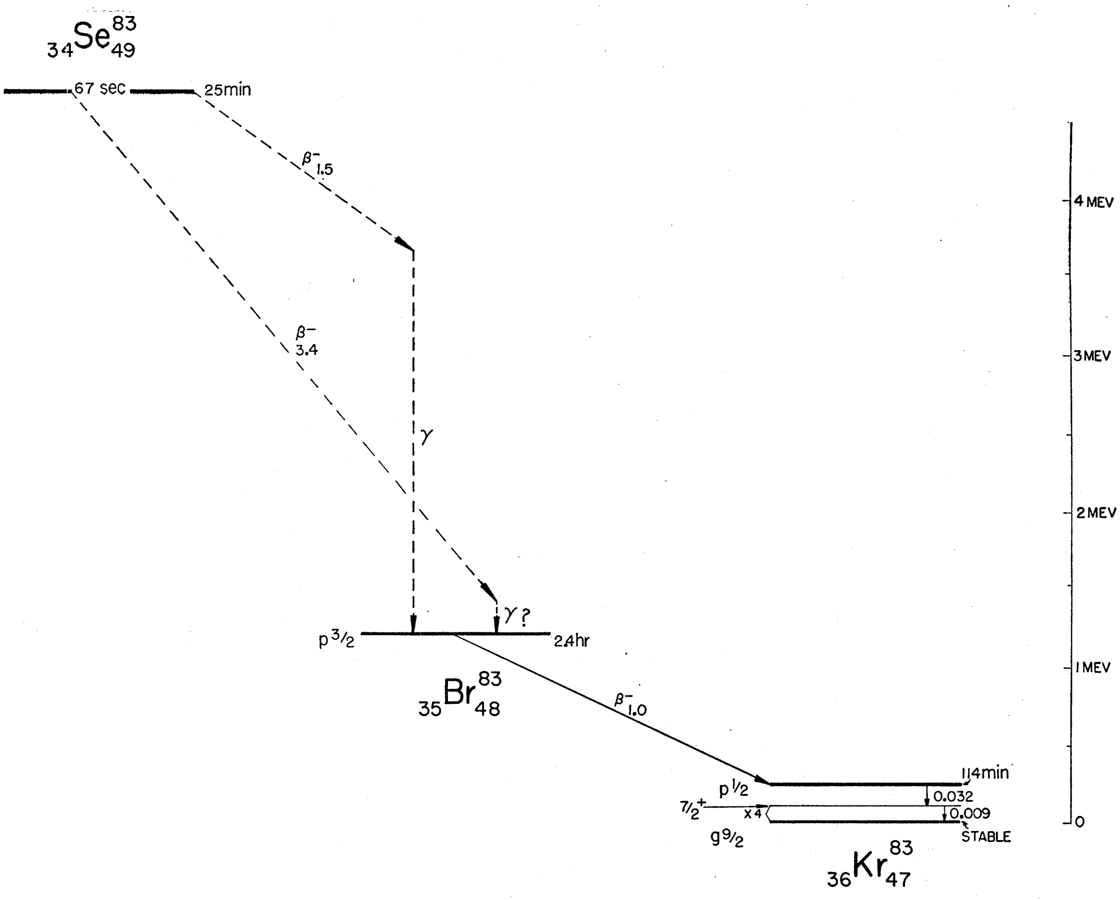

FIG. 14. $A=83$.

A spin 2 has been measured for the 19.5-day state of $_{37}Rb^{86}$ (B5). The odd nucleon configurations are probably proton $f_{5/2}$, neutron $g_{9/2}$, and the parity is negative (S6).

References:

$_{37}Rb^{86}$, ND p. 86, NDS p. 20, NDS2 p. 22.
(F8) A. Flammersfeld, Z. Naturforsch. **6a**, 559 (1951).
(B5) E. H. Bellamy, Nature **168**, 556 (1951).
(S6) J. M. C. Scott, Cavendish Laboratory, unpublished manuscript (1951).

$A=87$

I. Both the 0.384 isomeric transition of $_{38}Y^{87}$ and the 0.390 isomeric transition of $_{38}Sr^{87}$ have been identified as M4 (H17) (M3) (G10). The measured spin of $_{38}Sr^{87}$ is 9/2, and the 2.8-hr $_{38}Sr^{87}$ state is therefore assigned a spin 1/2.

II. The log*ft* value for the 80-hr $_{39}Y^{87}$ 0.70 β^+ transition is 7.68, and for the ϵ-capture to the 0.875 excited state of $_{38}Sr^{87}$ it is 5.56. Both transitions are interpreted as allowed. The 80-hr state of $_{39}Y^{87}$ is therefore identified as $p_{1/2}$, and the 14-hr $_{39}Y^{87}$ state is identified as $g_{9/2}$. From the absence of the $g_{9/2}-g_{9/2}$ transition from $_{39}Y^{87m}$ to $_{38}Sr^{87}$, the log*ft* value for the β^+, ϵ transition is >8.45. This is an unusually large *ft* value for an apparently allowed transition (note similarity with case of Kr^{85}).

III. Curran *et al.* (C20) recently studied the shape of the $_{37}Rb^{87}$ β^- spectrum. They find an end point of 275 kev and $\log ft=17.6$, compatible with $\Delta I=3$, yes.

References:

$_{37}Rb^{87}$, ND p. 86, NDS p. 20; $_{38}Sr^{87}$, ND p. 90; $_{39}Y^{87}$, ND p. 92, NDS2 p. 23; $_{40}Zr^{87}$, ND p. 96, NDS p. 21.
(H17) E. K. Hyde and G. D. O'Kelley, Phys. Rev. **82**, 944 (1951).
(M3) L. G. Mann and P. Axel, Phys. Rev. **84**, 221 (1951).
(C20) S. C. Curran, D. Dixon, and H. W. Wilson, Phys. Rev. **84**, 151 (1951).

$A=89$

I. The transitions from both 4.4-min $_{40}Zr^{89}$ and 14-sec $_{39}Y^{89}$ isomeric states are described as M4 (G10).

II. The measured ground-state spin of $_{39}Y^{89}$ is 1/2 (K14), and the 14-sec isomeric state of $_{39}Y^{89}$ is therefore identified as $g_{9/2}$ (G6) (S34).

III. The log*ft* value for the 80-hr $(\beta^+ + \epsilon)$ transition is 6.16, with $f_k/f_+=3$; and for the 4.4-min Zr^{89} level, $\log(f_+ + f_k)t=6.8$. These transitions are identified as allowed and are consistent with the spins and parities shown.

IV. The log*ft* for the β^- transition of $_{38}Sr^{89}$ is 8.59.

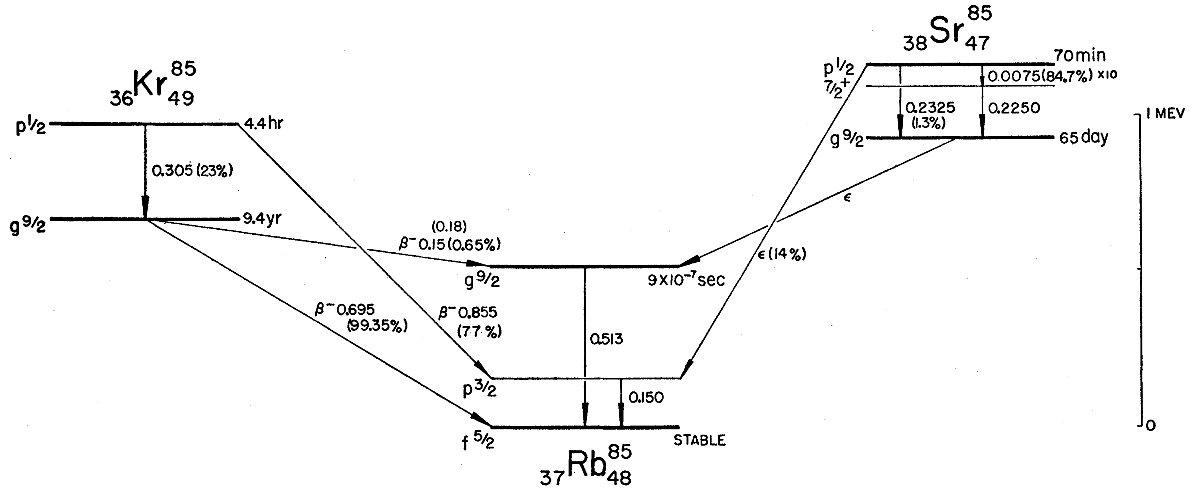

FIG. 15. $A=85$.

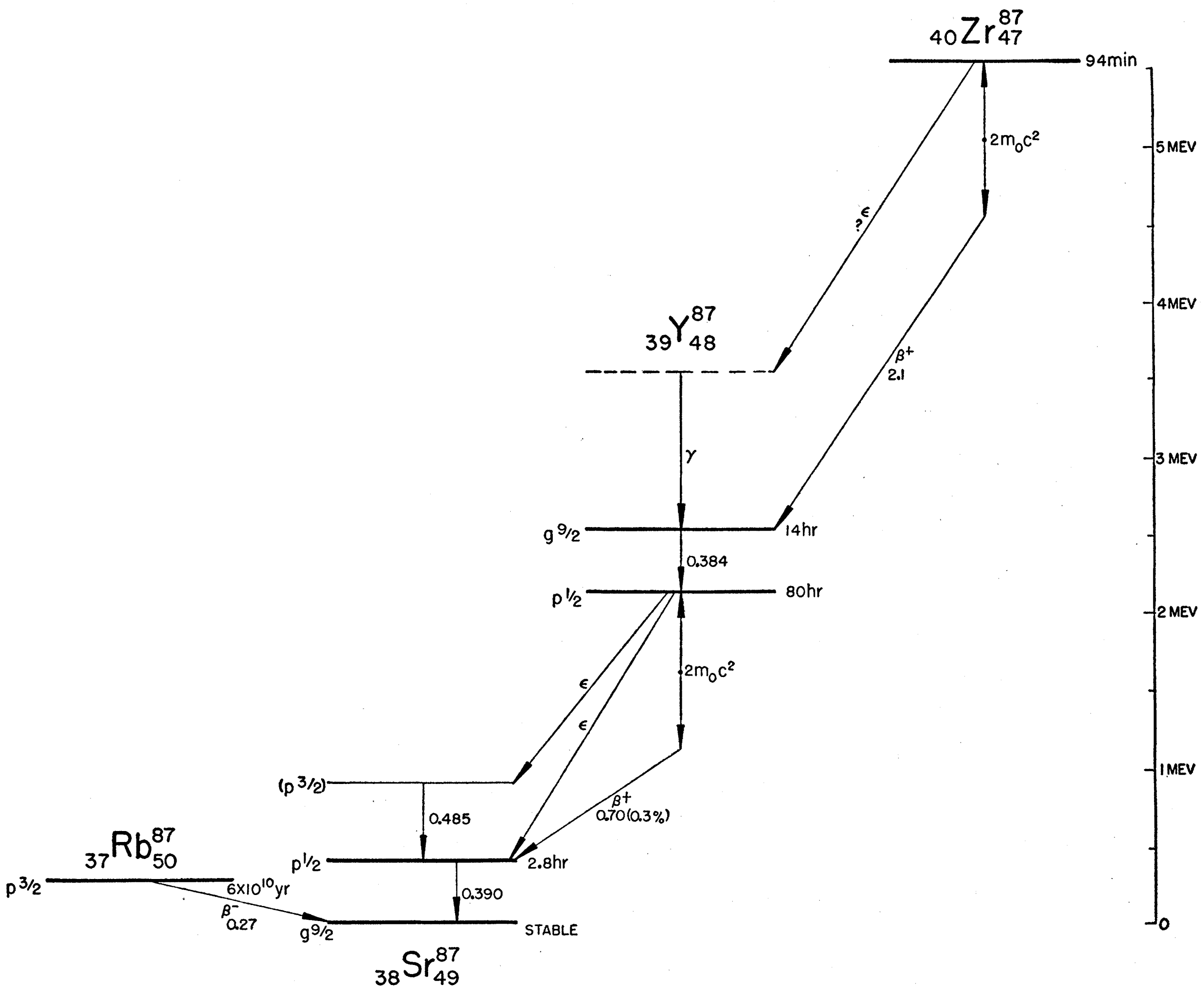

FIG. 16. $A=87$.

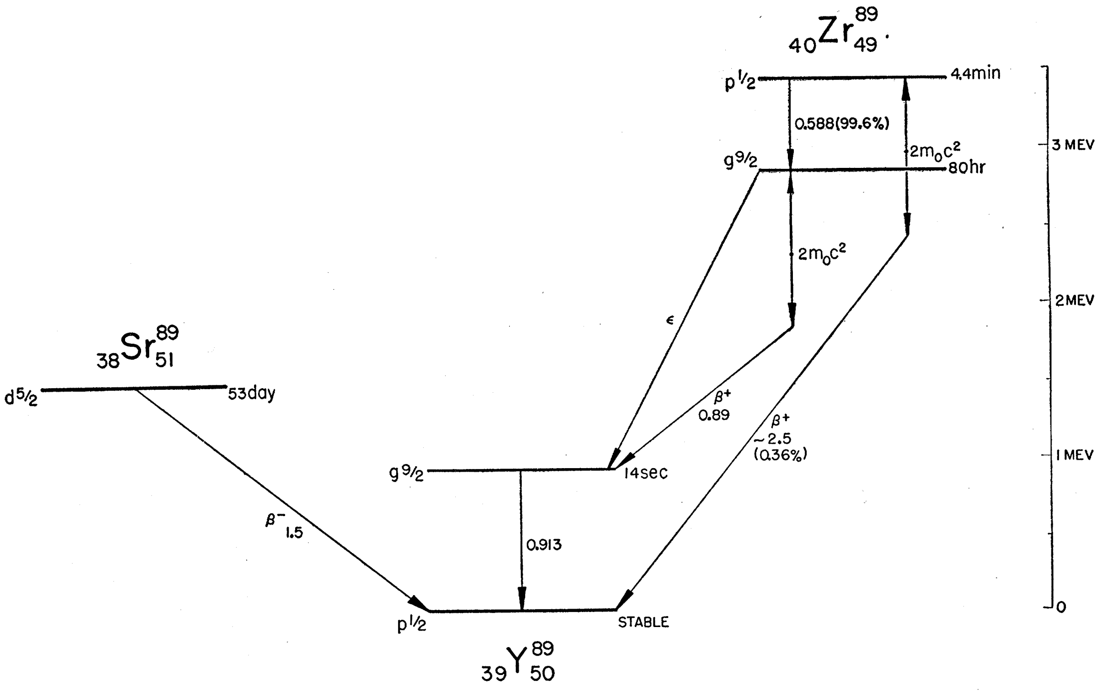

FIG. 17. $A=89$.

From the shape of the β-spectrum it has been identified as a $\Delta I=2$, yes, type ($\log f_1t=8.3$). The spin of 53-day Sr^{89} is therefore characterized as $d_{5/2}$ (D2).

References:

$_{40}Zr^{89}$, ND p. 96, NDS p. 21.
(D2) J. P. Davidson, Jr., Phys. Rev. **82**, 48 (1951).
(G6) M. Goldhaber, E. der Mateosian, G. Scharff-Goldhaber, A. W. Sunyar, M. Deutsch, and N. S. Wall, Phys. Rev. **83**, 661 (1951).
(K14) H. Kuhn and G. K. Woodgate, Proc. Phys. Soc. (London) **A63**, 830 (1950).
(S34) F. J. Shore, W. L. Bendel, and R. A. Becker, Phys. Rev. **83**, 688 (1951).

A=91

I. The isomeric transitions from 51-min $_{39}Y^{91}$ and 60-day $_{41}Nb^{91}$ levels have been identified as M4 transitions (G10). No isomeric transition between the 75-sec and 15.5-min states of $_{42}Mo^{91}$ has yet been observed.

II. The β^- spectrum from 57-day $_{39}Y^{91}$ has been identified as 1st forbidden $\Delta I=2$, yes (D2), and as the measured ground state of $_{40}Zr^{91}$ is 5/2, the shell model gives for the ground state of $_{39}Y^{91}$ an assignment of $p_{1/2}$. The 51-min isomeric state of $_{39}Y^{91}$ is therefore $g_{9/2}$.

III. Assuming a value of $W_0\sim1$ for the ε-capture decay of ~8-yr $_{41}Nb^{91}$, we obtain $\log ft=8.4$. It is possible that the ground state of $_{41}Nb^{91}$ has therefore a spin $p_{1/2}$, since a $g_{9/2}$ assignment would probably lead to a more forbidden decay. The regularities in the behavior of level displacements discussed at the end of this review also speak in favor of such an assignment.

IV. The 14-min and 100-sec $_{37}Rb^{91}$ isomers decay by complex β^- and γ-emission to $_{38}Sr^{91}$. The maximum β^- energies associated with these activities are 3.0 and 4.6 Mev, respectively (K11).

V. The 3.2 β^- transition from $_{38}Sr^{91}$ to the $p_{1/2}$ state of $_{39}Y^{91}$ has a $\log f_1t$ value ~8.5. This would be consistent with a probable $d_{5/2}$ assignment for the 9.7-hr state of $_{38}Sr^{91}$.

References:

$_{39}Y^{91}$, ND p. 94, NDS p. 20; $_{40}Nb^{91}$, ND p. 99; $_{42}Mo^{91}$, ND p. 102.
(D2) J. P. Davidson, Jr., Phys. Rev. **82**, 48 (1951).
(K11) O. Kofoed-Hansen and K. O. Nielson, Phys. Rev. **82**, 96 (1951).

A=93(±1)

I. The mass number of the 6.75-hr $_{42}Mo$ isomer is difficult to assign. The most significant feature is the absence of this activity in the reactions $Mo^{92}-n-\gamma$, $Mo^{92}-d-p$ (K15). This throws considerable doubt on the assignment to mass number 93.

II. Another surprising feature of the 6.75-hr $_{42}Mo$ isomer is its high excitation energy, about 2.5 Mev. If the ground state is either $d_{5/2}$ or $g_{7/2}$, it would be necessary to attribute a very high spin (~17/2 or 15/2) to the 6.75-hr state. The 256-kev transition, as shown from lifetime and K/L ratio considerations, must be E4 (D13).

III. A possible alternative is to assign the 6.75-hr $_{42}Mo$ isomer to $_{42}Mo^{92 (\text{or } 94)}$, though the other reactions reported (e.g., $Nb^{93}-p-n$, $Nb^{93}-d-2n$, $Mo^{94}-n-2n$, $Zr^{91}-\alpha-2n$) (K15) are then difficult to understand. However, the high spin of the 6.7-hr state (7 or 8) might then be attributed to the breaking of the $g_{9/2}$ shell of neutrons and the promotion of one neutron into

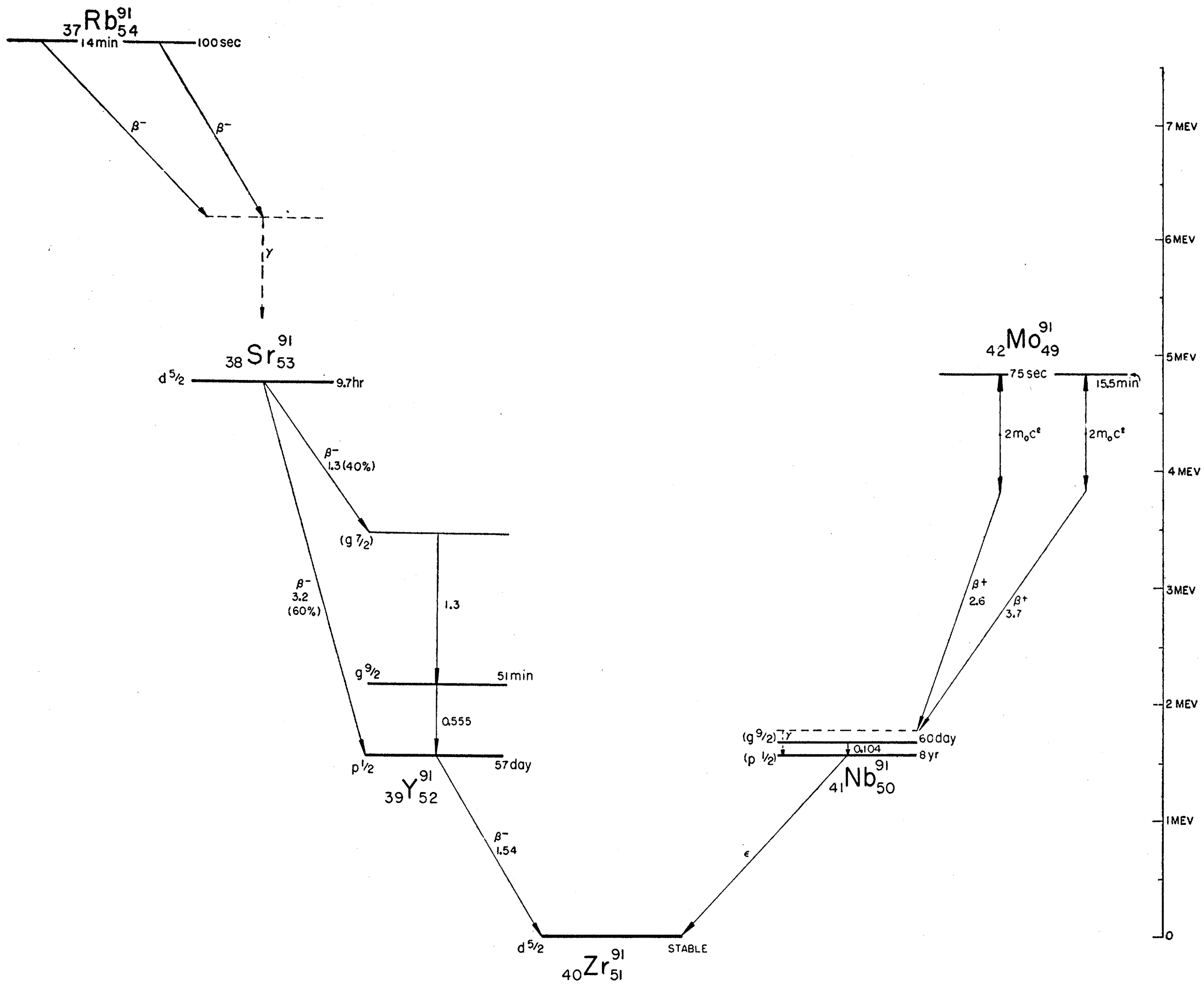

Fig. 18. $A=91$.

a $g_{7/2}$ orbit. The spin change of 2 between the first and second excited states is supported by angular correlation work (S24). A mass spectrographic assignment of this isomer would be very desirable.

IV. The existence of isomers of Tc^{92} (44-min and 4.5-min) is probable. A γ-ray of 1.5 Mev following ϵ-capture may be identical with the one found in the decay of 6.75-hr Mo.§

References:

${}_{42}Mo^{93}$, ND p. 103; ${}_{43}Tc^{92}$, ND p. 106, NDS1 p. 22.
(K15) D. N. Kundu, J. L. Hult, and M. L. Pool, Phys. Rev. **77**, 71 (1950).
(S24) D. T. Stevenson and M. Deutsch, Phys. Rev. **83**, 1202 (1951).
(D13) E. der Mateosian, D. Alburger, G. Friedlander, M. Goldhaber, J. W. Mihelich, G. Scharff-Goldhaber, and A. W. Sunyar, Brookhaven National Laboratory Quarterly Report No. 7 (1950).
(R9) L. Ruby and J. R. Richardson, Phys. Rev. **83**, 698 (1951).

A = 94

I. The 41.5-kev ${}_{41}Nb^{94m}$ transition has been identified from lifetime and K/L ratio considerations as E3 (G10).

II. The 1.3 β^- of 6.6-min ${}_{41}Nb^{94}$ has been found to lead to the 0.87 excited state of ${}_{42}Mo^{94}$ (D7). The logft of the 1.3 β^- transition from ${}_{41}Nb^{94m}$ for which the intensity is only roughly known as $\sim$0.1 percent is $\sim$7.3 and might characterize the transition as $\Delta I=1$ or 2, yes (log$f_1t\sim$6.9). In this case, since the final level has been identified as 2+ (M22), the initial 6.6-min Nb^{94} level might be between 0− and 4−. Since the life of the ground state is very long and the energy difference between initial and final states of the possible beta-transitions is considerable, the spin of the ground state of ${}_{41}Nb^{94}$ is probably high. According to odd-odd coupling theory, a 4− state could arise from a $p_{1/2}$, $g_{7/2}$ configuration and a 7+ state from a $g_{9/2}$, $d_{5/2}$ configuration.

III. No transition from ${}_{41}Nb^{94m}$ to stable ${}_{40}Zr^{94}$ by ϵ-capture is known.

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§ *Note added in proof.*—According to excitation curves with deuterons on stacked Mo foils, the 44-min isomeric activity is not Tc^{92}, but probably Tc^{93} (H. A. Medicus, private communication). The 44-min activity is associated with a 390-kev M4 transition. (H. A. Medicus and H. T. Easterday, University of California Radiation Laboratory, UCRL-1518 (1952).)

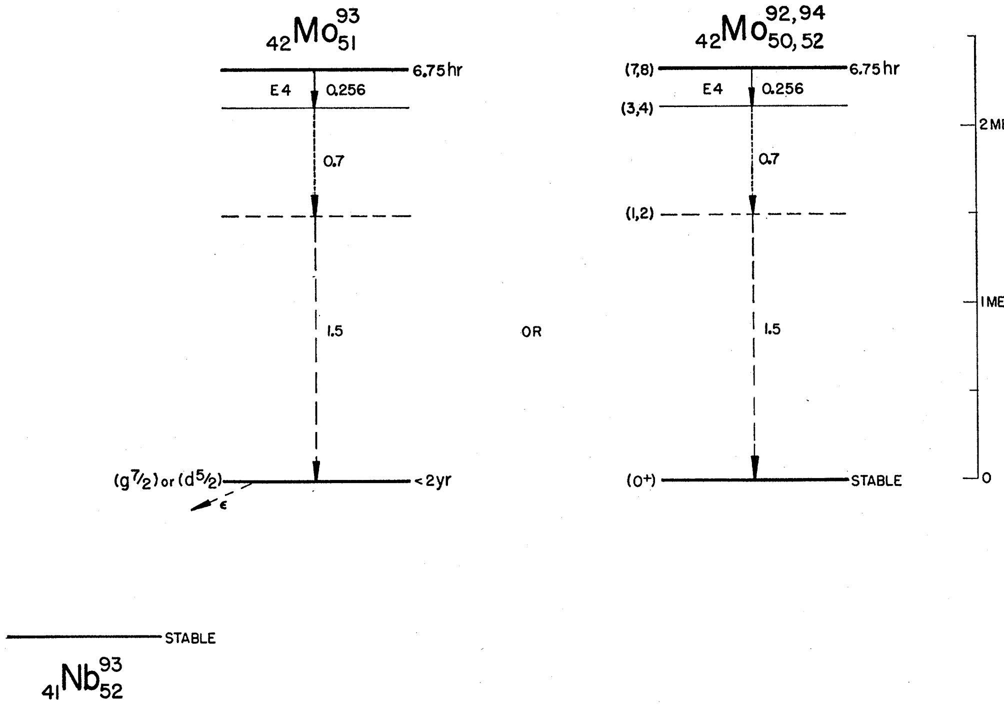

FIG. 19. $A=93$ (±1).

References:

$_{41}$Nb^{94}, ND p. 100, NDS p. 21; $_{43}$Tc^{94}, NDS p. 22.
(M22) H. A. Medicus, P. Preiswerk, and P. Scherrer, Helv. Phys. Acta **23**, 299 (1950).
(D7) E. der Mateosian, Phys. Rev. **83**, 223A (1951).

$A=95$

I. Both the 216- and 39-kev transitions of $_{41}$Nb^{95m} and $_{43}$Tc^{95m}, respectively, have been identified as M4 and take place from $p_{1/2}$ to $g_{9/2}$ levels (G10).

II. The isomeric level assignments of $_{41}$Nb^{95} and $_{43}$Tc^{95} are reasonably consistent with the beta- and γ-rays shown leading to $_{42}$Mo^{95} (M21). However, it seems more probable that the 0.4 β^+ transition from 62-day $_{43}$Tc^{95} goes to an excited state of $_{42}$Mo^{95} instead of to the ground state. In the latter case the loff_1t value $\sim$6.5 is too small for the $\Delta I=2$, yes, type of transition involved. If the transition were instead to the 200-kev excited state, the transition would be first forbidden and would be consistent with the logft value $\sim$7.5.

III. Logft values for the 0.4 and 0.887 β^- transitions of $_{40}$Zr^{95} are 6.6 and 9.9 (log$f_1t\sim$8.9), respectively (F4). The spin $d_{5/2}$ seems a possible assignment for the 65-day level of $_{40}$Zr^{95}, in agreement with shell theory.

References:

$_{40}$Zr^{95}, ND p. 97; $_{41}$Nb^{95}, ND p. 100, NDS2 p. 24; $_{43}$Tc^{95}, ND p. 107, NDS p. 21, NDS2 p. 26.
(M21) H. A. Medicus, P. Preiswerk, and P. Scherrer, Helv. Phys. Acta **23**, 299 (1950); H. A. Medicus and P. Preiswerk, Phys. Rev. **80**, 1101 (1950); P. Preiswerk and P. Stähelin, Helv. Phys. Acta **24**, 300 (1952).
(L7) J. S. Levinger, National Nuclear Energy Series **9**, paper 94, page 757.
(N1) V. A. Nedzel, National Nuclear Energy Series **9**, paper 87, page 719.

$A=96$

I. The 51.5-min $_{43}$Tc isomer has been assigned to $_{43}$Tc^{96} (M19), and from lifetime and K/L ratio considerations the 34.4-kev transition is M3. The above assignments of spins and parity are made mainly on the basis of conversion coefficients (M19).||

References:

$_{43}$Tc^{96}, ND p. 107, NDS p. 22, NDS2 p. 26.
(M19) H. A. Medicus and H. T. Easterday, Phys. Rev. **85**, 735A (1952); private communication of unpublished work by P. Stähelin and P. Preiswerk.

$A=97$

I. The 0.747-Mev transition of 60-sec $_{41}$Nb^{97} and the 0.096-Mev transition of 90-day $_{93}$Tc^{97} have been identified as M4 transitions (G10), and they occur between $p_{1/2}$ and $g_{9/2}$ in agreement with shell theory.

II. The level assignment of stable $_{42}$Mo^{97} is probably $d_{5/2}$ [5/2 or 7/2 according to (A5)]. From the conversion coefficient for the 0.665 γ-transition in $_{42}$Mo^{97}, this transition is probably E2 or M1. On this basis, the

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|| *Note added in proof.*—Revised spin assignments for the Tc^{96} isomeric levels have been given recently by H. A. Medicus and H. T. Easterday (UCRL-1518 (1952)). For the 51.5-min and 4.35-day levels 4+ and 7+ assignments, respectively, are given. For the two upper states of Mo^{96}, 6+ assignments are made, and a 4+ assignment is made for the 1.61-Mev excited state.

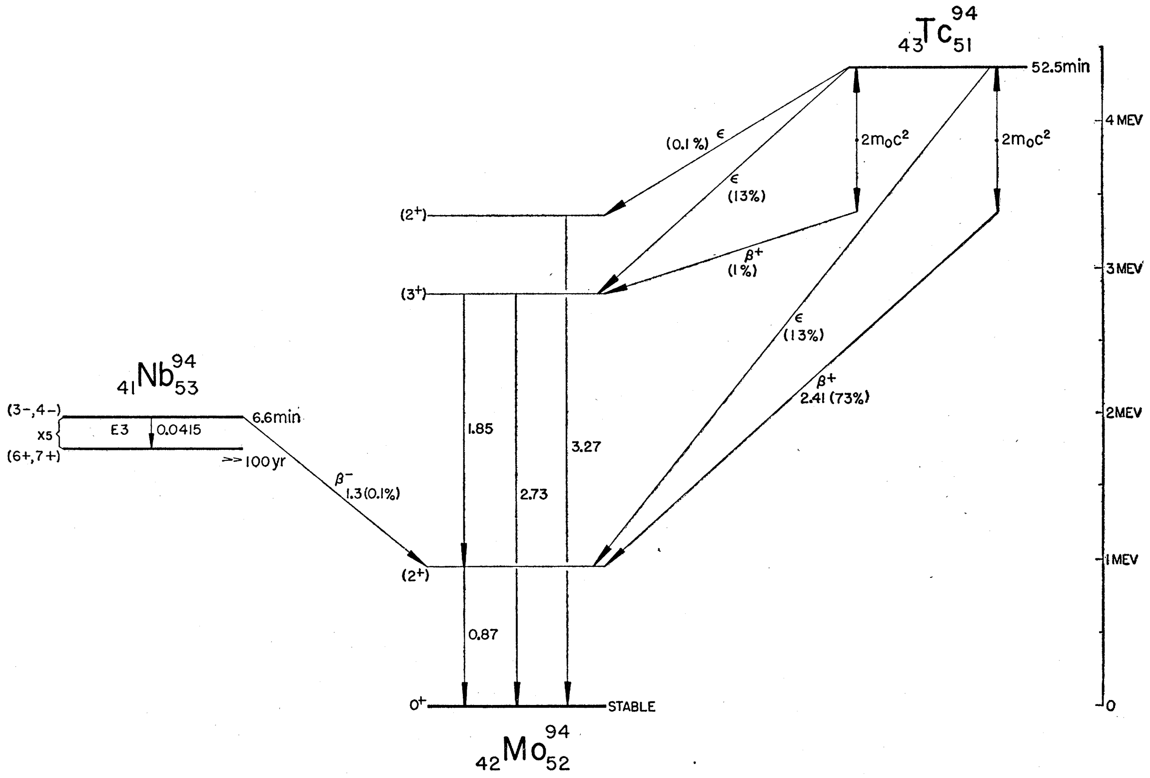

FIG. 20. $A=94$.

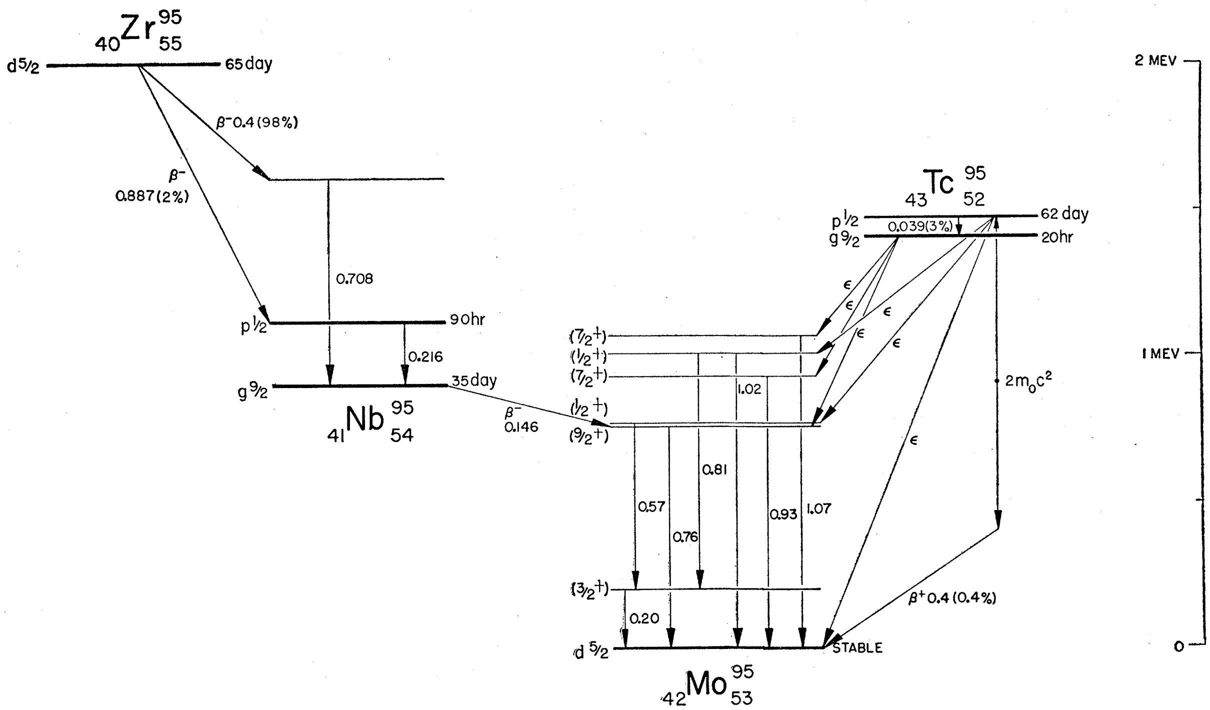

FIG. 21. $A=95$.

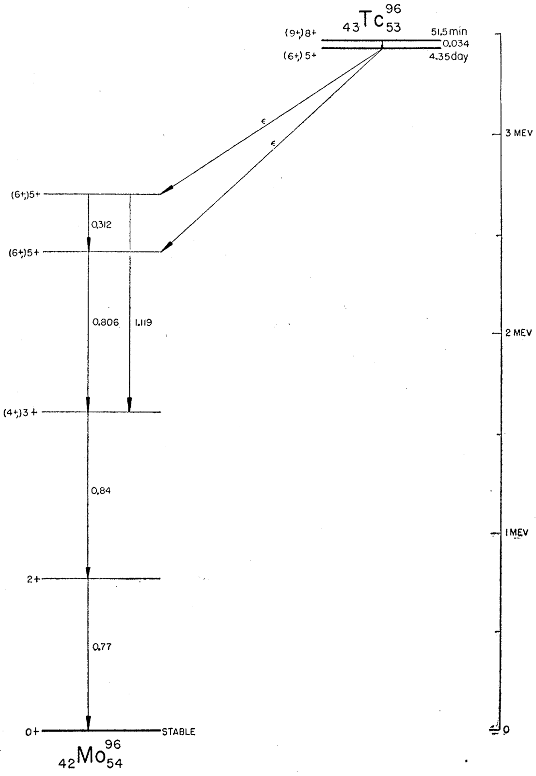

FIG. 22. $A=96$.

spin of the 0.665 excited level will therefore be any one of the following: 1/2+, 9/2+, 3/2+, or 7/2+.

III. The log*ft* value of the 1.267 beta-transition from 75-min $_{41}Nb^{97}$ is 5.42 (B34), and it is therefore probably an allowed transition. The log*ft* value of the 1.91 beta-transition from 17-hr $_{41}Nb^{97}$, on the other hand, is 7.15 (B34) and is probably 1st forbidden. The 17-hr ground state of $_{40}Zr^{97}$ should be expected to have a spin of $d_{5/2}$ or $g_{7/2}$ from shell theory, but this would not be compatible with the shape and *ft* value found for the β-spectrum. The 60-sec and 75-min levels of $_{41}Nb^{97}$ have been assigned as $p_{1/2}$ and $g_{9/2}$, respectively; the 0.665 excited level of $_{42}Mo^{97}$ is therefore probably $g_{7/2}$.

References:

$_{40}Zr^{97}$, $_{41}Nb^{97}$, $_{43}Tc^{97}$, NDS p. 22.
(B34) W. H. Burgus, J. D. Knight, and R. J. Prestwood, Phys. Rev. **79**, 104 (1950).
(A5) O. H. Arroe, Phys. Rev. **79**, 212A (1950).

A = 98

$_{43}Tc_{55}$ $T_1=2.7$ day, $\beta^-=.75$, $\gamma=1.0$ (G4), $T_2=41$ min, ϵ, γ (B21).

References:

ND p. 108.
(G4) L. E. Glendenin, National Nuclear Energy Series **9**, paper 329, page 1936.
(B21) G. E. Boyd and Q. V. Larson, private communication to K. Way.

A = 99

I. The 6-hr isomeric state of $_{43}Tc^{99}$ decays by two branching transitions (M20) (M30). These are identified as M4 (142-kev) and E3 (2-kev), and the isomeric, intermediate, and ground states are characterized as $p_{1/2}$, 7/2+, and $g_{9/2}$, respectively (G10).

II. Log*ft* equals 12.74 for the $0.29\beta^-$ transition from the ground state of $_{43}Tc^{99}$ (F4). As no γ-ray has been observed to accompany this beta-ray (K9), this indicates a value $d_{5/2}$ for the spin of $_{44}Ru^{99}$ (W10). The log*ft* values for the 1.23- and 0.445-Mev β-transitions from Mo^{99} are 7.2 and 6.2, respectively (F4).

III. The β- and γ-spectra of $_{42}Mo^{99}$ are complex (B32). Since no transition to the $g_{9/2}$ level of $_{43}Tc^{99}$ is observed, this may indicate a low value for the spin of the 68-hr $_{42}Mo^{99}$ level. (Owing to the close proximity of the $p_{1/2}$ and 7/2+ levels of $_{43}Tc^{99}$, the γ-transition indicated in the figure as going to the $p_{1/2}$ level are in doubt. It could be that the 40-kev γ-rays lead instead to the 7/2+ level.)

IV. The lifetime of the 6-hr state has been shown to depend on the chemical state of Tc (B1).

References:

$_{42}Mo^{99}$, ND p. 104, NDS2 p. 25; $_{43}Tc^{99}$, ND p. 108, NDS p. 21, NDS2 p. 26.
(M30) J. W. Mihelich, M. Goldhaber, and E. Wilson, Phys. Rev. **82**, 972 (1951).
(K9) B. H. Ketelle and J. W. Ruch, Phys. Rev. **77**, 565 (1950).
(B32) M. E. Bunker and R. Canada, Phys. Rev. **80**, 961 (1950).
(M20) H. A. Medicus, D. Maeder, and H. Schneider, Helv. Phys. Acta **24**, 72 (1951).
(W10) C. S. Wu and L. Feldman, Phys. Rev. **82**, 332 (1951).
(B1) K. T. Bainbridge, M. Goldhaber, and E. Wilson, Phys. Rev. **84**, 1260 (1951).

A = 103

I. The 40-kev transition from 57-min $_{45}Rh^{103}$ has been described as E3 on the basis of lifetime and K/L ratio considerations (G10).

II. The measured spin and magnetic moment of stable $_{45}Rh^{103}$ speak for a $p_{1/2}$ ground state (K13). The 57-min isomeric state of $_{45}Rh^{103}$ is therefore given a 7/2+ assignment.

III. The log*ft* values for the 43-day $_{44}Ru^{103}$ beta-disintegrations are 5.6 ($0.222\ \beta^-$) and 8.25 ($0.0684\ \beta^-$). It is energetically possible that the 0.494 γ-transition goes to the ground state of $_{45}Rh^{103}$. This γ-ray has been tentatively identified as either E2 or M1 (M23) (S1).

References:

$_{44}Ru^{103}$, ND p. 111, NDS p. 23, NDS2 p. 26; $_{45}Rh^{103}$, ND p. 114, NDS p. 23, NDS2 p. 27; $_{46}Pd^{103}$, ND p. 116.
(K13) H. Kuhn and G. K. Woodgate, Nature **166**, 906 (1950); Proc. Phys. Soc. (London) **A64**, 1090 (1951).
(S1) A. J. Saur, P. Axel, L. G. Mann, and J. Ovadia, Phys. Rev. **79**, 237A (1950).
(M23) J. Y. Mei, C. M. Huddleston, and A. C. G. Mitchell, Phys. Rev. **79**, 237A (1950); **79**, 429 (1950).

A = 104

I. The 4.7-min $_{45}Rh^{104}$ activity is attributed to a 52-kev γ-transition of E3 or M3 character (G10) (D9).

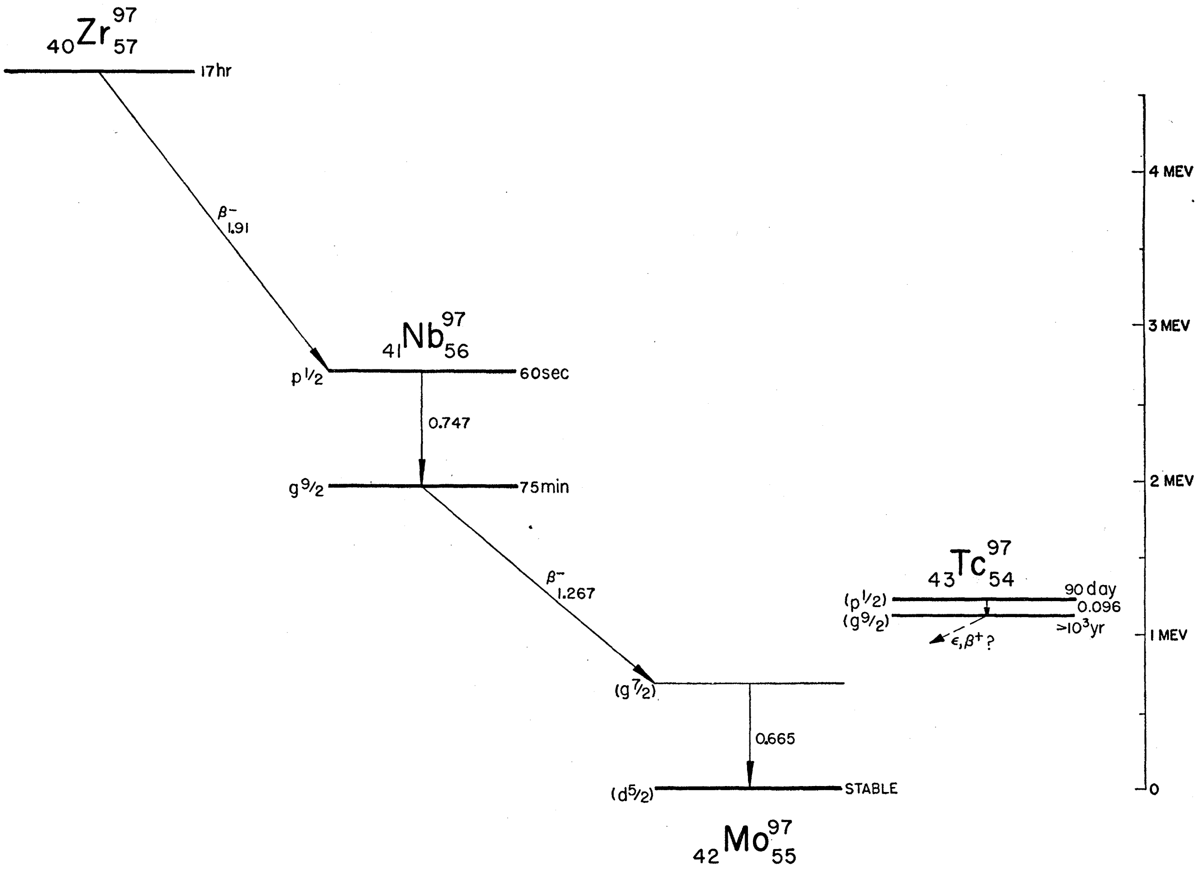

FIG. 23. $A=97$.

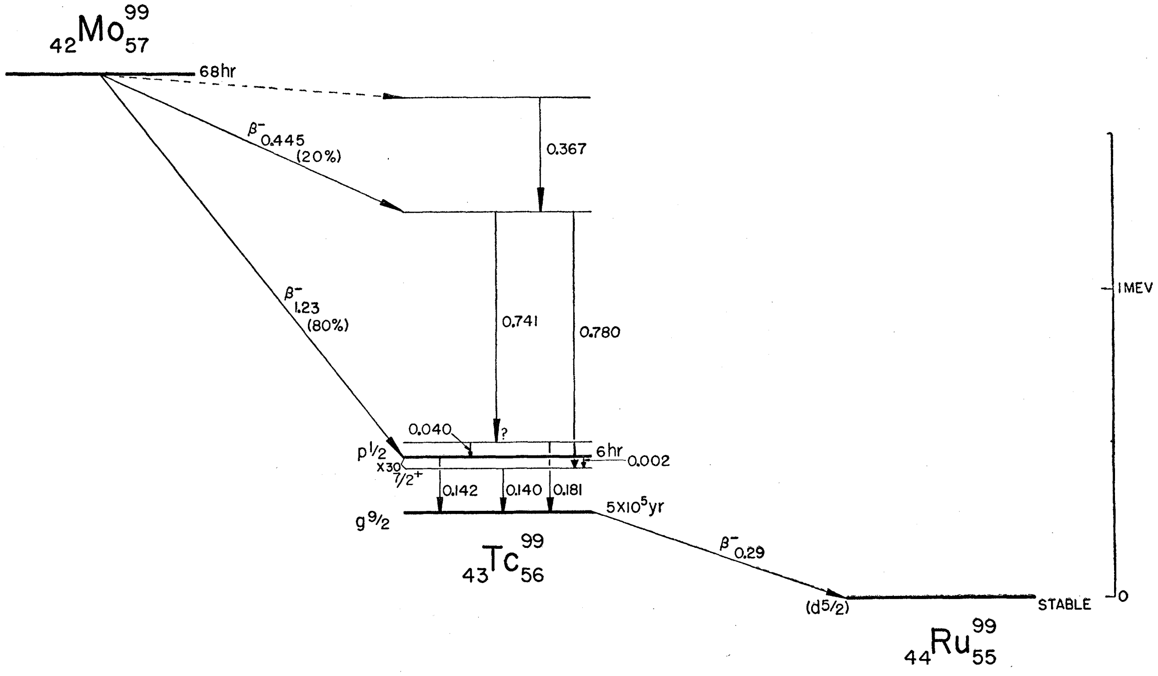

FIG. 24. $A=99$.

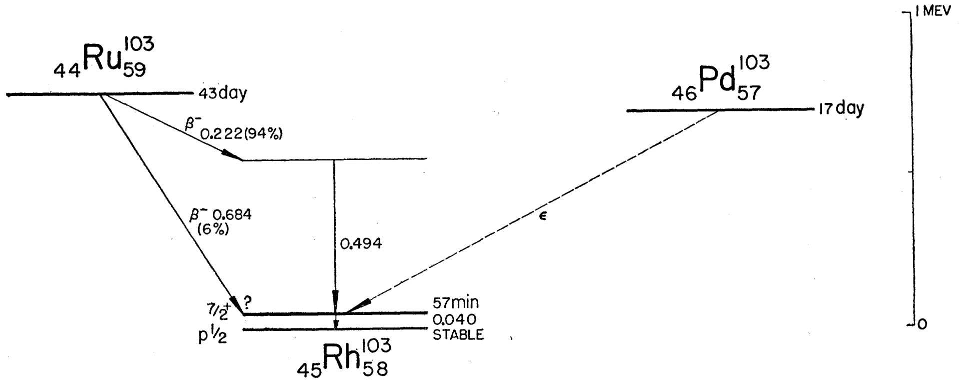

FIG. 25. $A=103$.

II. There are published data for two γ-transitions, of 50 and 80 kev, as well as a strong conversion line of $\sim$50 kev (H15) (ND p. 114). The conversion line interpreted by Hole as a K line may probably be the L line of a 52-kev γ-transition.

III. The logft value of the 2.6 β^- transition from 44-sec $_{45}$Rh^{104} is 4.67 (F4), and the transition is therefore allowed. There are γ-rays reported associated with the 44-sec activity (ND p. 114); however, the 2.6 β^- is here assumed to lead to the $_{46}$Pd^{104} ground state.

IV. According to shell theory states of 1+ and 4− for the 44-sec and 4.7-min levels of $_{45}$Ru^{104} are likely to result from 7/2+, $g_{9/2}$ and $p_{1/2}$, $g_{7/2}$ odd-proton, odd-neutron configurations, respectively. A 4+ state seems to be definitely excluded.

References:

$_{45}$Rh^{104}, ND p. 114.
(D9) E. der Mateosian and M. Goldhaber, Phys. Rev. **82**, 115 (1951).
(H15) N. Hole, Arkiv Fysik **34**, No. 5 (1947).

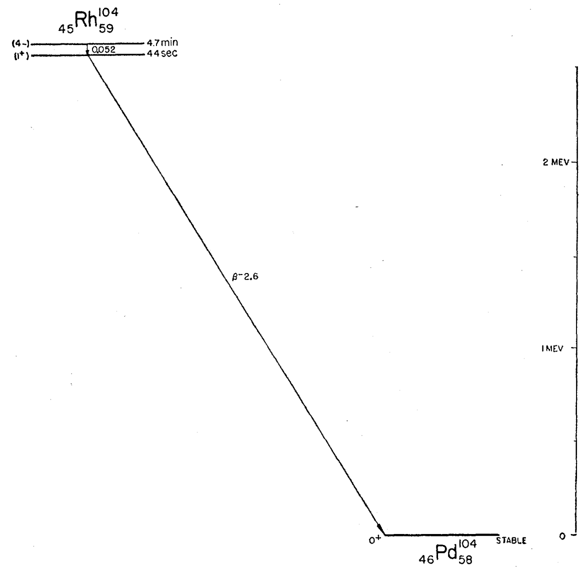

FIG. 26. $A=104$.

A = 105

I. The 130-kev isomeric transition of 45-sec $_{45}$Rh^{105} has been identified as an E3 transition from conversion and lifetime considerations (D28) (D22). The 45-sec and 36-hr $_{45}$Rh^{105} have been assigned spins of $p_{1/2}$ and 7/2+, respectively (G10).

II. The assignment of 7/2+ to the 36-hr $_{45}$Rh^{105} state is supported by the allowedness (logft values $\sim$5.5) of the 0.25 and 0.57 β^- transitions to $_{46}$Pd^{105}. The most likely assignments for the $_{46}$Pd^{105} states on the basis of shell structure are $d_{5/2}$ and $g_{7/2}$. The γ-spectrum of $_{46}$Pd^{105} following 45-day ϵ-capture of $_{47}$Ag^{105} is complex and at present does not seem to tie in with the $_{45}$Rh^{105} decay. The decay scheme of $_{46}$Ag^{105} shown here has been proposed by Hayward (H29) (D19) (B26) (D22) (M39).

III. The 1.15 β^- decay of $_{44}$Ru^{105} has been observed to occur only to a highly excited level of $_{45}$Rh^{105}. The logft value of the 1.15 β^- spectrum is $\sim$5.6, and the Fermi plot is straight so that the transition must be characterized as allowed (D28). The 726-kev γ-ray following the 1.15 β^- is of low multipole order. These facts would appear to indicate a low spin, possibly $s_{1/2}$, for the $_{44}$Ru^{105} ground state, although a fraction ($\sim$10 percent) of the $_{41}$Ru^{105} beta-decays might then be expected to go to the $p_{1/2}$ $_{45}$Rh^{105} state.

IV. The probable spin of the $_{46}$Pd^{105} ground state, observed from the hyperfine structure isotope displacement effect, is 5/2 (B28). Other possible shell structure assignments, such as $s_{1/2}$, $g_{7/2}$, or $h_{11/2}$, can be excluded on experimental grounds (B28).¶

References:

$_{44}$Ru^{105}, ND p. 112; $_{45}$Rh^{105}, ND p. 114; $_{46}$Pd^{105}, ND p. 117; $_{47}$Ag^{105}, ND p. 119, NDS2 p. 28.
(D28) R. B. Duffield and L. M. Langer, Phys. Rev. **81**, 203 (1951).
(D19) M. Deutsch, A. Roberts, and L. G. Elliott, Phys. Rev. **61**, 389A (1942).
(M39) J. Y. Mei, C. M. Huddleston, and A. C. G. Mitchell, Phys. Rev. **79**, 1010 (1950).
(B26) H. L. Bradt and D. J. Tendam, Phys. Rev. **72**, 1117 (1947).
(D22) R. B. Duffield and P. Axel, private communication.
(B28) P. Brix and A. Steudel, Naturwiss. **38**, 431 (1951).

¶ *Note added in proof.*—A 23-sec isomeric activity in $_{46}$Pd^{105} has been observed recently by A. Flammersfeld (Z. Naturforsch. **7a**, 296 (1952)).

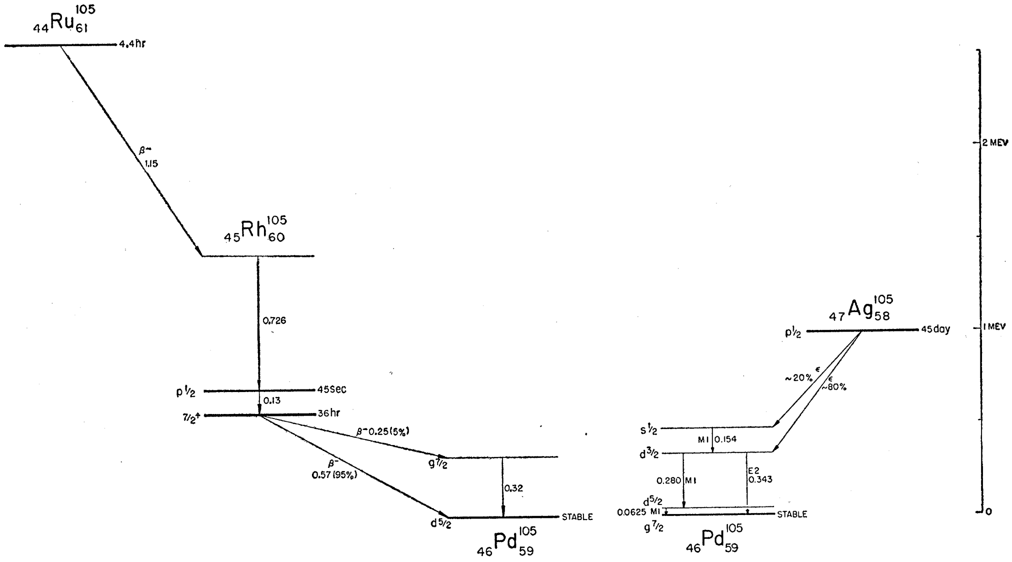

FIG. 27. $A=105$.

(M35) C. E. Mandeville and E. Shapiro, J. Franklin Inst. **253**, 145 (1952).
(H20) R. W. Hayward (private communication, 1952).

$A=106$

I. The relative energy of the $_{47}Ag^{106}$ (8.6 days and 24 min) isomers is not known. The β^- spectrum of Ag^{106} (24.0 min) was studied by Bendel *et al.* (B44), who find a log*ft* value of ~4.93 for each of the β^+ transitions. There may also be present a β^- component of 0.45 Mev and 2 percent intensity.

II. The decay schemes of $_{45}Rh^{106}$ (A10) and $_{47}Ag^{106}$ (8.6 days) (H20) shown here are based on recent work of Alburger (A10) and Hayward (H20), kindly communicated to us. The 0.410-Mev γ-ray was only observed by Hayward. The log*ft* values of $_{45}Rh^{106}$ are

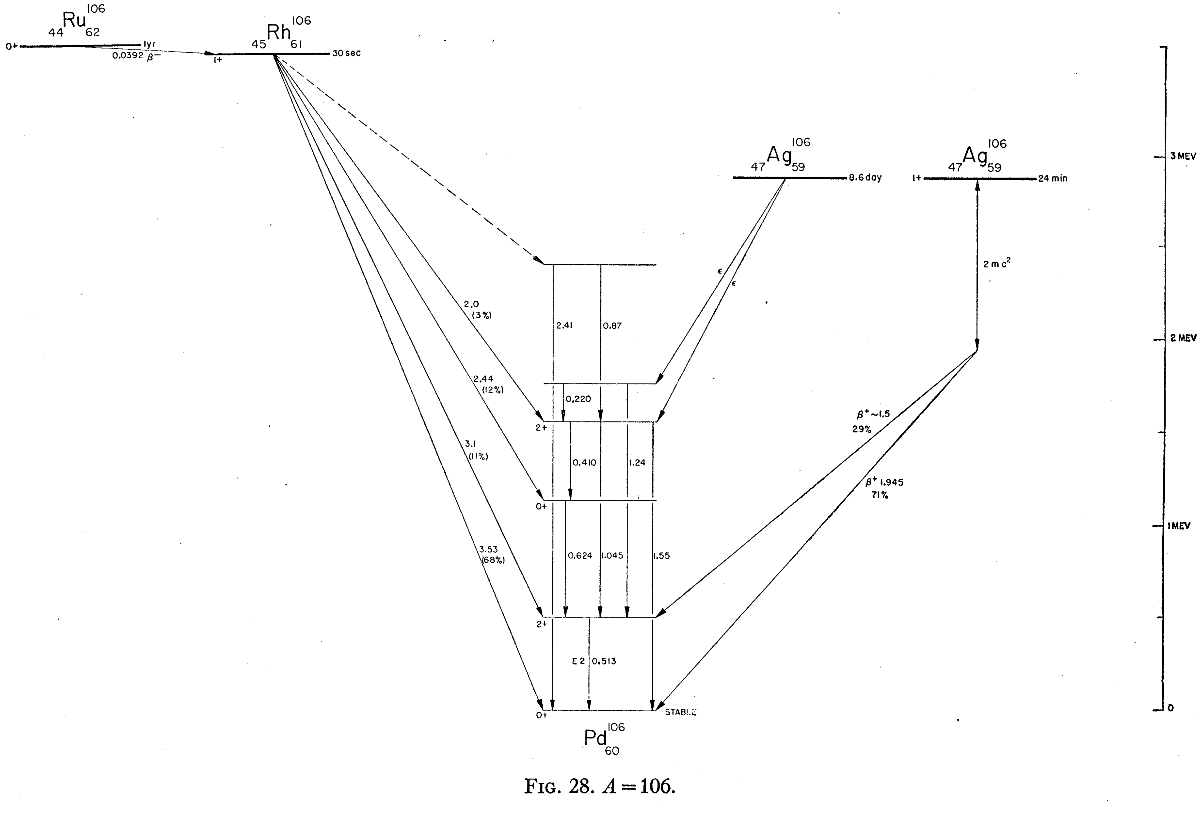

FIG. 28. $A=106$.

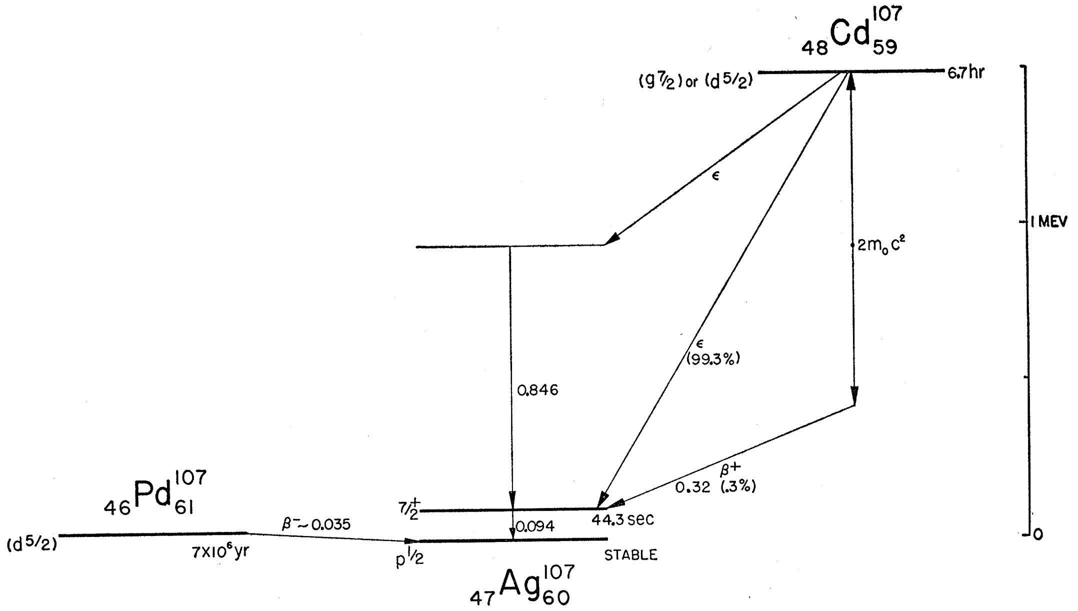

FIG. 29. $A=107$.

5.24, 5.78, 5.30, and 5.54 for the β^- branches of 3.53-, 3.1-, 2.44-, and 2.0-Mev energy, respectively, indicating allowed transitions and therefore probably spin 1+ for $_{45}$Rh^{106}. The logft of the 0.0392-Mev β^- of $_{44}$Ru^{106} is 4.29, speaking even more strongly for an allowed transition and a spin 1+ for $_{45}$Rh^{106}.

III. The angular correlation of the γ-rays following β-decay of $_{45}$Rh^{106} has been studied by many investigators (B27) (K18) (S38). The experimentally obtained correlation between the 0.62- and 0.51-Mev γ-rays is not in agreement with that expected from the most likely level assignments.

References:

$_{44}$Ru^{106}, ND p. 112, NDS1 p. 23; $_{45}$Rh^{106}, ND p. 115, NDS1 p. 23, NDS2 p. 27; $_{47}$Ag^{106}, ND p. 120; $_{47}$Ag^{106}, NDS2 p. 28.

(A10) D. Alburger (private communication).
(H20) R. W. Hayward (private communication, 1952).
(B27) E. L. Brady and M. Deutsch, Phys. Rev. **78**, 558 (1950); **74**, 1541 (1948).
(K18) J. J. Kraushaar, Phys. Rev. **85**, 727A (1952).
(S38) R. M. Steffen, Phys. Rev. **86**, 632A (1952).
(B44) W. L. Bendel, F. J. Shore, and R. A. Becker, Phys. Rev. **83**, 677 (1951).

A = 107

I. The E3 character of the 94-kev transition of 44.3-sec $_{47}$Ag^{107m} is well established (B23). The level assignments are 7/2+ and $p_{1/2}$ for the 44-sec and stable levels of $_{47}$Ag^{107}, respectively (G10) (M34).

II. The logft value for the $_{46}$Pd^{107} long-lived β^- transition is ~11 and for the β^+ $_{48}$Cd^{107} 6.7-hr transition is 4.8. The logf_1t value for the $_{46}$Pd^{107} β^- transition is

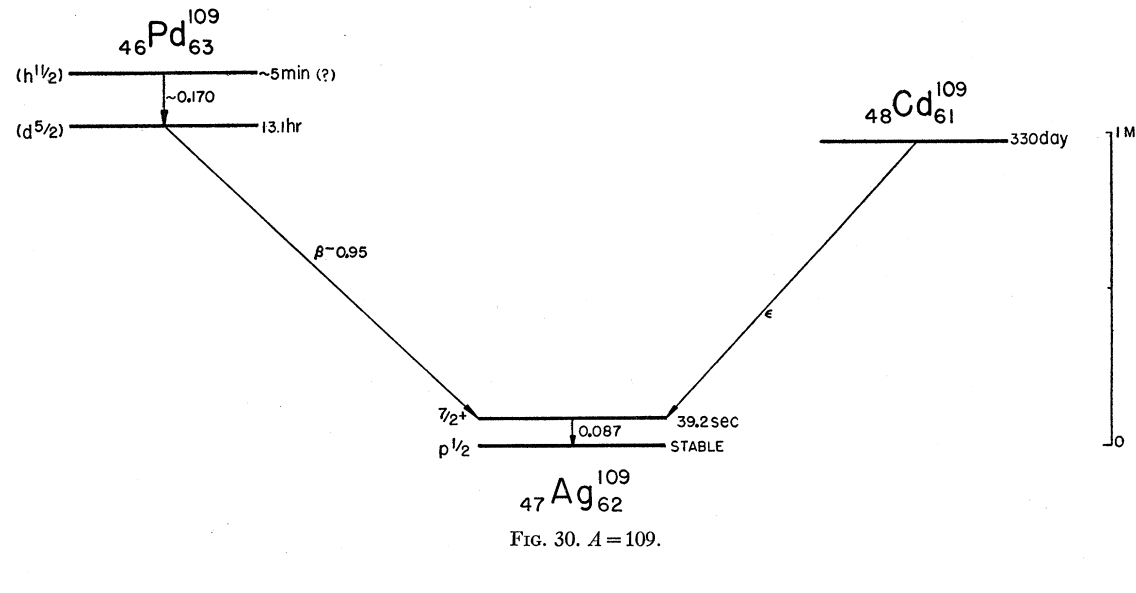

FIG. 30. $A=109$.

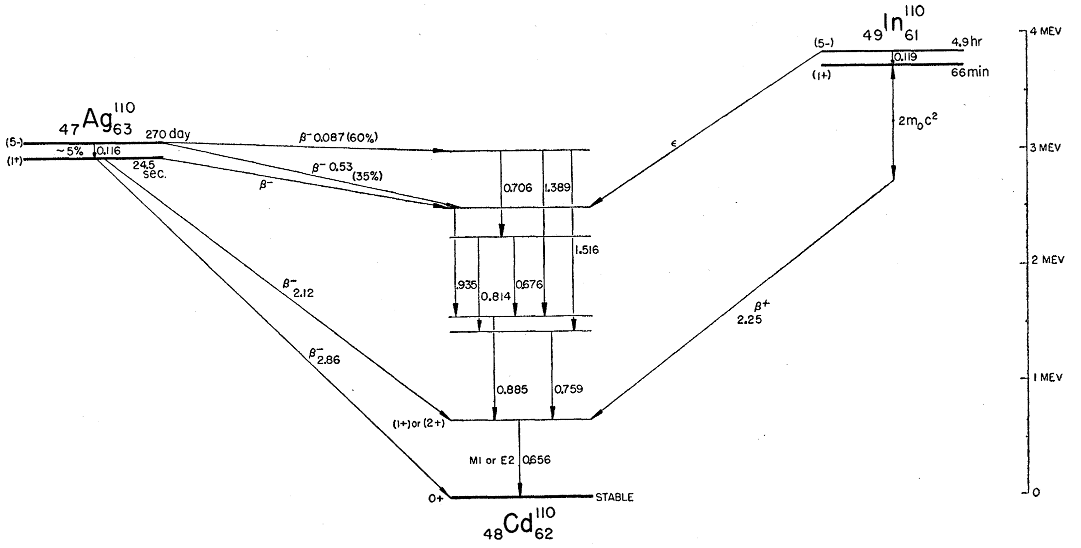

FIG. 31. $A=110$.

$\sim$8.5 which is consistent with a $\Delta I=2$, yes, transition. The level assignment for $_{46}$Pd^{107} is therefore most likely $d_{5/2}$. The 6.7-hr $_{48}$Cd^{107} level assignment may be $d_{5/2}$ or $g_{7/2}$.

References:

$_{47}$Ag^{107}, ND p. 120; $_{48}$Cd^{107}, ND p. 124.

(B23) H. Bradt, P. C. Gugelot, O. Huber, H. Medicus, P. Preiswerk, and P. Scherrer, Phys. Rev. **68**, 57 (1945); Helv. Phys. Acta **20**, 153 (1947).

(M34) S. A. Moszkowski, Phys. Rev. **83**, 1071 (1951); 240A (1951).

$A=109$

I. The 87-kev transition from 39.2-sec $_{47}$Ag^{109} has been identified from lifetime, K/L ratio, and K conversion coefficient to be E3 (G10) (S14) (B22) (O3). Since the measured ground-state spin of stable $_{47}$Ag^{109} is 1/2, the 39.2-sec isomeric state is described as 7/2+ (G10) (M34).

II. A 5-min isomer in Pd has been reported (C4). It may be an isomer of the 13.1-hr β^- active $_{46}$Pd^{109}, since it is produced with approximately the same Cd ratio (D6). The logft value of the β^- decay is 5.98 (F4). The 13.1-hr $_{46}$Pd^{109} state is therefore probably $d_{5/2}$. From its lifetime and energy, the $_{46}$Pd^{109m} 5-min transition is probably E3, and the isomeric level is probably $h_{11/2}$.**

References:

$_{46}$Pd^{109}, ND p. 117, NDS p. 23; $_{47}$Ag^{109}, ND p. 120; $_{48}$Cd^{109}, ND p. 125, NDS p. 24.

(B22) H. Bradt, P. C. Gugelot, O. Huber, H. Medicus, P. Preiswerk, P. Scherrer, and R. Steffen, Helv. Phys. Acta **20**, 153 (1947).

(S14) K. Siegbahn, E. Kondaiah, and S. Johansson, Nature **164**, 405 (1949).

(M34) S. A. Moszkowski, Phys. Rev. **83**, 1071 (1951); 240A (1951).

(C4) E. C. Campbell, private communication; J. H. Kahn, Oak Ridge National Laboratory, ORNL-1089 (1951).

(O3) J. Ovadia, Ph.D. thesis, Illinois (1951).

(D6) E. der Mateosian (private communication, 1951).

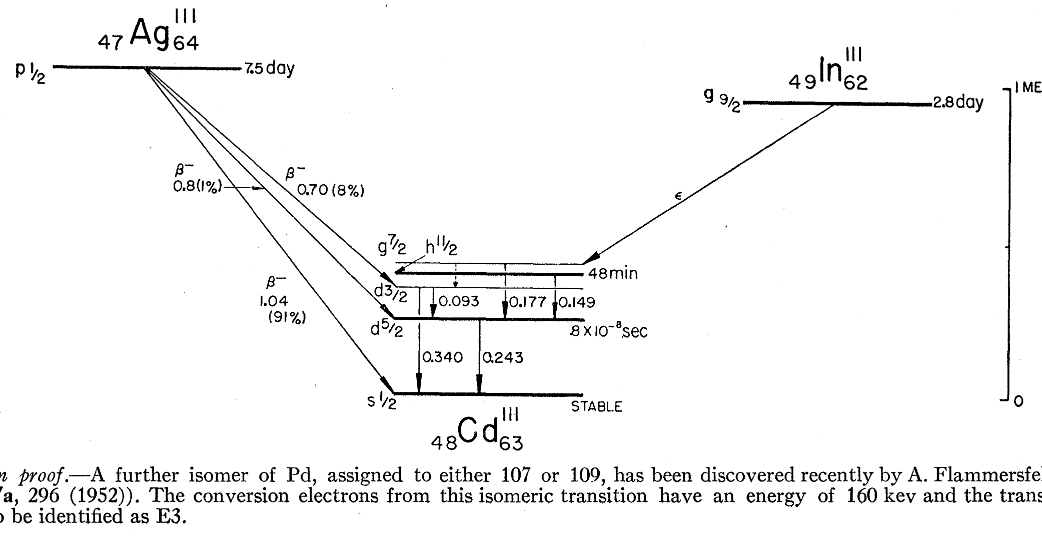

FIG. 32. $A=111$.

** *Note added in proof.*—A further isomer of Pd, assigned to either 107 or 109, has been discovered recently by A. Flammersfeld (Z. Naturforsch. **7a**, 296 (1952)). The conversion electrons from this isomeric transition have an energy of 160 kev and the transition is probably to be identified as E3.

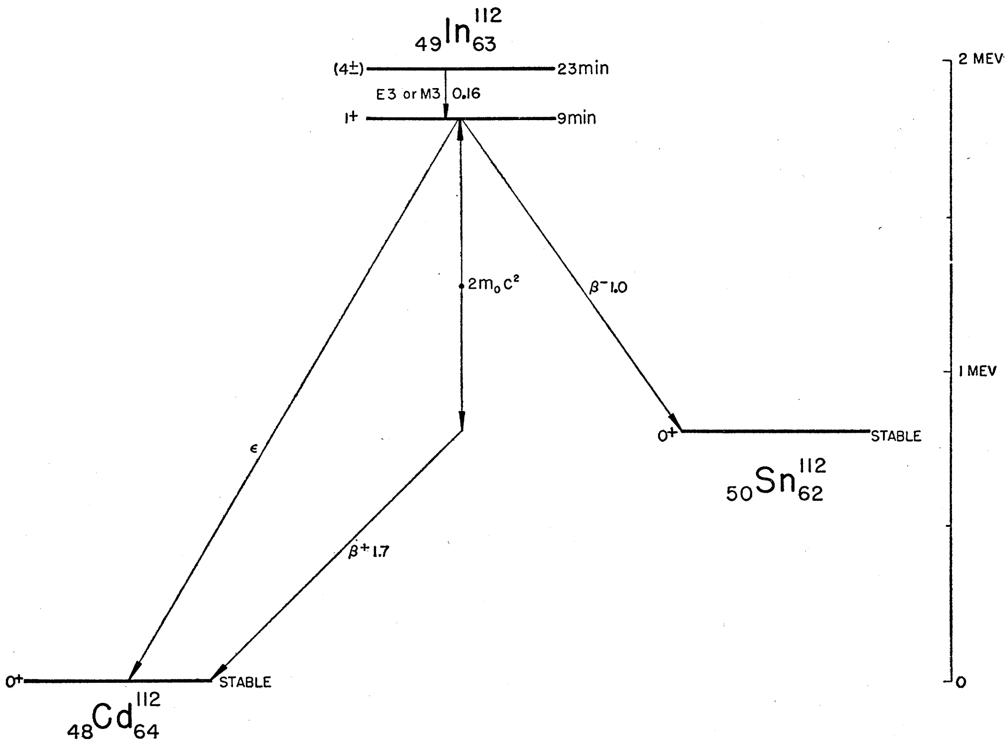

FIG. 33. $A=112$

A=110

I. The 116-kev isomeric transition from 270-day $_{47}Ag^{110}$ is identified from lifetime and K/L ratio considerations as M4 (G10). Similarly the $_{49}In^{110}$ 4.9-hr 119-kev transition is probably M4 (B17). These identifications must be considered as tentative.

II. The logft value for the 2.86 β^- transition from 24.5-sec $_{47}Ag^{110}$ is 4.6 (F4). The lower isomeric state of $_{47}Ag^{110}$ is therefore identified as probably 1+ and the upper isomeric state as 5−. Similarly, since the 2.25 β^+ transition from 66-min $_{49}In^{110}$ is allowed, log$ft=5.5$, the upper and lower isomeric states of $_{49}In^{110}$ are also probably 5− and 1+.

III. The 656-kev γ-ray of $_{48}Cd^{110}$ has a conversion coefficient corresponding either to M1 or E2 (S12). A weak γ-ray ($\sim 0.03-0.05$ percent) above the Be (γ, n) threshold (1.666 Mev) exists in the decay of Ag^{110m} (D34) (W12), but its place in the decay scheme is unknown.

IV. Odd-odd nucleon coupling theory together with shell theory indicates that the 1+ states of the above nuclei probably arise from $g_{9/2}$, $g_{7/2}$ configurations (S6) (M7). The 5− isomeric states are, however, difficult to account for.

References:

$_{47}Ag^{110}$, ND p. 122, NDS p. 24, NDS2 p. 29; $_{49}In^{110}$, ND p. 128.
(B17) E. Bleuler, J. W. Blue, and A. C. Johnson, Phys. Rev. **82**, 333A (1951).
(S12) K. Siegbahn, Phys. Rev. **77**, 233 (1950).
(S6) J. M. C. Scott, Cavendish Laboratory, unpublished manuscript (1951).
(M7) M. G. Mayer, S. A. Moszkowski, and L. W. Nordheim, Argonne National Laboratory, ANL-4626 (1951); Revs. Modern Phys. **23**, 315 (1951).
(D34) E. der Mateosian and M. Goldhaber, Phys. Rev. **78**, 326A (1950).
(W12) R. W. Wilson, Phys. Rev. **79**, 1004 (1950).

A=111

I. The 149-kev isomeric transition of 48-min $_{48}Cd^{111}$ has been identified as E3 (M8) (S26) and the upper and lower states assigned as $h_{11/2}$ and $d_{5/2}$ (J1) (G10). The 243-transition of 9×10^{-8} sec $_{48}Cd^{111}$ occurs between the $d_{5/2}$ excited state and $s_{1/2}$ ground state and is identified from lifetime and conversion coefficient considerations as E2 (E4) (D20). The magnetic moment of the $d_{5/2}$ state has been measured ($\mu=-(0.85\pm0.22)$ (A12)).

II. The spin and magnetic moment of stable $_{48}Cd^{111}$ have been measured, and are consistent with an assignment $s_{1/2}$.

III. The β^- decay components from $_{47}Ag^{111}$ have logft values of 7.78 (.70 β^-), 8.85 (.80 β^-), and 7.30 (1.04 β^-). They are described as 1st forbidden (J1). The logf_1t value for the 0.80β^- component is 8.1, a value that is compatible with a transition $\Delta I=2$, yes.††

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†† *Note added in proof.*—Two isomeric activities of mass number 111 have been discovered recently by C. L. McGinnis (Phys. Rev. **87**, 202 (A) (1952)). A 5.5-hr $_{46}Pd^{111m}$ isomeric activity decays with a 2.15 β^- spectrum to the ground state of Ag^{111}. A 27-min $_{46}Pd^{111}$ ground-state activity decays with a 2.15 β^- spectrum to a Ag^{111m} state. The isomeric activity, Ag^{111m}, for which no lifetime is as yet known, decays by an I.T. $\sim$85 kev, and the isomeric state is probably characterized by 7/2+.

References:

${}_{47}Ag^{111}$, ND p. 123, NDS2 p. 29; ${}_{48}Cd^{111}$, ND p. 125, NDS p. 24; ${}_{49}In^{111}$, ND p. 129.
(M8) C. L. McGinnis, Phys. Rev. **81**, 734 (1951); **83**, 686 (1951).
(E4) D. Englekemeir, Phys. Rev. **82**, 552 (1951).
(D20) M. Deutsch and W. E. Wright, Phys. Rev. **77**, 139 (1950).
(J1) S. Johansson, Phys. Rev. **79**, 896 (1950).
(S26) A. W. Sunyar, Phys. Rev. **83**, 864 (1951).
(A12) H. Aeppli, H. Albers-Schönberg, A. S. Bishop, H. Frauenfelder, and E. Heer, Phys. Rev. **84**, 370 (1951).

$A=112$

I. On the basis of lifetime, the 160-kev transition from the 23-min ${}_{49}In^{112}$ isomer has been identified as either E3 or M3 (G10).

II. The log*ft* values for both the (β^+, ϵ) and β^- transitions from the 9-min ${}_{49}In^{112}$ state are equal to 4.4 (F4). This identifies the 9-min ${}_{49}In^{112}$ state as probably 1+. The upper isomeric state is therefore probably 4±. Shell theoretical arguments support a $g_{9/2}$, $g_{7/2}$ odd-proton, odd-neutron configuration for the 1+ state, but are indefinite for the spin 4 state (S6).

References:

${}_{49}In^{112}$, ND p. 129, NDS2 p. 31.
(S6) J. M. C. Scott, Cavendish laboratory, unpublished manuscript (1951).

$A=113$

I. The 390-kev isomeric transition of 1.73-hr ${}_{49}In^{113}$ is clearly identified from its conversion coefficient and lifetime as M4 (G10) (A8) (S7). Since the ground state of stable ${}_{49}In^{113}$ has a measured spin of 9/2, the isomeric levels are identified as $p_{1/2}$ and $g_{9/2}$ on the basis of shell theory.

II. The log*ft* value for the ∼.5 β^- transition of 5.1-yr [3.5-yr (C8)] ${}_{48}Cd^{113}$ is ∼8.6. This value could be consistent with a 1st forbidden transition from a $h_{11/2}$ state to the $g_{9/2}$ state of ${}_{49}In^{113}$. The measured spin of stable ${}_{48}Cd^{113}$ is 1/2. The apparent absence of the $h_{11/2}\rightarrow s_{1/2}$ isomeric transition is not inconsistent with current estimates for E5 transitions (G10). It should be noted, however, that x-rays have also been observed in approximately 10 percent of the decays from 5.1-yr Cd^{113m} (C7). These could arise from the isomeric transition, as it is extremely improbable that a transition to the $p_{1/2}$ state in ${}_{49}In^{113}$ will occur.

III. From the ratio of *K* to *L* capture in 112-day ${}_{50}Sn^{113}$, it has been concluded that ${}_{50}Sn^{113}$ decays by an allowed transition of 42 kev to ${}_{49}In^{113m}$ (T2). As the 1.73-hr ${}_{49}In^{113}$ state is $p_{1/2}$, this is difficult to reconcile with the likelihood from shell structure theory that the ground state of ${}_{50}Sn^{113}$ is an even parity state, probably of $s_{1/2}$.

IV. The log*ft* value of the ${}_{47}Ag^{113}$ 5.3-hr 2.1 β^- transition is 6.95 (F4). This value is consistent with a 1st forbidden transition from a $p_{1/2}$ to an $s_{1/2}$ state.

V. No activity of ground states Cd^{113} or In^{113} has yet been observed (L9). It is probable from β-ray systematics (W2) that Cd^{113} has a higher mass than In^{113}.

VI. Evidence for another case of probable triple isomerism, similar to the case of Sb^{124}, has been recently reported: A 2.5-sec I.T. of 153 kev has been observed when enriched In^{113} was bombarded by fast neutrons (K1). This activity may therefore belong to In^{112} (or possibly to In^{113} or In^{114}).

References:

${}_{48}Cd^{113}$, ND p. 126, NDS2 p. 30; ${}_{49}In^{113}$, ND p. 130; ${}_{50}Sn^{113}$, ND p. 133.
(C7) W. L. Carss, J. R. Gum, and M. L. Pool, Phys. Rev. **80**, 1028 (1950).
(T2) D. A. Thomas, S. K. Haynes, C. D. Broyles, and H. C. Thomas, Phys. Rev. **82**, 961 (1951).
(L9) W. F. Libby (private communication, 1951) (could not confirm earlier claims that In^{113} is active).
(C8) J. M. Cassidy, Phys. Rev. **83**, 483A (1951).
(W2) K. Way (private communication).
(K1) J. H. Kahn, Oak Ridge National Laboratory, ORNL-1089 (1951); E. C. Campbell, private communication (1951).

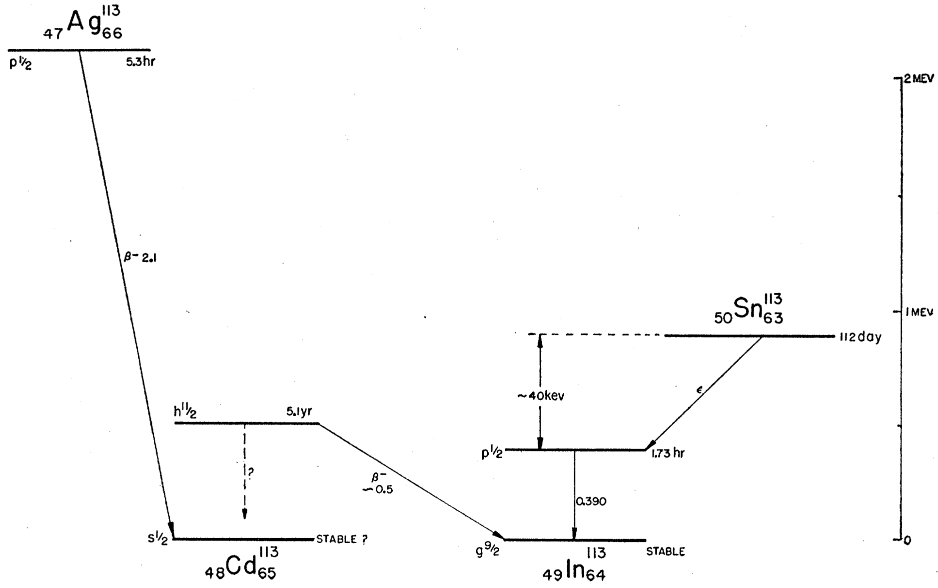

FIG. 34. $A=113$.

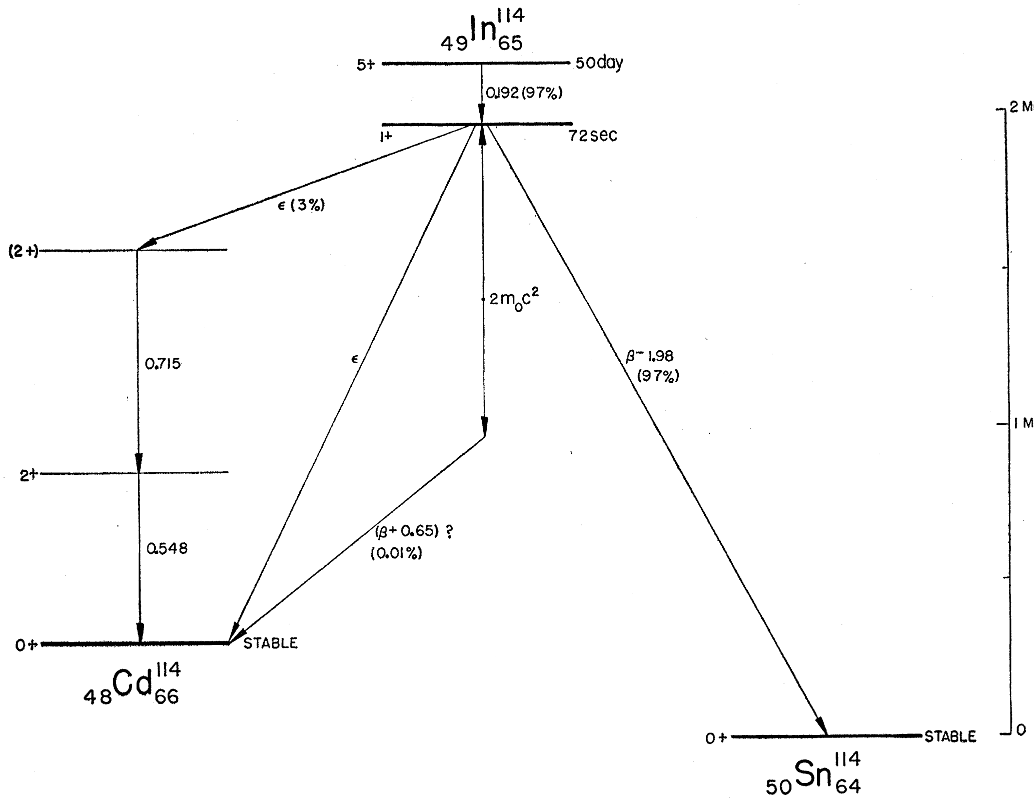

FIG. 35. $A = 114$.

A=114

I. The 192-kev isomeric transition of 50-day $_{49}In^{114}$ has been identified from conversion coefficient data as E4 (S21).

II. The log*ft*-value for the β^- transition from 72-sec $_{49}In^{114}$ is 4.5 (F4), and the transition is evidently allowed. The 72-sec $_{49}In^{114}$ state is therefore identified as 1+. The spin of the 50-day isomeric state is assigned a value 5+.

III. Recent work (J2) makes it more probable that the ϵ-branch arises from the ground state of In^{114} rather than the metastable state as previously believed (S21). The evidence for positrons has also been doubted. The spin of the second excited state is probably 2+ (J2). The γ-ray from the first excited state has also been identified among the capture γ-rays from Cd^{113} (n, γ) Cd^{114} (T5).

IV. According to shell theory the 1+ state can be explained as due to a $g_{9/2}$, $g_{7/2}$ odd proton—odd neutron configuration, and the 5+ state as due to a $g_{9/2}$, $s_{1/2}$ configuration.

References:

$_{49}In^{114}$, ND p. 130.
(S21) R. M. Steffen, Phys. Rev. **83**, 166 (1951); R. M. Steffen and W. Zobel, Bull. Am. Phys. Soc. **27**, No. 4, 19 (1952).
(J2) M. W. Johns, C. D. Cox, and C. C. McMullen, Phys. Rev. **86**, 632A (1952).
(T5) W. A. Thornton, E. der Mateosian, H. T. Motz, and M. Goldhaber, Phys. Rev. **86**, 604A (1952).

A=115

I. The 340-kev isomeric transition from 4.5-hr $_{49}In^{115}$ has been identified from lifetime and conversion data as an M4 transition (G10). The spin of $_{49}In^{115}$ in the ground state is measured as 9/2, and the shell theory assignment is $g_{9/2}$. The 4.5-hr $_{49}In^{115}$ state is therefore assigned a $p_{1/2}$ character.

II. The assignments of $p_{1/2}$ and $g_{9/2}$ to the isomeric levels of $_{49}In^{115}$ are also consistent with the β^- transitions to the known $s_{1/2}$ state of stable $_{50}Sn^{115}$. The log*ft* value of the 0.83 β^- transition from the 4.5-hr $_{49}In^{115}$ state is 6.4, which is consistent with a 1st forbidden transition. The log*ft* value for the 0.63 β^- transition from 6×10^{14}-yr $_{49}In^{115}$ is 23.2 (M5) and is consistent with a 4th forbidden transition. It should be noticed that the β^- energy difference is not in too good agreement with the I.T. energy. It is probable that β-energy of the naturally radioactive ground state has been overestimated. The absorption method used (M5) is not very accurate for β-spectra which do not have an allowed shape.

III. No isomeric transition between 43-day and 2.3-day $_{48}Cd^{115}$ states has yet been observed. From β-ray measurements of Langer (L1) and Hayward (H20), one would expect the energy difference to be 120±40 kev (L1) or 170 kev. This would require the I.T. from the 43-day state to be an E5 transition in order that it should not occur with a probability comparable to the 1.6 β^- transition. On this basis, the 43-day and 2.3-day $_{48}\mathrm{Cd}^{115}$ states are probably $h_{11/2}$ and $s_{1/2}$ states, respectively (G10). Hayward's decay scheme for the $_{48}\mathrm{Cd}^{115}$ isomers, which he kindly communicated to us before publication, is shown here.

IV. The log*ft* value of the 1.12 β^- transition from 2.3-day $_{48}\mathrm{Cd}^{115}$ is 7.07 (F4), and the transition is consistent with a 1st forbidden transition between the states shown. The log*ft* value of the 1.604 β^- transition from 43-day $_{48}\mathrm{Cd}^{115}$ is 8.8 and indicates probably a 1st forbidden transition. Although this is a high log*ft* value, it is not inconsistent with the spin assignments shown. A complex γ-spectrum is also associated with the 2.3-day $_{48}\mathrm{Cd}^{115}$ decay (C16).

V. No γ-rays are associated with the ~3-Mev β^- transition from 20-min $_{47}\mathrm{Ag}^{115}$ (D24). The log*ft* value for this transition is 6.4 (F4). The most probable assignment for the 20-min $_{47}\mathrm{Ag}^{115}$ level is therefore $p_{1/2}$, consistent with a 1st forbidden β^- transition to the 2.3-day $_{48}\mathrm{Cd}^{115}$ $s_{1/2}$ state.

VI. The 4.5-hr $_{49}\mathrm{In}^{115m}$ is found to grow from 43-day

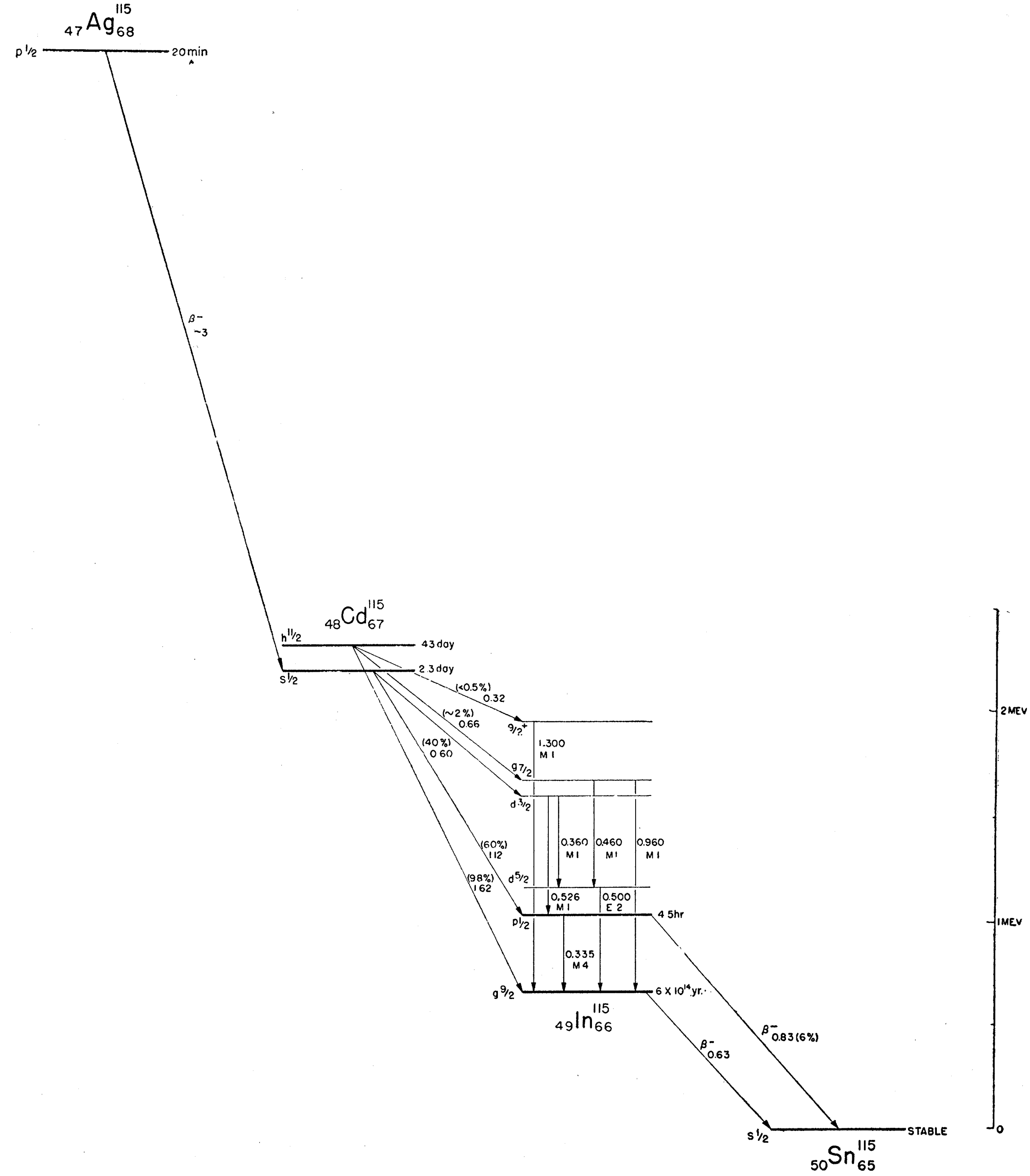

FIG. 36. $A = 115$.

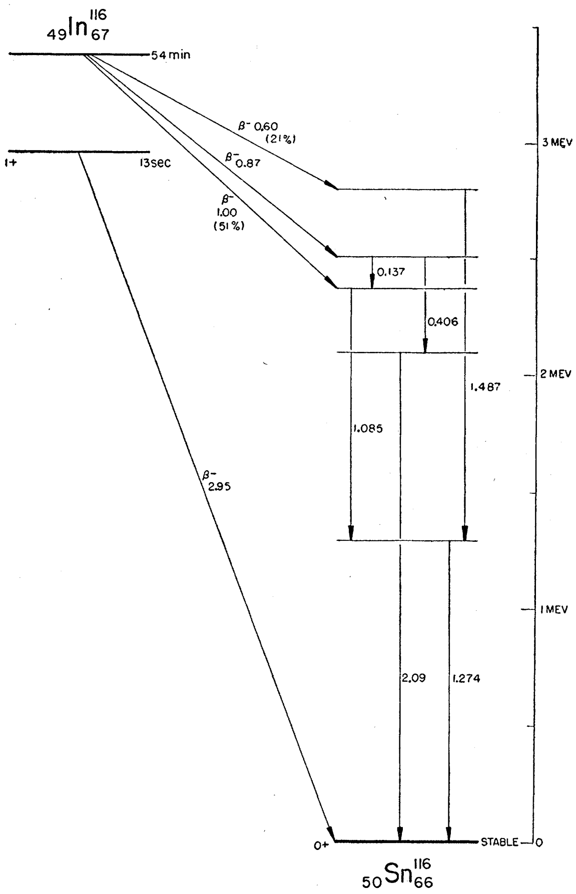

FIG. 37. $A=116$.

$_{48}Cd^{115m}$ with an intensity of $\sim 7\times 10^{-3}$ percent (E5) (W11). It is not known whether or not this takes place by an E5 I.T. to the ground state of Cd^{115} followed by a β-transition or through a weak β- (and γ-) ray branch directly from Cd^{115m}.

References:

$_{47}Ag^{115}$, ND p. 123; $_{48}Cd^{115}$, ND p. 127, NDS p. 24, NDS2 pp. 30, 31; $_{49}In^{115}$, ND p. 131, NDS2 p. 31.
(M5) E. A. Martell and W. F. Libby, Phys. Rev. **80**, 977 (1950).
(B4) P. R. Bell, B. H. Ketelle, and J. M. Cassidy, Phys. Rev. **76**, 574 (1949).
(H6) R. W. Hayward and A. C. Helmholz, Phys. Rev. **75**, 1469A (1949).
(A3) D. E. Alburger, E. der Mateosian, and M. Goldhaber, Brookhaven National Laboratory, BNL-64 (1950).
(L1) L. M. Langer, private communication (1951).
(C16) J. M. Cork, W. C. Rutledge, A. E. Stoddard, C. E. Branyan, and J. M. LeBlanc, Phys. Rev. **79**, 938 (1950).
(D24) R. B. Duffield and J. D. Knight, Phys. Rev. **75**, 1613 (1949).
(D1) E. B. Dale and J. D. Kurbatov, Phys. Rev. **80**, 126A (1950).
(G2) P. S. Gill, C. E. Mandeville, and E. Shapiro, Phys. Rev. **80**, 284 (1950).
(H20) R. W. Hayward (private communication, 1952).
(E5) D. W. Engelkemeir, Argonne National Laboratory (unpublished).
(W11) A. C. Wahl and N. A. Bonner, Phys. Rev. **85**, 570 (1952).

$A=116$

I. No isomeric transition between the 54-min and 13-sec In^{116} states has been observed. However, the disintegration schemes seem sufficiently well known to identify the 54-min level as the upper state (S17).

II. Log*ft* values are 4.33 for the 2.95 β^- transition and 5.26 (1.00), 5.29 (.87), and 4.85 (.60) for the 54-min β^- transitions (F4). The ground state of $_{49}In^{116}$ may therefore be identified as 1+.

References:

$_{49}In^{116}$, ND p. 132, NDS p. 25, NDS2 p. 31.
(S17) H. Slätis, S. J. duToit, and K. Siegbahn, Phys. Rev. **78**, 498 (1950).

$A=117$

I. The isomeric transition from 14.5-day $_{50}Sn^{117}$ has been identified as a 159-kev M4 transition (M29). The isomeric transition is followed by a second step of 162 kev and M1 character. More recent energy determinations are 155.9 and 157.4 (C17) and 156.6 and 159.3 (M27) for these two successive steps.

II. The measured spin of stable $_{50}Sn^{117}$ is 1/2, and the first and second excited states are then identified as $d_{3/2}$ and $h_{11/2}$ states, respectively.

III. The 2.8-hr $_{51}Sb^{117}$ probably decays to the 162-kev excited state of $_{50}Sn^{117}$ (T1). This is consistent with the high K/L ratio found for the conversion lines associated with the $_{51}Sb^{117}$ decay. It is also consistent with the probable assignment of $d_{5/2}$ for the ground state of $_{51}Sb^{117}$.

IV. A low yield of 14.5-day $_{50}Sn^{117}$ has been obtained from the decay of $_{49}In^{117}$ (K10). If the spin of $_{49}In^{117}$ is $g_{9/2}$ one would expect practically all of the transitions for a β^- energy of 1.73 Mev to go to the 14.5-day isomer. The log*ft* value for the 1.73 β^- transition from $_{49}In^{117}$ is 6.22 and would be consistent with a $g_{9/2}\rightarrow h_{11/2}$ transition. Until the question of the yield is decided quantitatively this decay scheme must be considered as tentative.‡‡

References:

$_{50}Sn^{117}$, ND p. 134, NDS2 p. 32; $_{51}Sb^{117}$, ND p. 137.
(M29) J. W. Mihelich and R. D. Hill, Phys. Rev. **79**, 781 (1950).
(T1) G. M. Temmer, Phys. Rev. **76**, 424 (1949).
(K10) J. D. Knight (private communication, 1951).
(C17) J. M. Cork, A. E. Stoddard, C. E. Branyan, W. J. Childs, D. W. Martin, and J. M. LeBlanc, Phys. Rev. **84**, 596 (1951).
(M27) J. W. Mihelich, private communication, (1951).

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‡‡ *Note added in proof.*—Evidence from fission studies has been presented by H. G. Richter and C. D. Coryell (L.N.S.E. Progress Report, May, 1952) that there is a ~40-min Cd^{117} activity isomeric with the 2.83-hr Cd^{117}. It was suggested that the ~40-min metastable state has an $h_{11/2}$ assignment and that the 2.83-hr ground-state assignment is $s_{\frac{1}{2}}$. No isomeric transition between states was observed. Concerning the decay of 1.95-hr In^{117}, Lévêque, Richter, and Coryell (private communication) find that there is no appreciable production of 14.5-day Sn^{117m}. According to G. A. Cowan (private communication, 1952) the experiments of J. D. Knight (K10) are to be interpreted that the fraction of 2.8-hr Cd^{117} atoms decaying through In^{117} to 14-day Sn^{117} is $\sim 3.6\times 10^{-4}$. Thus it seems highly probable that the 1.95-hr In'^{17} state has a $p_{\frac{1}{2}}$ assignment, as in fact suggested by Mayer, Moszkowski, and Nordheim (M7).

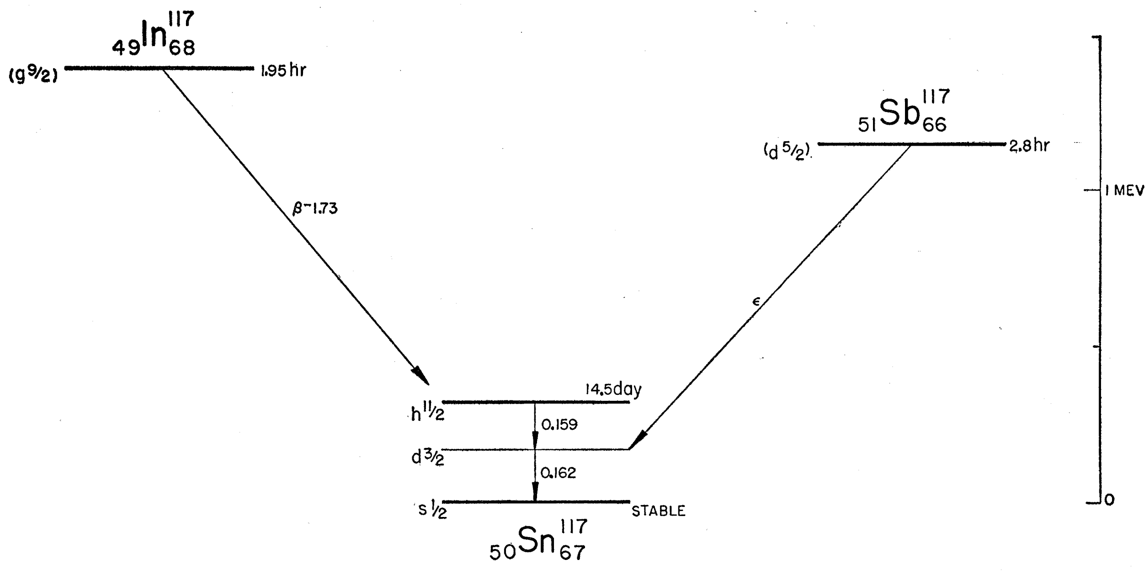

Fig. 38. $A=117$.

A=118

$_{51}Sb_{67}$ $T_1=5.1$ hr e^-, $\gamma=.26$, $\gamma=1.5$, $T_2=3.9$ min β^+ 3.1, γ.

References:

$_{51}Sb^{118}$, ND p. 137.
(C11) K. D. Coleman and M. L. Pool, Phys. Rev. **72**, 1070 (1947).
(T1) G. M. Temmer, Phys. Rev. **76**, 424 (1949).
(R6) J. R. Risser, K. Lark-Horovitz, and R. N. Smith, Phys. Rev. **57**, 355A (1940).

A=119

I. The 65-kev isomeric transition from 250-day $_{50}Sn^{119}$ has been identified as M4 (M29). A second transition of 24 kev following the 64-kev transition was identified as M1 (S2) (H11) (B19).

II. The measured spin of stable $_{50}Sn^{119}$ is 1/2, and the isomeric 250-day state and intermediate state are identified as $h_{11/2}$ and $d_{3/2}$, respectively.

III. The log*ft* value of the 2.7 β^- transition from

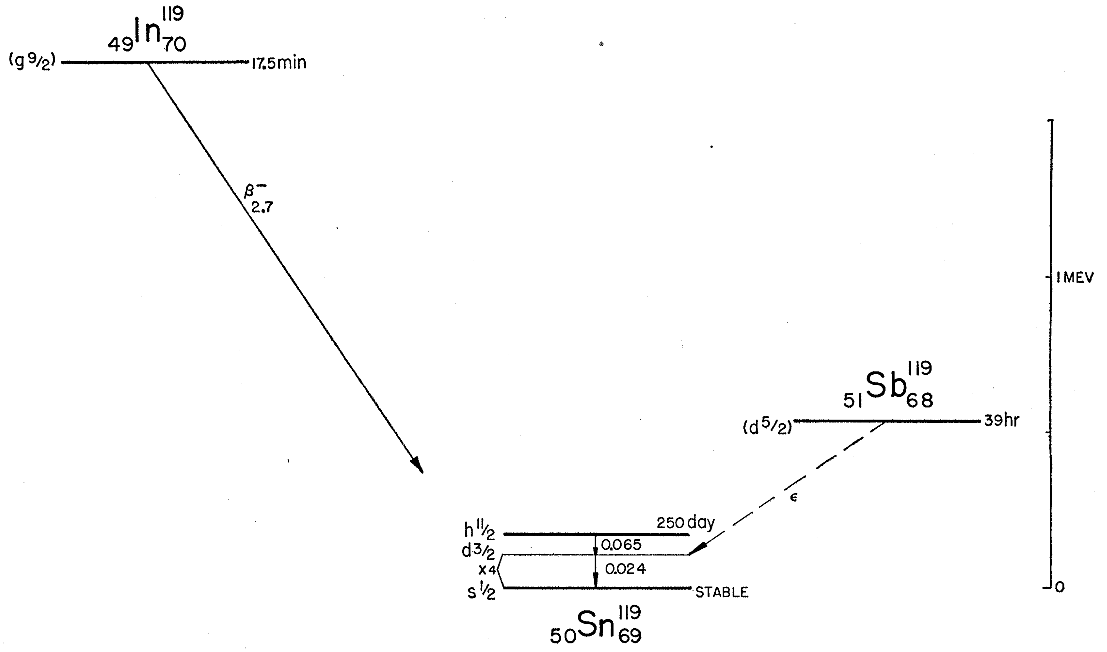

Fig. 39. $A=119$.

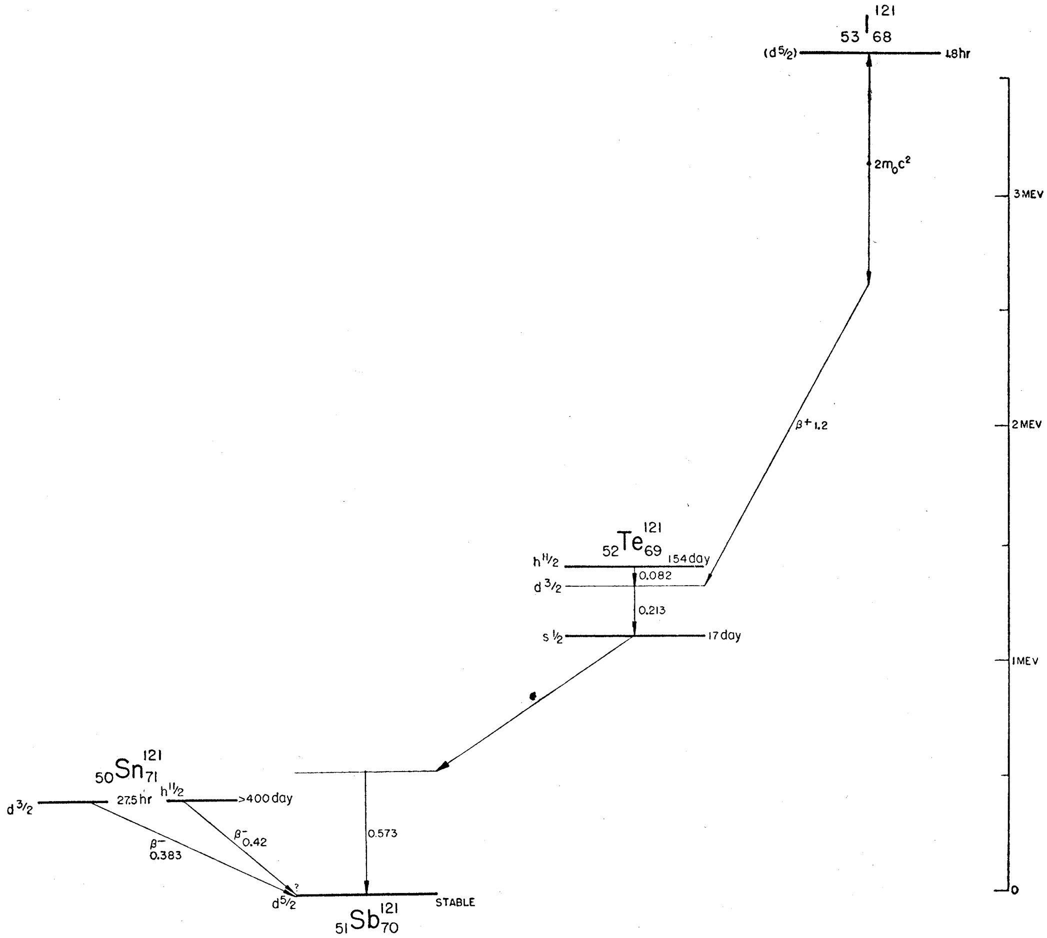

FIG. 40. $A=121$.

$_{49}In^{119}$ is 6.17. On the basis of shell theory one might expect the $_{49}In^{119}$ ground state to have a $g_{9/2}$ assignment, and the β^- transition would lead to the $h_{11/2}$ level and would be 1st forbidden in agreement with the logft value. The absence of prompt γ-rays in the $_{49}In^{119}$ decay (D25) would not be inconsistent with a β^- transition to the $h_{11/2}$ state (M29).§§

IV. On the basis of a $d_{5/2}$ ground state for the $_{51}Sb^{119}$ nucleus as is suggested from shell structure and the spin of $_{51}Sb^{121}$, the ϵ-capture would occur to the 24-kev excited level of $_{50}Sn^{119}$ and the ϵ-capture should be accompanied by this low energy γ-ray. It is not surprising therefore that no γ-ray other than the Sn x-ray has so far been seen (C11).

References:

$_{49}In^{119}$, ND p. 132; $_{50}Sn^{119}$, ND p. 135, NDS p. 25, NDS2 p. 32; $_{51}Sb^{119}$, ND p. 137.
(M29) J. W. Mihelich and R. D. Hill, Phys. Rev. **79**, 781 (1950).
(S2) G. Scharff-Goldhaber, E. der Mateosian, M. Goldhaber, G. W. Johnson, and M. McKeown, Phys. Rev. **83**, 480 (1951).
(H11) R. D. Hill, Phys. Rev. **83**, 865 (1951).
(D25) R. B. Duffield and J. D. Knight, Phys. Rev. **75**, 1967 (1949).
(C11) K. D. Coleman and M. L. Pool, Phys. Rev. **72**, 1070 (1947).
(B19) J. Bowe and P. Axel, Phys. Rev. **84**, 939 (1951).

A = 120

$_{51}Sb_{69}$ $T_1=14.5$ min, 1.7 β^+; 0.90, 1.30, 2.20 γ, (B42), ND p. 138, $T_2=6.0$ day, ϵ, 1.1 γ (L11).

No evidence for the existence of 6.0-day $_{51}Sb^{120}$ was found by Blaser *et al.* (B43).

References:

(B42) J. P. Blaser, F. Boehm, and P. Marmier, Helv. Phys. Acta **23**, 623 (1950).
(B43) J. P. Blaser, F. Boehm, P. Marmier, and H. Wäffler, Helv. Phys. Acta **24**, 245 (1951).
(L11) M. Lindner and I. Perlman, Phys. Rev. **73**, 1124 (1948).

A = 121

I. No isomeric transition between the >400-day and 27.5-hr $_{50}Sn^{121}$ states has been observed. The energies of the beta-spectra associated with these activities are

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§§ *Note added in proof.*—See, however, the note added in proof for In^{117}.

given as 0.42 and 0.383 Mev, respectively (N2) (D26). The log*ft* values calculated for these transitions are then >7.75 and 5.03, respectively.

II. Since the ground state of ${}_{51}\mathrm{Sb}^{121}$ is known to be of $d_{5/2}$ character, the 0.383 β^- transition of ${}_{50}\mathrm{Sn}^{121}$, 27.5 hr, would be consistent with an allowed transition from a $d_{3/2}$ state. However, the 0.42 β^- transition of ${}_{50}\mathrm{Sn}^{121}$, >400 day, would be a third forbidden transition on the basis of the above level assignments.

III. There are a number of ways in which the decay of the >400-day ${}_{50}\mathrm{Sn}^{121}$ isomer might be understood whilst retaining its $h_{11/2}$ character: (a) There may be a considerable amount of decay by an I.T. which would raise the partial lifetime of the 0.42 β^- transition. (b) There may be a transition to a low excited state of ${}_{51}\mathrm{Sb}^{121}$. (c) There may be a complete I.T. to the 27.5-hr ${}_{50}\mathrm{Sn}^{121}$ via a low energy transition and the β-spectrum of the >400-day ${}_{50}\mathrm{Sn}^{121}$ may then be identical with that of the 27.5-hr ${}_{50}\mathrm{Sn}^{121}$.

IV. The 154-day ${}_{52}\mathrm{Te}^{121}$ and 17-day ${}_{52}\mathrm{Te}^{121}$ have been identified as $h_{11/2}$ and $s_{1/2}$ isomeric levels (H10). Transitions from the 154-day ${}_{52}\mathrm{Te}^{121}$ state occur by an M4 step to a $d_{3/2}$ intermediate state, followed by an M1 step.

V. The 1.2 β^+ transition from 1.8-hr ${}_{53}\mathrm{I}^{121}$ goes to the $d_{3/2}$ level of ${}_{52}\mathrm{Te}^{121}$. The log*ft* value of 5.03 for this transition is consistent with an allowed transition from a $d_{5/2}$ state of ${}_{53}\mathrm{I}^{121}$.

References:

${}_{50}\mathrm{Sn}^{121}$, ND p. 135, NDS2 p. 33; ${}_{52}\mathrm{Te}^{121}$, ND p. 143, NDS p. 27; ${}_{53}\mathrm{I}^{121}$, ND p. 148.
(D26) R. B. Duffield and L. M. Langer, Phys. Rev. **76**, 1272 (1949).
(N2) C. M. Nelson, G. E. Boyd, and B. H. Ketelle, Oak Ridge National Laboratory, ORNL-828 (1950).
(H10) R. D. Hill, Phys. Rev. **76**, 186A, 333 (1949).
(C17) J. M. Cork, A. E. Stoddard, C. E. Branyan, W. J. Childs, D. W. Martin, and J. M. LeBlanc, Phys. Rev. **84**, 596 (1951).

A = 122

I. The 69-kev transition from 3.5-min ${}_{51}\mathrm{Sb}^{122}$ has been identified as either M3 or E3 (D9) (G10). There is a strong possibility that the isomeric transition takes place in two steps (59 and 74 kev) (C4).

II. The log*ft* values of the 1.36 β^- and 1.94 β^- transitions from 2.8-day ${}_{51}\mathrm{Sb}^{122}$ are given as 7.37 and 7.99, respectively (F4). The shape of the 1.94 β^- spectrum has been determined as α-type, $\Delta I=2$, yes, (W9) (G3).

III. The reported $\beta-\gamma$ angular correlations of 2.8-day ${}_{51}\mathrm{Sb}^{122}$ would indicate a forbidden 1.36 β^- transition of allowed shape (M1), (S8). Gamma-gamma angular correlation experiments between the 680- and 568-kev transitions are consistent with 2, 2, 0 levels (G3).

IV. The level assignment of 2− for the 2.8-day ${}_{51}\mathrm{Sb}^{122}$ ground state is consistent with a $g_{7/2}$ and $h_{11/2}$ odd-proton, odd-neutron configuration (S6).

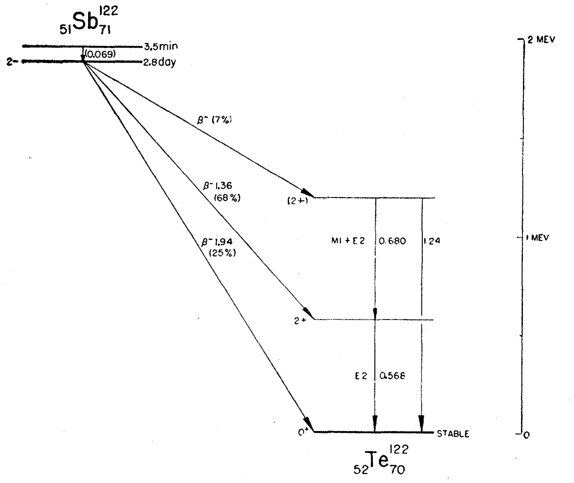

FIG. 41. $A=122$.

References:

${}_{51}\mathrm{Sb}^{122}$, ND p. 138.
(D9) E. der Mateosian and M. Goldhaber, Phys. Rev. **82**, 115 (1951).
(C4) E. C. Campbell (private communication, 1951); J. H. Kahn, Oak Ridge National Laboratory, ORNL-1089 (1951).
(S8) I. Shaknov, Phys. Rev. **82**, 333A (1951).
(M1) P. A. Macklin, L. I. Lidofsky, and C. S. Wu, Phys. Rev. **82**, 334A (1951).
(G3) M. Glaubman and F. R. Metzger (private communication, 1952).
(S6) J. M. C. Scott, Cavendish Laboratory (unpublished manuscript, 1951).
(W9) C. S. Wu, International Conference on Nuclear Physics, Chicago, Illinois (1951).

A = 123

I. From the energies of the beta-rays associated with the 126-day ${}_{50}\mathrm{Sn}^{123}$ and of the beta- and γ-rays associated with the 39.5-min ${}_{50}\mathrm{Sn}^{123}$, it is found that the two isomeric levels have nearly the same energy, to within about 20 kev (D26) (N2).

II. The log*ft* value of the 1.42 β^- spectrum is 9.0 ($\log f_1 t=8.8$), and the shape is of the characteristic α-type ($\Delta I=2$, yes) (N2). Since the ground state of ${}_{51}\mathrm{Sb}^{123}$ has a measured spin of 7/2, the 126-day ${}_{50}\mathrm{Sn}^{123}$ state is characterized as $h_{11/2}$. Similarly the log*ft* value of the 1.26 β^- spectrum is 5.3. The assignment of a $d_{3/2}$ character to the 39.5-min ${}_{50}\mathrm{Sn}^{123}$ isomeric state is based on (1) the identification of the 1.26 β^- decay as an allowed transition, (2) the 153-kev γ-ray as an M1 transition from its conversion coefficient, and (3) the prediction of a $d_{3/2}$ state on the basis of nuclear shell theory.

III. The 104-day ${}_{52}\mathrm{Te}^{123}$ isomeric state has been identified as $h_{11/2}$ (H10). The stable ${}_{52}\mathrm{Te}^{123}$ ground state of measured spin 1/2 is reached by the emission of an 88-kev M4 transition and a 159-kev M1 transition. The 159-kev transition is also exhibited in the decay of 13-hr ${}_{53}\mathrm{I}^{123}$ (M32), and the ϵ-capture transition probably occurs directly to the 159-kev excited level.

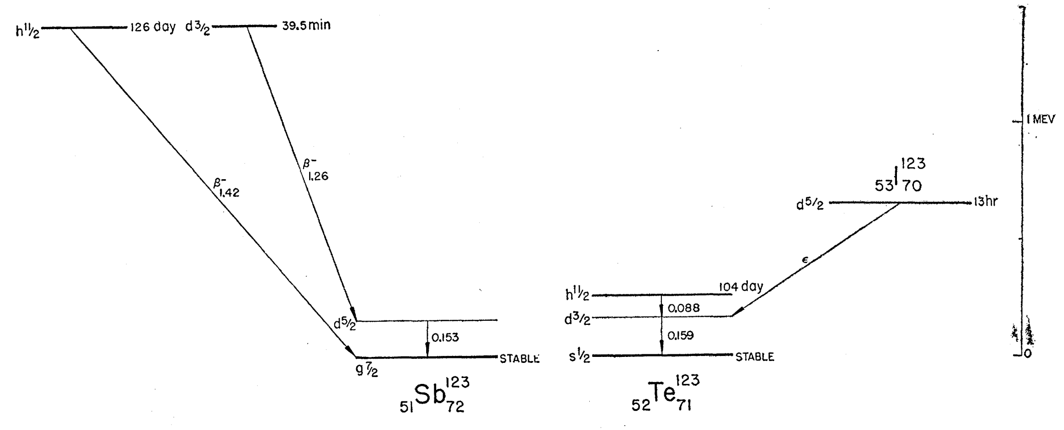

FIG. 42. $A=123$.

References:

$_{50}Sn^{123}$, ND p. 136; $_{52}Te^{123}$, ND p. 143, NDS p. 27; $_{53}I^{123}$, ND p. 149.

(D26) R. B. Duffield and L. M. Langer, Phys. Rev. **76**, 1272 (1949).

(N2) C. M. Nelson, G. E. Boyd, and B. H. Ketelle, Oak Ridge National Laboratory, ORNL-828 (1950).

(H10) R. D. Hill, Phys. Rev. **76**, 186A, 333 (1949).

(M32) A. C. G. Mitchell, J. Y. Mei, F. C. Maienschein, and C. L. Peacock, Phys. Rev. **76**, 1450 (1949).

A=124

I. The 18.5-kev isomeric transition of 21-min $_{51}Sb^{124}$ from its lifetime is probably E3 or M3. A weak β^- branch ~2.5 Mev, possibly complex, followed by γ-rays, has been also observed from 21-min $_{51}Sb^{124}$ (D14). The 1.3-min $_{51}Sb^{124}$ isomer decays by an approximately 12-kev isomeric transition, as well as by β-rays ~3.2 Mev. This beta-branch is evidently allowed and proceeds directly to the ground state of $_{52}Te^{124}$ (D14). The 1.3-min Sb^{124} state is thus tentatively assigned a spin 1+. (The 1.3-min and 21-min $_{51}Sb^{124}$ isomers have so far only been produced by an Sb^{123} (n, γ) reaction, in which the isomeric ratio strongly favors the 60-day state. This fact, as well as the exceedingly soft radiations connected with the isomeric transitions, renders a detailed study difficult.)

II. The β^- spectrum of 60-day $_{51}Sb^{124}$ is complex, and it has been observed that the highest energy component of 2.29 Mev appears to have a shape consistent

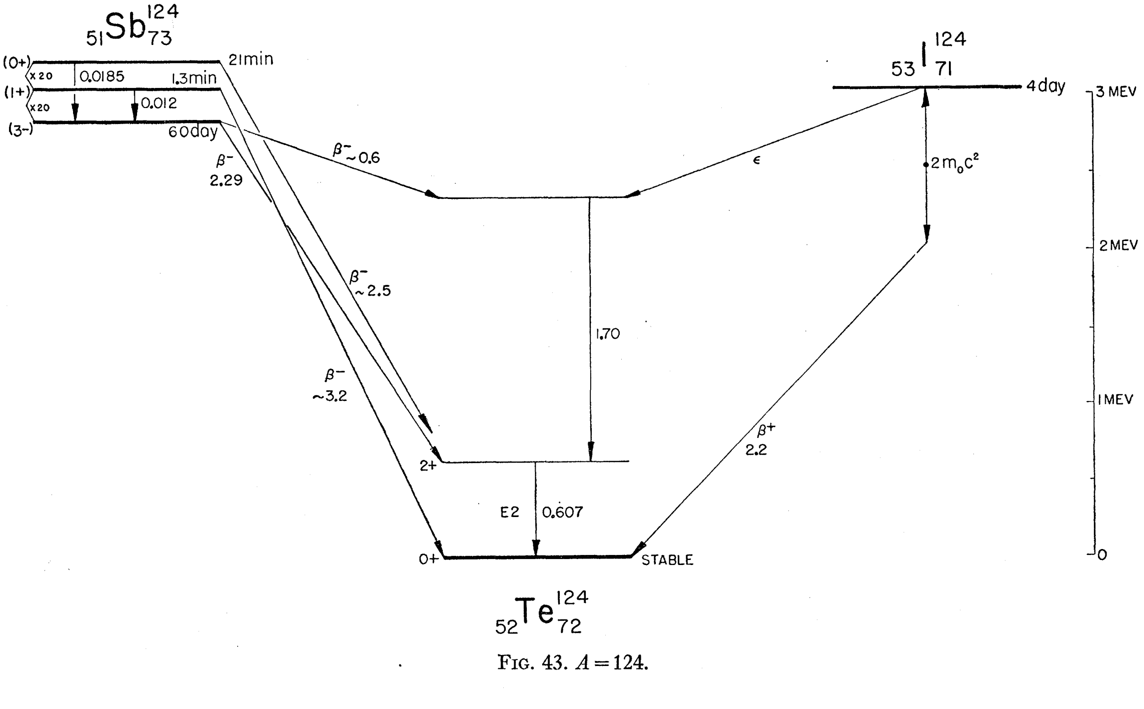

FIG. 43. $A=124$.

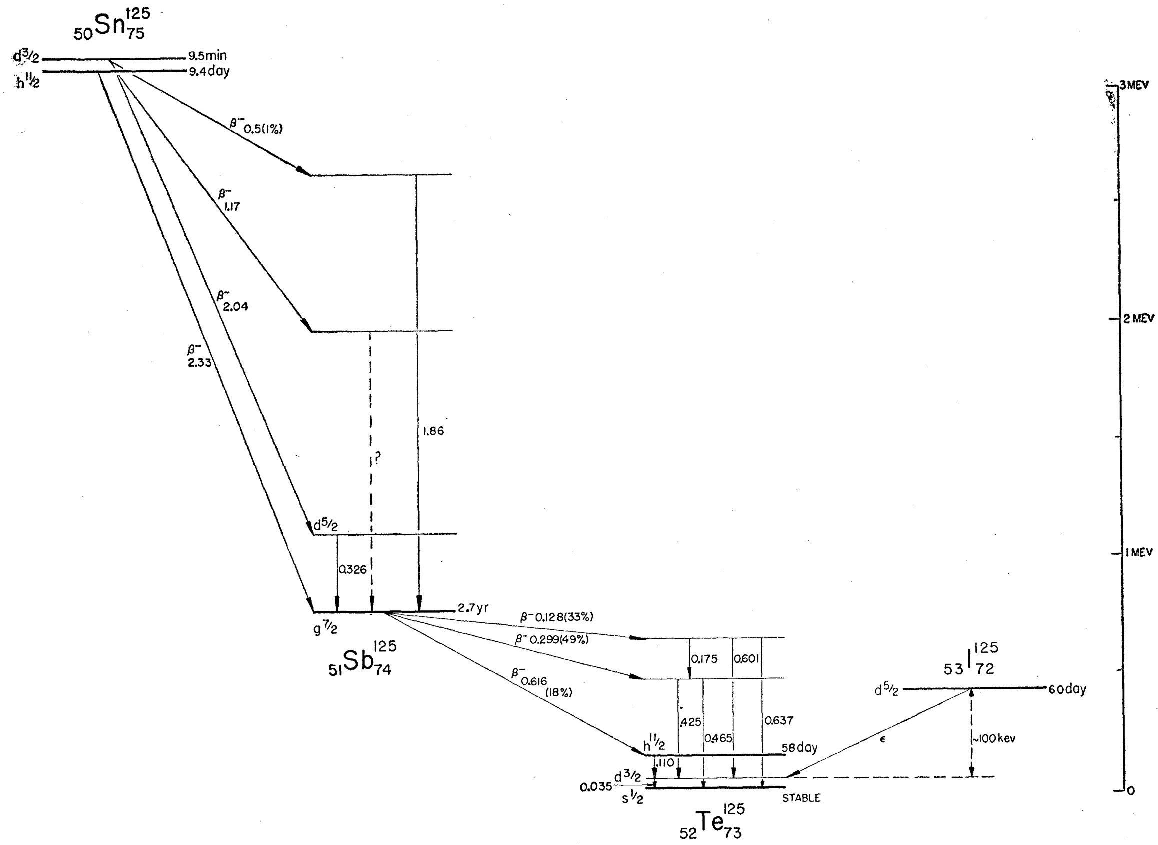

FIG. 44. $A=125$.

with a $\Delta I=2$, yes, transition (L3). The log*ft* value for this transition is high and equal to 10.3. However, $\beta-\gamma$ angular correlation experiments (S23) (D30) between this 2.29 β^- component and the 0.607 γ transition in Te^{124} appear to indicate either 3, 2, 0 or 1, 1, 0 level assignments. Recent experiments on the conversion coefficient of the 0.607 γ-transition identify the 0.607 excited level as 2+ (M37) in preference to 1− (L3). On this basis the spin of the 60-day $_{51}Sb^{124}$ level would appear to be probably 3−. The complex β^- and γ-spectra from 60-day $_{51}Sb^{124}$ are not shown in the diagram since experimental data from various sources are in disagreement. With the spin of the 60-day level identified as 3−, the level assignment for the 21-min isomer becomes probably 0+. These assignments are very tentative, and it is clear that considerably more experimental work is required on the $_{51}Sb^{124}$ decay schemes.

III. A complex γ-spectrum of $_{52}Te^{124}$ has been also observed following the decay of 4-day $_{53}I^{124}$ (M32). The 2.2 β^+ component of the $_{53}I^{124}$ spectrum has been found to lead directly to the ground state of $_{52}Te^{124}$ (S23).

References:

$_{51}Sb^{124}$, ND p. 139, NDS p. 26, NDS2 p. 34; $_{52}Te^{124}$, ND p. 144; $_{53}I^{124}$, ND p. 149.
(D14) E. der Mateosian, M. Goldhaber, C. O. Muehlhause, and M. McKeown, Phys. Rev. **72**, 1271 (1947); and unpublished data.
(L3) L. M. Langer, R. D. Moffat, and H. C. Price, Jr., Phys. Rev. **79**, 808 (1950).
(M32) A. C. G. Mitchell, J. Y. Mei, F. C. Maienschein, and C. L. Peacock, Phys. Rev. **76**, 1450 (1949).
(S23) D. T. Stevenson, Phys. Rev. **82**, 333 (1951).
(D30) E. K. Darby, Can. J. Phys. **29**, 569 (1951).
(S24) D. T. Stevenson and M. Deutsch, Phys. Rev. **83**, 1202 (1951).
(M37) F. R. Metzger, Phys. Rev. **86**, 435 (1952).

$A=125$

I. The 9.5-min and 9.4-day isomeric states of $_{50}Sn^{125}$ have been identified as $d_{3/2}$ and $h_{11/2}$, respectively (N2). No isomeric transition between the states has been observed, and theoretically it would be of very low intensity, indeed, relative to the 9.5-min β^- transitions. Based on β- and γ-ray energies the 9.5-min state would lie at an excitation of 36 (±20) kev above the 9.4-day state. If this is correct, we have here a possible example of an $h_{11/2}$ ground state (N2) (D27) (H5) (L5).

II. The 2.33 β^- spectrum of 9.4-day $_{50}Sn^{125}$ has been identified, from shape and log*ft* value (8.9), as 1st forbidden, $\Delta I=2$, yes (N2). This β^- transition is consistent with an $h_{11/2}$ to $g_{7/2}$ spin change. The 2.04 and 1.17 β^- transitions of 9.5-min $_{50}Sn^{125}$ have log*ft* values ~ 5 and are probably allowed transitions from the initial $d_{3/2}$ state.

III. The 58-day and stable $_{52}Te^{125}$ states have been identified with spins $h_{11/2}$ and $s_{1/2}$, respectively (H10). The measured spin of stable $_{52}Te^{125}$ is 1/2 (F10). The isomeric states are separated by an intermediate $d_{3/2}$ state and the successive M4 and M1 transitions from the 58-day state have been observed (H10) (S13). The complex β- and γ-spectra from $_{51}Sb^{125}$ correlate well with the $_{52}Te^{125}$ levels (S13) (K6).

IV. The logft values of the 0.616, 0.299, and 0.128 β^- component transitions of $_{51}Sb^{125}$ are 9.41, 7.93, and 6.93, respectively (F4). All groups are probably 1st forbidden, with the highest energy group probably of the type $\Delta I = 2$, yes, since log$f_1t = 8.9$.

V. ϵ-capture from 58-day $_{53}I^{125}$ occurs to the 35-kev excited $d_{3/2}$ state of $_{52}Te^{125}$ (R2) (B11). The spin assignment for the ground state of $_{53}I^{123}$ is probably $d_{5/2}$ (F16). $_{53}I^{125}$ also possesses a number of known γ-ray levels following the decay of $_{54}Xe^{125}$ which are not included in the scheme here (B11). The energy difference between the $_{53}I^{125}$ ground state and the $_{52}Te^{125}$ $d_{3/2}$ state is deduced from the L/K electron capture ratio of ~ 0.23 (F16) (D31).

References:

$_{50}Sn^{125}$, ND p. 136, NDS p. 25, NDS2 p. 33; $_{51}Sb^{125}$, ND p. 140' NDS p. 26; $_{52}Te^{125}$, ND p. 144, NDS p. 27, NDS2 p. 35; $_{53}I^{125}$, ND p. 149.
(N2) C. M. Nelson, G. E. Boyd, and B. H. Ketelle, Oak Ridge National Laboratory, ORNL-828 (1951).
(D27) R. B. Duffield and L. M. Langer, Phys. Rev. **77**, 743A (1950).
(H5) R. W. Hayward, Phys Rev. **79**, 409 (1950).
(L5) J. C. Lee and M. L. Pool, Phys. Rev. **76**, 606 (1949).
(H10) R. D. Hill, Phys. Rev. **76**, 186A, 333 (1949).
(F10) G. R. Fowles, Phys. Rev. **76**, 571 (1949).
(S13) K. Siegbahn and W. Forsling, Arkiv. Fysik. **1**, 505 (1950).
(K6) B. D. Kern, A. C. G. Mitchell, and D. J. Zaffarano, Phys. Rev. **76**, 94 (1949).
(R2) A. F. Reid and A. S. Keston, Phys. Rev. **70**, 987 (1946).
(B11) I. Bergstrom, Phys. Rev. **82**, 111 (1951).
(F16) G. Freidlander and W. C. Orr, Phys. Rev. **84**, 484 (1951).
(B41) J. C. Bowe and P. Axel, Phys. Rev. **85**, 858 (1952).
(D31) E. der Mateosian (unpublished).

A = 127

I. The 88.5-kev transition in $_{52}Te^{127}$ has been identified, mainly from lifetime considerations, as M4 (H7) (S7) (H10). The 113-day and 9.3-hr $_{52}Te^{127}$ isomeric states are very probably $h_{11/2}$ and $d_{3/2}$, respectively.

II. Growth of 113-day and 9.3-hr $_{52}Te^{127}$ isomers, in the ratio 16 percent to 84 percent, from $_{51}Sb^{127}$ has been shown, but the detailed β^- and γ-spectra are not known (S18) (B16).

III. The decay of 9.3-hr $_{52}Te^{127}$ by 0.70 β^- emission, of log$ft = 5.6$, is consistent with the assignment of $d_{3/2}$ to the $_{52}Te^{127}$ initial state and a $d_{5/2}$ assignment to the final $_{53}I^{127}$ of measured spin 5/2.

IV. The 75-sec and 34-day isomers of $_{54}Xe^{127}$ have been identified with the states $h_{11/2}$ and $s_{1/2}$, respectively (G10). Decay ,from the 75-sec $_{54}Xe^{125}$ state occurs to an intermediate $d_{5/2}$ state by an E3, 175-kev transition, identified on the basis of lifetime. The 96-kev transition energy of the second transition is a re-evaluation based on the assumption that it is electric quadrupole (G10) (C19).

V. The γ-spectrum observed to follow the 34-day $_{54}Xe^{127}$ ϵ-capture is complex, and the scheme shown

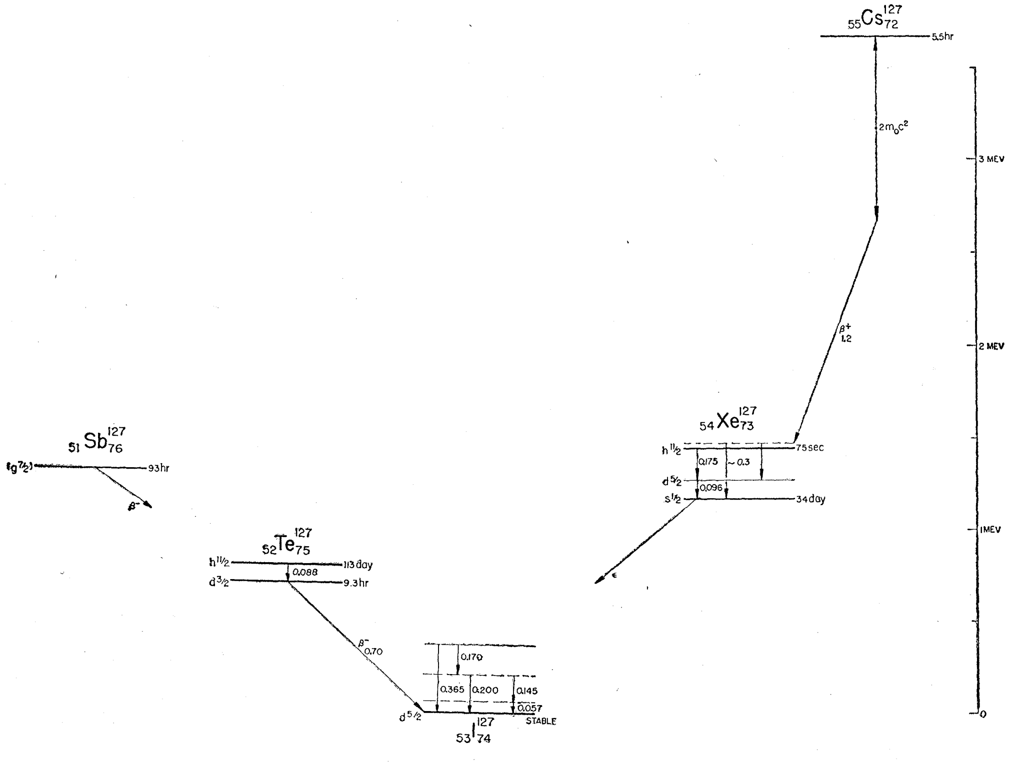

FIG. 45. $A = 127$.

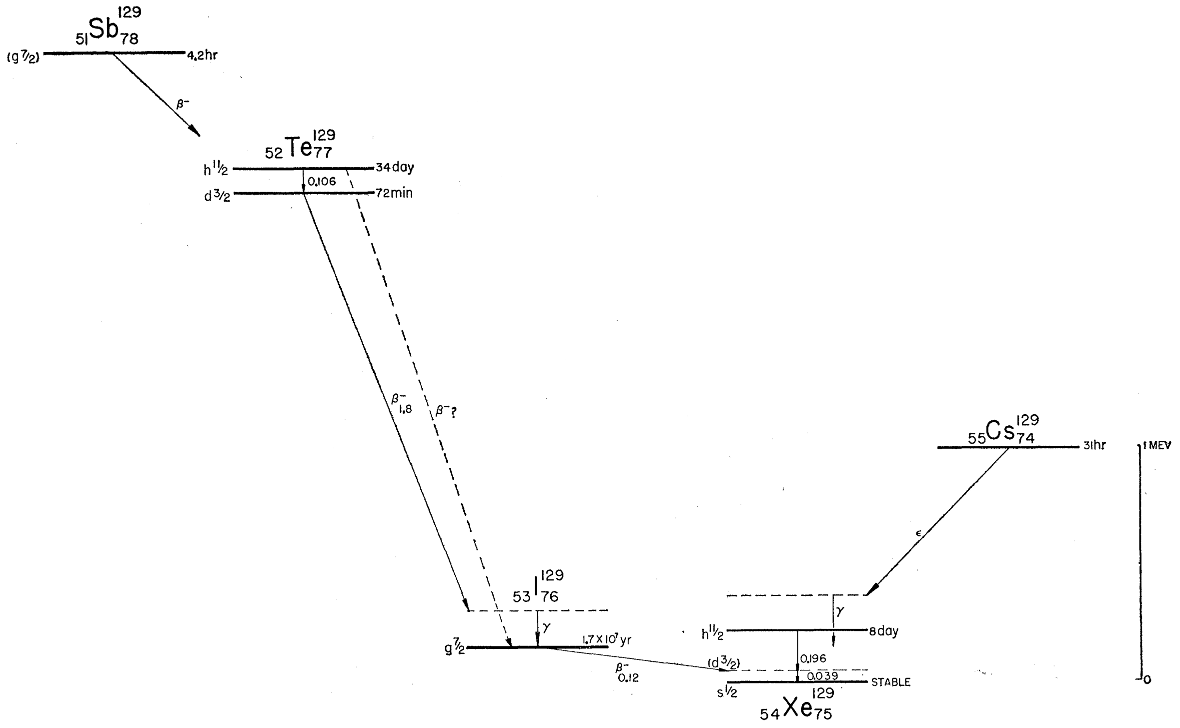

FIG. 46. $A=129$.

above is very tentative (B7). The 5.5-hr $_{55}Cs^{127}$ 1.2 β^+ activity has been shown to lead only to the 34-day $_{54}Xe^{125}$, and again this decay scheme must be regarded as tentative (F5).

References:

$_{51}Sb^{127}$, ND p. 140; $_{52}Te^{127}$, ND p. 145; $_{53}I^{127}$, ND p. 150; $_{54}Xe^{127}$, ND p. 154, NDS p. 28; $_{55}Cs^{127}$, ND p. 159.
(S7) E. Segrè and A. C. Helmholz, Revs. Modern Phys. **21**, 271 (1949).
(H7) A. C. Helmholz, Phys. Rev. **60**, 415 (1941).
(H10) R. D. Hill, Phys. Rev. **76**, 186A, 333 (1949).
(B16) J. Beydon, Compt. rend. **227**, 1159 (1948).
(S18) N. R. Sleight and W. H. Sullivan, National Nuclear Energy Series **9**, paper 131.
(C19) E. C. Creutz, L. A. Delsasso, R. B. Sutton, M. G. White, and W. H. Barkas, Phys. Rev. **58**, 481 (1940).
(B7) I. Bergstrom, Nature **167**, 634 (1951).
(F5) R. W. Fink, F. L. Reynolds, and D. H. Templeton, Phys. Rev. **77**, 614 (1950).

$A=129$

I. The 34-day and 72-min $_{52}Te^{129}$ isomers have been identified with $h_{11/2}$ and $d_{3/2}$ states (H10) and the 106-kev transition has been observed to be M4 (H7) (S7).

II. The 72-min $_{52}Te^{129}$ grows from $_{51}Sb^{129}$ (A1). If the 4.2-hr ground state of $_{51}Sb^{129}$ has the assigned spin $g_{7/2}$, it is unlikely that the β^- transition is directly to the 72-min $_{52}Te^{129}$ ground state.

III. The measured spin of 1.7×10^7 yr $_{53}I^{129}$ is 7/2 (L12) (K3). The 1.8 β^- transition of 72-min $_{53}Te^{129}$ (R1), $\log ft=6.13$ (F4), is therefore unlikely to proceed to the 1.7×10^7 yr state of $_{53}I^{129}$. The β^- transition from the 34-day $_{52}Te^{129}$ state to the ground state of I^{129} should be of the type $\Delta I=2$, yes, on the basis of the assignments shown. The half-life for such a transition is computed to be <25 days, and there should be therefore considerable competition with the 106-kev I.T. The existence of a β-branch has been postulated also (G10) to explain the low Szilard-Chalmers yield observed by Williams (W7) for this isomer.

IV. A 196-kev transition arising from 8-day $_{54}Xe^{129}$ has been identified as M4 (B7) (G10). However, the stable $_{54}Xe^{129}$ has spin 1/2, and it seems necessary to postulate a low-excited $d_{3/2}$ level (G10). β-branching may occur in I^{129}. There is evidence for a 39-kev transition arising from the 1.7×10^7 yr $_{53}I^{129}$ following a 0.12 β^- transition, which might be the $d_{3/2}$ to $s_{1/2}$ transition (B18). A $\log ft$ value for this β^- transition is 13.37, which may be consistent with a $g_{7/2}$ to $d_{3/2}$ transition ($\Delta I=2$, no, 2nd forbidden). The value of $\log ft$ (D2) appears to be too small by a factor of 10^3 to identify the 0.12 β^- transition as of the special type $\Delta=3$, no. It is improbable therefore that this transition leads to the ground state of $_{54}Xe^{129}$. The 2nd, $d_{3/2}\rightarrow s_{1/2}$ transition of 40 kev in the decay of $_{54}Xe^{129m}$ has recently been observed (T3).

V. The 31-hour $_{55}Cs^{129}$ ϵ-capture activity is not observed to decay through the 8-day $_{54}Xe^{129}$ isomeric state (F5). Conversion electrons of $\sim$0.3 Mev are associated with the $_{55}Cs^{129}$ activity (F5).

References:

$_{51}Sb^{129}$, ND p. 140; $_{52}Te^{129}$, ND p. 145; $_{53}I^{129}$, ND p. 150, NDS p. 28.

(H10) R. D. Hill, Phys. Rev. **76**, 186A, 333 (1949).
(H7) A. C. Helmholz, Phys. Rev. **60**, 415 (1941).
(S7) E. Segrè and A. C. Helmholz, Revs. Modern Phys. **21**, 271 (1949).
(A1) P. Abelson, Phys. Rev. **56**, 1 (1939).
(L12) R. Livingston, O. R. Gilliam, and W. Gordy, Phys. Rev. **76**, 149 (1949).
(R1) W. Rall and R. G. Wilkinson, Phys. Rev. **71**, 321 (1947).
(B7) I. Bergstrom, Nature **167**, 634 (1951).
(B18) C. J. Borkowski and A. R. Brosi, Oak Ridge National Laboratory, ORNL-607 (1950); quoted by NDS p. 28.
(P3) G. W. Parker, G. E. Creek, G. N. Herbert, and P. M. Lanitz, Oak Ridge National Laboratory, ORNL-286 (1949).
(F5) R. W. Fink, F. L. Reynolds, and D. H. Templeton, Phys. Rev. **77**, 614 (1950).
(K3) S. Katcoff, O. A. Schaeffer, and J. M. Hastings, Phys. Rev. **82**, 688 (1951).
(T3) S. Thulin and I. Bergstrom (private communication, 1952); Phys. Rev. **85**, 1055 (1952).
(W7) R. R. Williams, Jr., J. Chem. Phys. **16**, 513 (1948).

$A=131$

I. The 1.25-day ${}_{52}\mathrm{Te}^{131}$ 183-kev transition is identified as an M4 transition (H7). The possibility of a 60 percent β^- branch from the 1.25-day ${}_{52}\mathrm{Te}^{131}$ state is also indicated (W7) (G10). The logft of such a transition $\gtrsim 2$ Mev would be $\gtrsim 8$, a value which is not unreasonable for a 1st forbidden transition, $\Delta I=2$, yes.

II. The 25-min ${}_{52}\mathrm{Te}^{131}$ and 1.25-day ${}_{52}\mathrm{Te}^{131}$ isomers have been given assignments, $d_{3/2}$ and $h_{11/2}$, on the basis of the nuclear shell model (H10).

III. The logft value for the 25-min ${}_{52}\mathrm{Te}^{131}$ and a β^- energy of ~ 2 Mev (S35) is 5.7. This value is too low for the $d_{3/2}$ to $g_{7/2}$ transition shown. It is possible that the β^- transition from the 25-min ${}_{52}\mathrm{Te}^{131}$ state goes to an excited state of ${}_{53}\mathrm{I}^{131}$.

IV. The decay of 8-day ${}_{53}\mathrm{I}^{131}$ is associated with complex β^- and γ-spectra. It has been studied by many investigators. The decay scheme shown is that adopted by Metzger and Schiff (M24) (S4). Some weak cross-over transitions observed by these authors are not shown. The following states of ${}_{54}\mathrm{Xe}^{131}$ have been identified definitely: (1) a 12-day ${}_{54}\mathrm{Xe}^{131m}$ which decays with an I.T. of 163 kev to the ground state and which has been identified with an $h_{11/2}$ state (B29) (B9); (2) a $(5\pm 1)\times 10^{-10}$ sec ${}_{54}\mathrm{Xe}^{131m}$ (G15) which decays by an 80-kev I.T. to the ground state and which must be identified from the K/L ratio (M25) (K6) of the transition as mainly M1, suggesting an $s_{1/2}$ state (S4); and (3) the ground state ${}_{54}\mathrm{Xe}^{131}$ which has a measured spin of 3/2 and suggests a ground state of $d_{3/2}$.

V. The approximately 1 percent yield of 12-day ${}_{54}\mathrm{Xe}^{131m}$ from 8-day ${}_{53}\mathrm{I}^{131}$ is consistent with a 1st forbidden, $\Delta I=2$, yes, transition from a $g_{7/2}$ to an $h_{11/2}$ level (B29) (B9) (Z1) ($\log f_1 t \sim 8.96$) (K19).

VI. The 9.6-day ${}_{55}\mathrm{Cs}^{131}$ ϵ-capture activity proceeds to the ground state of ${}_{54}\mathrm{Xe}^{131}$, and the probable spin of ${}_{55}\mathrm{Cs}^{131}$ is $d_{5/2}$ (C6).

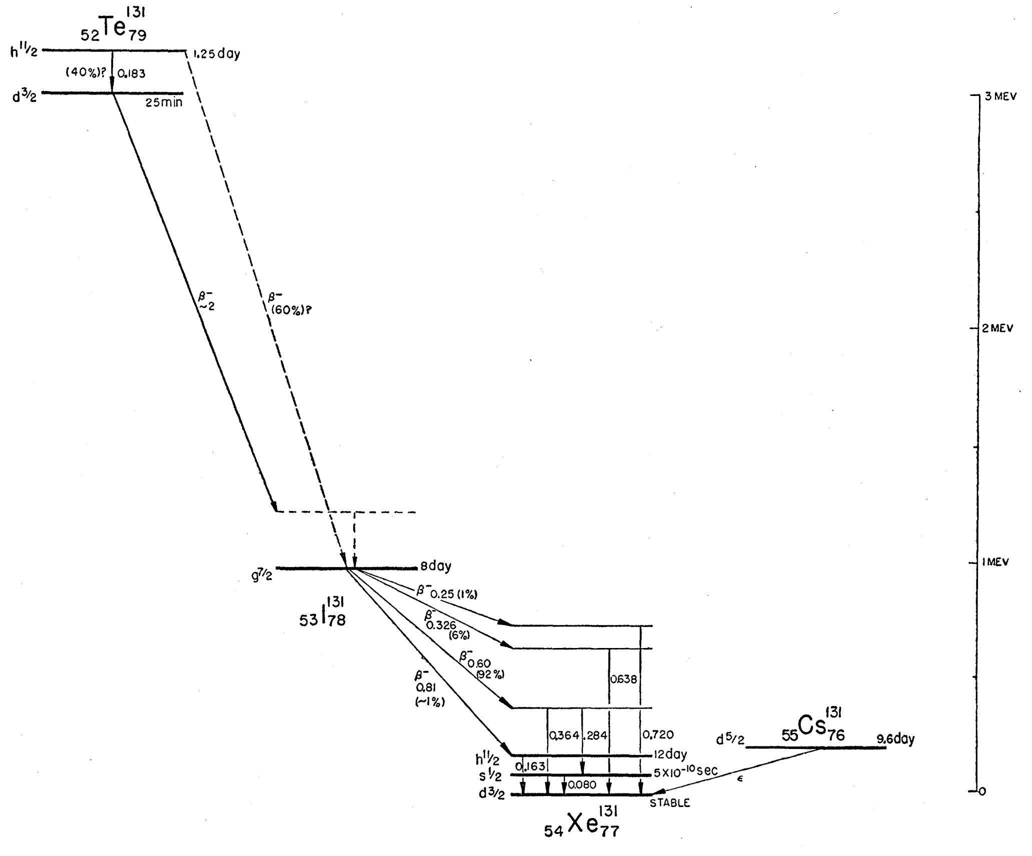

FIG. 47. $A=131$.

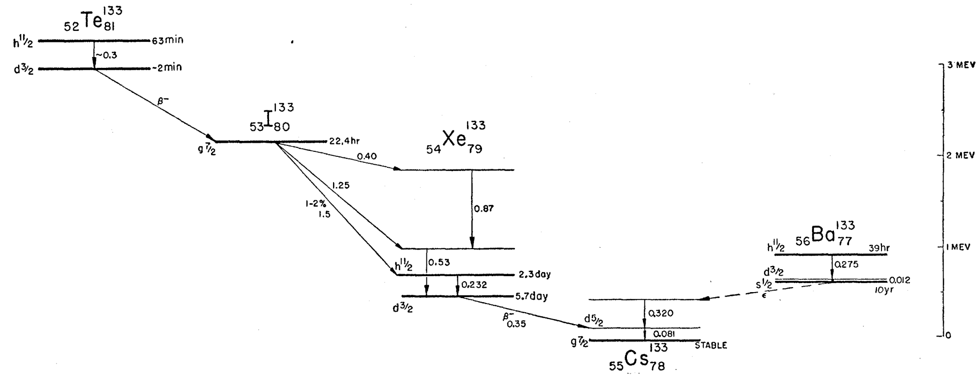

FIG. 48. $A=133$.

References.

$_{52}Te^{131}$, ND p. 146; $_{53}I^{131}$, ND p. 151, NDS2 p. 35; $_{54}Xe^{131}$, ND p. 155, NDS p. 28, NDS2 p. 36; $_{55}Cs^{131}$, ND p. 159.
(H7) A. C. Helmholz, Phys. Rev. **60**, 415 (1951).
(W7) R. R. Williams, Jr., J. Chem. Phys. **16**, 513 (1948).
(H10) R. D. Hill, Phys. Rev. **76**, 186A, 333 (1949).
(B29) A. R. Brosi, T. W. DeWitt, and H. Zeldes, Phys. Rev. **75**, 1615 (1949).
(B9) I. Bergstrom, Phys. Rev. **80**, 114 (1950).
(G15) R. L. Graham (private communication, 1951); R. L. Graham and R. E. Bell, Phys. Rev. **84**, 380 (1951).
(M25) F. Metzger and M. Deutsch, Phys. Rev. **74**, 1640 (1948).
(K6) B. D. Kern, A. C. G. Mitchell, and D. J. Zaffarano, Phys. Rev. **76**, 94 (1949).
(Z1) H. Zeldes, A. R. Brosi, and B. H. Ketelle, Phys. Rev. **81**, 642 (1951).
(B2) P. R. Bell, J. M. Cassidy, and G. G. Kelley, Phys. Rev. **82**, 103 (1951).
(C6) R. Canada and A. C. G. Mitchell, Phys. Rev. **83**, 76 (1951).
(S4) D. Schiff, Phys. Rev. **86**, 727A (1952).
(S35) L. Seren, H. N. Friedlander, and S. H. Turkel, Phys. Rev. **72**, 888 (1947).
(K16) B. H. Ketelle, H. Zeldes, A. R. Brosi, and R. A. Dandl, Phys. Rev. **84**, 585 (1951).
(V1) N. F. Verster, G. J. Nijgh, R. van Lieshout, and C. J. Bakker, Physica **17**, 637 (1951).
(N6) G. J. Nijgh, N. F. Verster, R. H. Nussbaum, R. van Lieshout, and C. J. Bakker, Physica **17**, 658 (1951).
(M24) F. Metzger (private communication).
(K19) R. W. King (private communication).

A = 133

I. The isomeric transitions from 63-min $_{52}Te^{133m}$, 2.3-day $_{54}Xe^{133m}$, and 39-hr $_{56}Ba^{133m}$ have been identified as M4 transitions from $h_{11/2}$ to $d_{3/2}$ states (P1) (B8) (H12).

II. The decay of the 39-hr $_{56}Ba^{133m}$ is by two steps of 275 and 11.7 kev. The 10-yr ground state of $_{56}Ba^{133}$ is therefore identified as $s_{1/2}$, by similarity arguments with $_{54}Xe^{129}$ and $_{52}Te^{125}$ (H13).

III. The ground state of $_{54}Xe^{133}$ can be identified as $d_{3/2}$, via the 0.35 β^- and 0.081 γ-transitions to the known $g_{7/2}$ ground state of $_{55}Ca^{133}$. The 0.35 β^- transition of $_{54}Xe^{133}$, 5.7 day, is undoubtedly allowed, $\log ft=5.48$; and the 81-kev γ-ray is M1 (Y1) (B8).

IV. The decay scheme for $_{53}I^{133}$ given here is based on unpublished work of Brosi (B39), kindly communicated to us by K. Way, who suggested the spin assignments connected with this scheme. An unassigned γ-ray of 1.2 Mev was also found.‖ ‖

References:

$_{51}Sb^{133}$, NDS2 p. 34; $_{52}Te^{133}$, ND p. 146; $_{53}I^{133}$, ND p. 152; $_{54}Xe^{133}$, ND p. 156, NDS p. 28, NDS2 p. 36; $_{55}Cs^{133}$, ND p. 160; $_{56}Ba^{133}$, ND p. 165.
(P1) A. C. Pappas and C. D. Coryell, Phys. Rev. **81**, 329A (1951).
(B8) I. Bergstrom and S. Thulin, Phys. Rev. **79**, 538 (1950); I. Bergstrom, Phys. Rev. **81**, 638 (1951).
(H12) R. D. Hill and F. R. Metzger, Phys. Rev. **83**, 455 (1951).
(H13) R. D. Hill, G. Scharff-Goldhaber, and M. McKeown, Phys. Rev. **84**, 382 (1951).
(Y1) Fu-Chun Yu and J. D. Kurbatov, Phys. Rev. **74**, 34 (1948).
(T4) S. Thulin, I. Bergstrom, and A. Hedgran, Phys. Rev. **76**, 871 (1949).
(M2) J. Macnamara, G. B. Collins, and H. G. Thode, Phys. Rev. **78**, 129 (1950).
(K7) B. H. Ketelle, A. R. Brosi, and H. Zeldes, Phys. Rev. **80**, 485 (1950).
(B39) A. R. Brosi (unpublished work, communicated by K. Way).

A = 134

I. The 128-kev isomeric transition from the 3.1-hr $_{55}Cs^{134}$ state is identified from lifetime and conversion considerations as E3 (G10) (C1) (S26).

II. The spin of the 2.3-yr $_{55}Cs^{134}$ state has a measured value of 4 (F17).

III. Angular correlation experiments have shown that the spins of the first and second excited states of $_{56}Ba^{134}$ are 2 and 4, respectively (B27), and that the third excited state has spin 5 (R7).

IV. The $\log ft$ value of the 0.66 β^- component of the 2.3-yr $_{55}Cs^{134}$ decay is 8.88 (F4), and the spectrum has an allowed shape (E3). The $\log ft$ value of the 0.09 component is 6.47 (F4). Although the $\log ft$ values are high, both transitions may be allowed, and the parity of the 2.3-yr $_{55}Cs^{134}$ state is therefore uncertain.

V. No direct β^- transition from the 3.1-hr $_{55}Cs^{134}$ state to the ground state of $_{56}Ba^{134}$ has been observed (D6). The spin of the 3.1-hr isomeric state may therefore be high (7±), rather than low (1±).

‖ ‖ *Note added in proof.*—Beta-decay from 2-min Te^{133} does not take place directly (as shown in Fig. 48) to the ground state of $_{53}I^{133}$. A provisional decay scheme involving two beta-branches to excited states of $_{53}I^{133}$ has been given by A. C. Pappas (Phys. Rev. **87**, 162 (1952)).

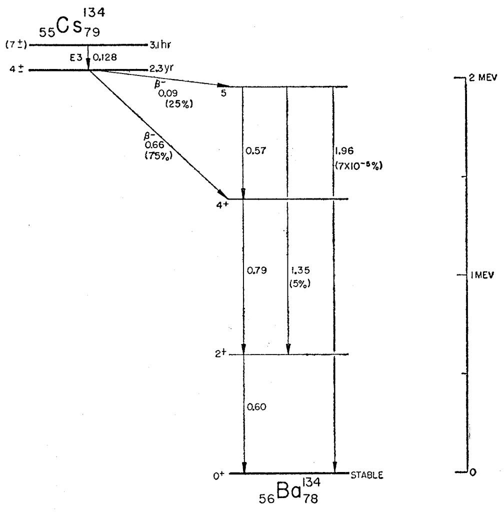

FIG. 49. $A=134$.

References:

$_{55}Cs^{134}$, ND p. 160, NDS p. 29, NDS2 p. 37.
(C1) R. L. Caldwell, Phys. Rev. **78**, 407 (1950).
(E3) L. G. Elliott and R. E. Bell, Phys. Rev. **72**, 979 (1947).
(B27) E. L. Brady and M. Deutsch, Phys. Rev. **78**, 558 (1950); **74**, 1541 (1948).
(S26) A. W. Sunyar, Phys. Rev. **83**, 864 (1951).
(R7) B. L. Robinson and L. Madansky, Phys. Rev. **84**, 604 (1951).
(F17) O. Frisch, E. H. Bellamy, and K. F. Smith, International Conference on Nuclear Physics, Chicago (1951).
(D6) E. der Mateosian (private communication, 1951).

A=135

I. Both the 520-kev I.T. in $_{54}Xe^{135}$ and the 269-kev I.T. in $_{56}Ba^{135}$ have been identified as M4 transitions (S7) (A8) (G10). The measured ground state of stable $_{56}Ba^{135}$ is $d_{3/2}$ (A6), thus making the 29-hr $_{56}Ba^{135m}$ state $h_{11/2}$. The 9.2-hr $_{54}Xe^{135}$ and 15.3-min $_{54}Xe^{135}$ are analogously identified as $d_{3/2}$ and $h_{11/2}$, respectively.

II. The β^- and γ-spectra of 6.7-hr $_{53}I^{135}$ have been fitted tentatively into a decay scheme (P4). The 1.4 β^- component on this scheme would be 1st forbidden, $\Delta I=2$, yes. The log*ft* value of 7.1 (F4) and re-analysis on the basis of the α-type β-spectrum shape might bring the *ft* value into better accord with a $\Delta I=2$, yes, transition. The 1.4 β^- component shows no $\beta-\gamma$ coincidences (P4).

III. The 0.93 β^- spectrum of 9.2-hr $_{54}Xe^{135}$ is of the allowed shape (B12) and is consistent with a $d_{3/2}$ to $d_{5/2}$ transition.

IV. The 0.21 β^- decay of 2×10^6 yr $_{55}Cs^{135}$ has log*ft* $=13.9$ (F4), a value which is consistent with a 2nd forbidden transition between the known spin states $g_{7/2}$ to $d_{3/2}$.

References:

$_{53}I^{135}$, ND p. 152; $_{54}Xe^{135}$, ND p. 156; $_{55}Cs^{135}$, ND p. 161, NDS2 p. 37; $_{56}Ba^{135}$, ND p. 165; $_{57}La^{135}$, ND p. 168.
(P4) C. L. Peacock, A. R. Brosi, and A. Bogard, Oak Ridge National Laboratory, ORNL reports, as quoted in ND p. 152.
(B12) I. Bergstrom, Phys. Rev. **82**, 112 (1951).
(H12) R. D. Hill and F. R. Metzger, Phys. Rev. **83**, 455 (1951).
(C10) W. H. Cuffey and R. Canada, Phys. Rev. **83**, 654 (1951).
(A6) O. H. Arroe, Phys. Rev. **79**, 836 (1950).

A=137

I. The 661-kev transition of 2.6-min $_{56}Ba^{137}$ has been identified as M4 (O2). Since the spin and magnetic moment of $_{56}Ba^{137}$ indicate a $d_{3/2}$ ground state, the 2.6-min $_{56}Ba^{137m}$ state is identified as $h_{11/2}$.

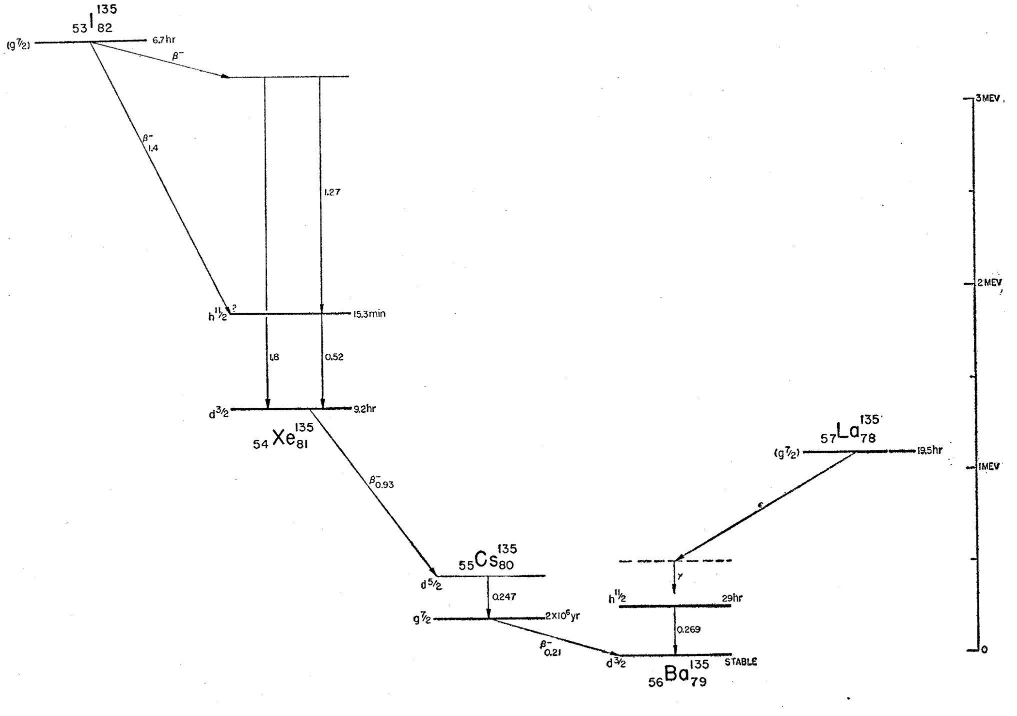

FIG. 50. $A=135$.

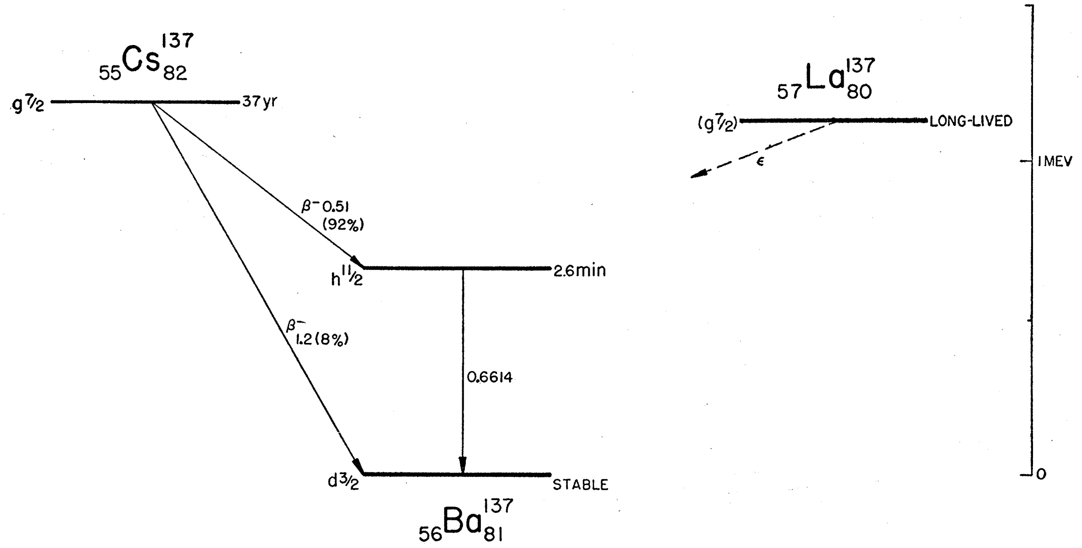

FIG. 51. $A=137$.

II. The assignment of $h_{11/2}$ to the 2.6-min $_{56}Ba^{137m}$ is consistent with the $\log ft$ value (9.6), $\log f_1t=8.85$, and the α-type shape of the 0.51 β^- transition from the measured $g_{7/2}$ state of 37-yr $_{55}Cs^{137}$ (O2) (L4) (P5) (D3) (A2) (W1).

III. The $\log ft$ value of the 8 percent 1.2 β^- transition from 37-yr $_{55}Cs^{137}$ is 11.6, and it is consistent with a 2nd forbidden transition as in the case of 2×10^6-yr $_{55}Cs^{135}$ (L2).

References:

$_{55}Cs^{137}$, ND p. 161, NDS2 p. 37; $_{56}Ba^{137}$, ND p. 166, NDS p. 29; $_{57}La^{137}$, ND p. 168.
(O2) J. S. Osaba, Phys. Rev. **76**, 345 (1949).
(L4) L. M. Langer and H. C. Price, Jr., Phys. Rev. **76**, 641 (1949).
(P5) C. L. Peacock and A. C. G. Mitchell, Phys. Rev. **75**, 1272 (1949); C. L. Peacock, Phys. Rev. **76**, 186A (1949).
(A2) H. M. Agnew, Phys. Rev. **77**, 655 (1950).
(D3) L. Davis, Jr., D. E. Nagle, and J. R. Zacharias, Phys. Rev. **76**, 1068 (1949).
(L2) L. M. Langer and R. J. D. Moffat, Phys. Rev. **82**, 635 (1951).
(W1) M. A. Waggoner, Phys. Rev. **80**, 489 (1950).

A = 152

$_{63}Eu_{89}$ $T_1=9.2$ hr, ϵ, β^-, γ,
$T_2=5.3$ yr, ϵ, β^-, γ.

I. No isomeric transition between these isomers has been observed. A considerable amount of information is available on the disintegration schemes. However, the data show serious contradictions which prevent the construction of satisfactory schemes at this stage.

References:

$_{63}Eu^{152}$, ND p. 186, NDS p. 33, NDS2 p. 40.
(K4) H. B. Keller, Argonne National Laboratory, ANL-4595 (1951).
(K5) H. B. Keller and J. M. Cork, Phys. Rev. **84**, 1079 (1951).

A = 153

I. A delay of 3×10^{-9} sec has been observed between β^- particles of 47-hr $_{62}Sm^{153}$ and internal conversions of a subsequent 70-kev γ-transition in $_{63}Eu^{153}$ (M13) (M9). The 70-kev isomeric transition is probably an M1 and E2 mixture (M13) (M9).

II. No delay has been observed between the x-rays arising from ϵ-capture of 225-day $_{64}Gd^{153}$ and the internal conversion electrons of a 103-kev transition in $_{63}Eu^{153}$ (M9) (M27). In view of this, the 70-kev transition must be considered as preceding the 103-kev transition. The 103-kev transition is also probably a mixture of M1 and E2 (M27) (S39).

III. The ground state of $_{63}Eu^{153}$ appears to be an $f_{5/2}$ state from spin and magnetic moment measurements. This assignment represents an anomaly with shell structure theory which predicts rather a $d_{5/2}$ state.

IV. Much work on the decay of 47-hr $_{62}Sm^{153}$ has been done, but it is apparent that the data are not all consistent (B37) (H8). The above scheme indicates that the main β^- component is the 0.70 Mev, and the 0.53 γ-transition is tentatively shown as ending on the 0.173 excited level (S39).

References:

$_{62}Sm^{153}$, ND p. 184, NDS p. 32; $_{63}Eu^{153}$, ND p. 186; $_{64}Gd^{153}$, ND p. 188, NDS p. 34.
(M13) F. K. McGowan, Phys. Rev. **80**, 482 (1950).
(M9) F. K. McGowan (private communication, 1951).
(M27) J. W. Mihelich (private communication, 1951).
(B37) S. B. Burson and C. O. Muehlhause, Phys. Rev. **74**, 1264 (1948).
(H8) J. M. Hill and L. R. Shepard, Proc. Phys. Soc. (London) **A63**, 126 (1950).
(S39) K. Siegbahn, M. Siegbahn Commemorative Volume, p. 241 (1952).

A = 160

$_{66}Dy_{94}$ $T_1=1.8\times 10^{-9}$ sec, I.T. = .085,
T_2 (stable).

I. The 85-kev I.T. of 1.8×10^{-9} sec half-life follows the 0.86 β^- transition of 71-day $_{65}Tb^{160}$ (M16).

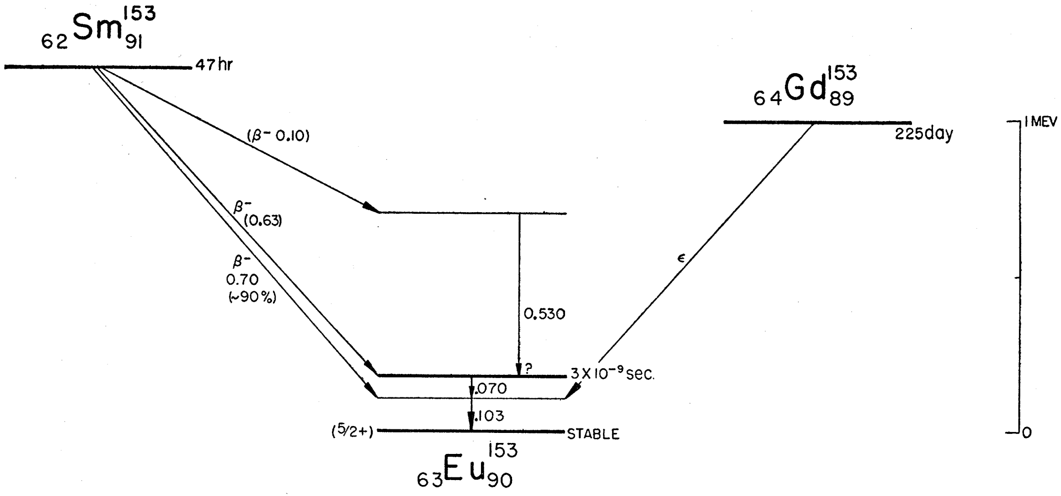

FIG. 52. $A=153$.

II. The disintegration of the 71-day $_{65}Tb^{160}$ is accompanied by complex β^- and γ-spectra (B36) (C12). The relationship of the 85-kev transition to the $_{65}Tb^{160}$ decay appears to be at present uncertain, and a decay is therefore not shown here.

References:

$_{65}Tb^{160}$, ND p. 192, NDS p. 35.
(M16) F. K. McGowan, Oak Ridge National Laboratory, ORNL-1005 (1951).
(B36) S. B. Burson, K. W. Blair, and D. Saxon, Phys. Rev. **77**, 403 (1950).
(C12) J. M. Cork, C. E. Branyan, W. C. Rutledge, A. E. Stoddard, and J. M. LeBlanc, Phys. Rev. **78**, 304 (1950).

$A=(163\text{–}171)$

$_{68}Er^{163-171}$ $T_1=2.5$ sec, I.T.$\sim$.18,
$T_2=$? (stable ?).

I. The mass number of the 2.5-sec activity that is produced by slow neutron capture (Er(n, γ)) has not yet been assigned (D8). The $\sim$180-kev I.T. has been characterized from lifetime considerations as probably E3 (G10).

Reference:

(D8) E. der Mateosian and M. Goldhaber, Phys. Rev. **76**, 187A (1949).

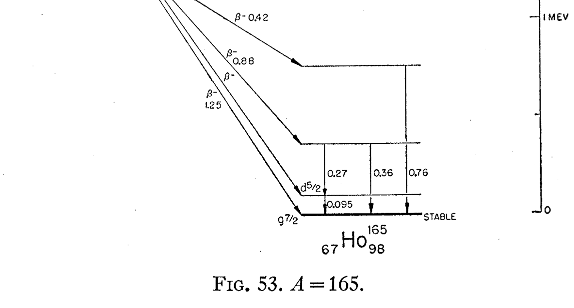

FIG. 53. $A=165$.

$A=165$

I. From lifetime and K/L ratio considerations, the 109-kev transition in 1.25-min $_{66}Dy^{165}$ has been identified as E3 (G10) (C1).

II. The logft values of 1.25, 0.88, and 0.42 β^- transitions from 2.42-hr $_{66}Dy^{165}$ are 6.18, 6.52, and 5.44, respectively (F4). Another β^- transition to the 95-kev excited state of $_{66}Dy^{165}$ is also required (S28).

III. The measured spin of $_{67}Ho^{165}$ is 7/2, and the assignment is probably $g_{7/2}$. An assignment of $f_{7/2}$ for the ground state of $_{66}Dy^{165}$ seems to be the only one consistent, on the basis of shell structure, with a 1st forbidden 1.25 β^- transition to $_{67}Ho^{165}$. In this case, the 1.25-min $_{66}Dy^{165}$ level assignment is $i_{13/2}$ or $s_{1/2}$.¶¶

IV. The 95-kev γ-transition (M27) in $_{67}Ho^{165}$ has been identified from its K/L ratio as an (M1+E2) transition (G10) (C1). In these circumstances, the 95-kev excited level would probably be $d_{5/2}$, and the postulated $f_{7/2}-d_{5/2}$ β^- transition from 2.42-hr $_{66}Dy^{165}$ would be a 1st forbidden transition.

References:

$_{66}Dy^{165}$, ND p. 196, NDS p. 35; $_{67}Ho^{165}$, ND p. 198.
(C1) R. L. Caldwell, Phys. Rev. **78**, 407 (1950).
(S16) H. Slätis, Arkiv Mat. Astron. Fysik **A33**, No. 17 (1947).
(M27) J. W. Mihelich (private communication, 1951).
(S28) A. W. Sunyar (private communication, 1951).

$A=166$

I. The 80-kev transition of 1.7×10^{-9} sec $_{68}Er^{166}$ can be identified from lifetime and conversion considerations, as an E2 transition (M14) (S15) (G10) (M40). Since the ground state of $_{68}Er^{166}$ is 0+, the 1.7×10^{-9} sec level is characterized as 2+.

¶¶ *Note added in proof.*—C. T. Hibdon and C. O. Muehlhouse (Phys. Rev., to be published) suggest possible $p_{\frac{1}{2}}$ and 7/2+ assignments for the Dy^{165} excited and ground states, respectively. A low spin assignment for the excited state seems plausible since the metastable state is formed more strongly than the ground state in thermal neutron capture (ND p. 195).

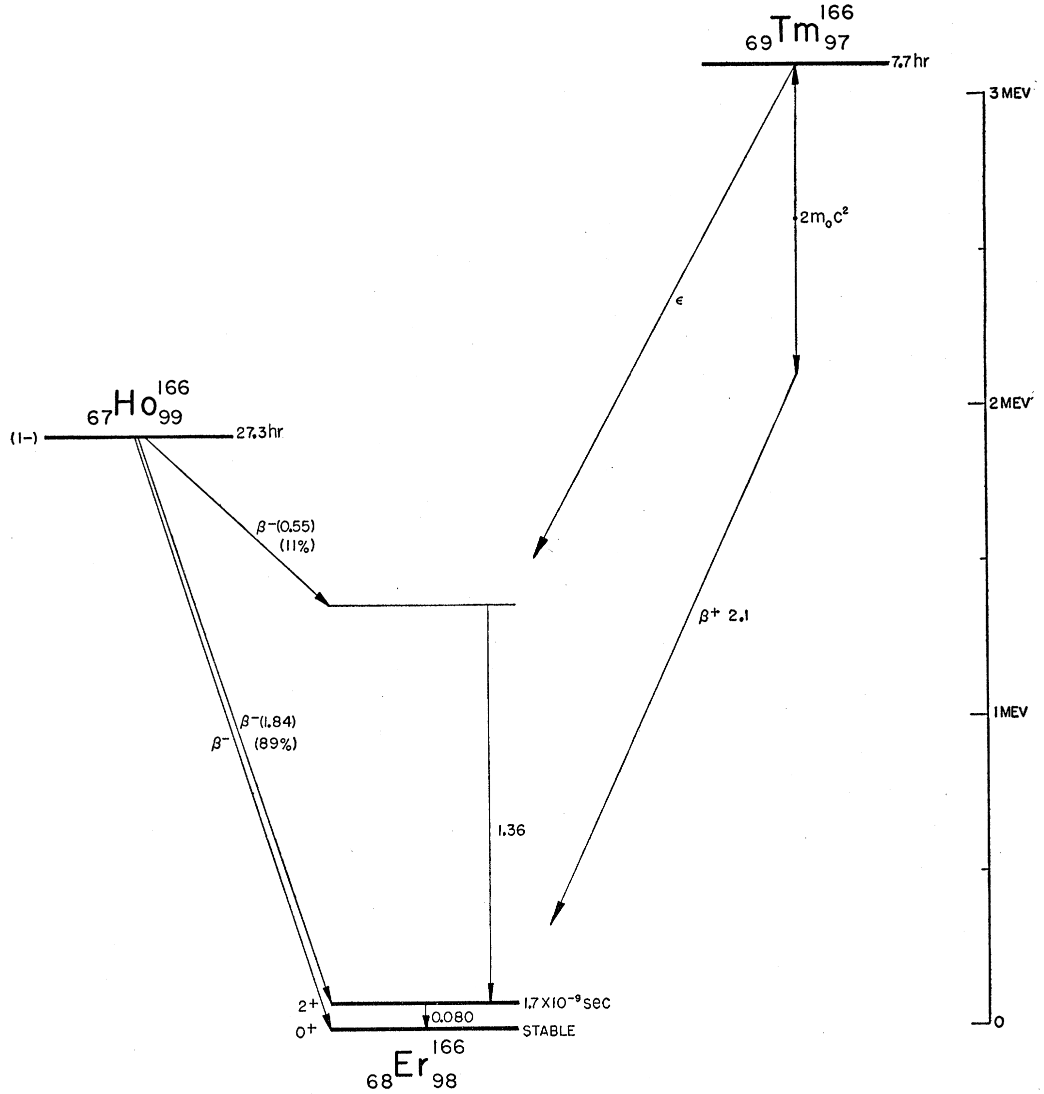

FIG. 54. $A=166$.

II. The logft values for the 1.84 and 0.55 β^- transitions from $_{67}Ho^{166}$ are 7.87 and 6.88, respectively (F4). The transitions are therefore probably 1st forbidden, and the parity of the 27.3-hr $_{67}Ho^{166}$ state is probably negative and the spin 1. A third β^- component to the ground state of $_{68}Er^{166}$ must be present, and $\gamma-\gamma$ coincidences have been observed (S28).***

References:

$_{67}Ho^{166}$, ND p. 198, NDS p. 36, NDS2 p. 40; $_{69}Tm^{166}$, ND p. 202.
(M14) F. K. McGowan, Phys. Rev. **80**, 923 (1950).
(S15) K. Siegbahn and H. Slätis, Arkiv Fysik **1**, 559 (1950).
(S28) A. W. Sunyar (private communication, 1951).
(M40) J. W. Mihelich and E. L. Church, Phys. Rev. **85**, 690 (1952).

A = 169

$_{69}Tm_{100}$ $T_1=6\times10^{-7}$ sec, I.T.
T_2 (stable).

I. The 6×10^{-7} sec metastable $_{69}Tm^{169}$ has been found following 33-day ε-capture of $_{70}Yb^{169}$. A number of complex γ-ray schemes of $_{69}Tm^{169}$ have been given. The metastable state, however, has not yet been clearly identified.

References:

$_{69}Tm^{169}$, ND p. 202; $_{70}Yb^{169}$, ND p. 204, NDS p. 38, NDS2 p. 41.
(F19) E. W. Fuller, Proc. Roy. Soc. (London) **A63**, 1044 (1950).
(S31) A. W. Sunyar and J. W. Mihelich, Phys. Rev. **81**, 300A (1951); Brookhaven National Laboratory, BNL 82(S-7) (1950).
(M6) D. S. Martin, Jr., E. N. Jensen, F. J. Hughes, and R. T. Nichols, Phys. Rev. **82**, 579 (1951).
(D5) S. DeBenedetti and F. K. McGowan, Phys. Rev. **74**, 728 (1948).
(C14) J. M. Cork, H. B. Keller, W. C. Rutledge, and A. E. Stoddard, Phys. Rev. **78**, 95 (1950).

*** *Note added in proof.*—An isomer of >30-year half-life has been reported by F. D. S. Butement (Proc. Phys. Soc. (London) **A65**, 254 (1952)) in $_{67}Ho^{166}$. No genetic relationship between the 27.3-hr and >30-yr isomers has been shown. The >30-yr $_{67}Ho^{166}$ activity decays by complex beta- and gamma-ray transitions.

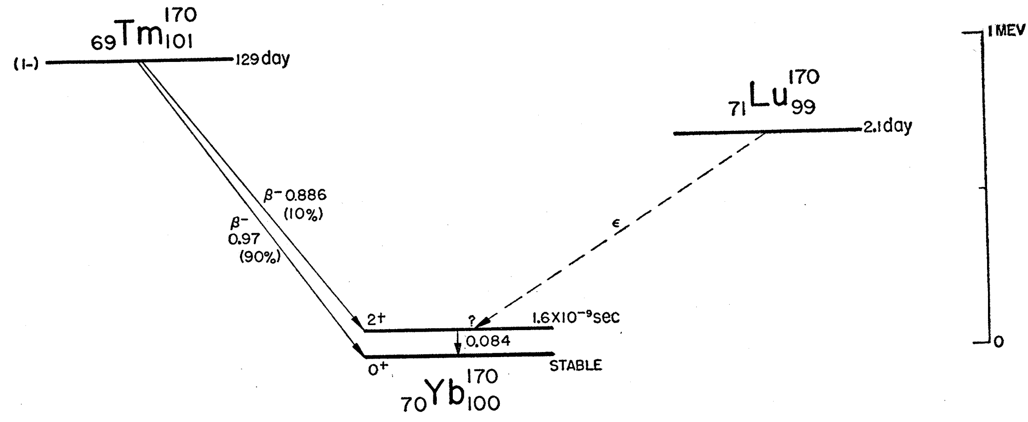

FIG. 55. $A=170$.

A = (169–177)

$_{70}$Yb$^{169-177}$ $T_1=50$ sec, I.T.$=0.025$ (D8),
$T_2=$ 6 sec, I.T.~ 0.2 (D8),
$T_3=.5$ sec, I.T.$=0.45$ (C4).

I. Three I.T.'s not yet identified by mass number, of 0.025, 0.2, and 0.45 Mev of 50-sec, 6-sec, and 0.5-sec half-lives, respectively, have been produced by neutron capture in Yb (D8) (C4). The last two I.T.'s have been characterized from lifetime considerations as either E3 or M3 transitions (G10).

References:

(D8) E. der Mateosian and M. Goldhaber, Phys. Rev. **76**, 187A (1949).
(C4) E. C. Campbell (private communication, 1951); J. H. Kahn, Oak Ridge National Laboratory, ORNL-1089 (1951).

A = 170

I. The 84-kev isomeric transition of 1.6×10^{-9} sec $_{70}$Yb^{170} has been identified from lifetime, K/L ratio and internal conversion considerations as an E2 transition (G10) (S28).††† Since stable $_{70}$Yb^{170} is assigned spin 0+ in the ground state, the 1.6×10^{-9} sec state is assigned spin 2+.

II. The logft values for the 0.97 and 0.886 β^- transitions of 129-day $_{69}$Tm^{170} are 8.9 and 9.7, respectively (F4). The transitions therefore are probably first forbidden, and the spin of the $_{69}$Tm^{170} ground state is probably 1−, since the β-ray shapes are of the allowed type.

References:

$_{69}$Tm^{170}, ND p. 203, NDS2 p. 41, NDS p. 37; $_{71}$Lu^{170}, ND p. 207.
(F13) J. S. Fraser, Phys. Rev. **76**, 1540 (1949).
(B3) R. E. Bell and R. L. Graham, Phys. Rev. **78**, 490 (1950).
(C1) R. L. Caldwell, Phys. Rev. **78**, 407 (1950).
(A2) H. M. Agnew, Phys. Rev. **77**, 655 (1950).
(N5) T. B. Novey, Phys. Rev. **78**, 66 (1950).
(G17) P. J. Grant, Nature **165**, 1018 (1950).
(S28) A. W. Sunyar (private communication, 1951).
(S10) K. Siegbahn, M. Siegbahn Commemorative Volume, p. 226 (1952).
(R5) R. Richmond and H. Rose, Phil. Mag. **43**, 367 (1952).

A = 171

$_{69}$Tm$_{102}$ $T_1=2.5\times10^{-6}$ sec, I.T.$=0.113$,
$T_2=680$ day, β^- 0.10.

I. The multipole character of the 113-kev I.T. is not known. No information is available as to the K/L ratio, and the conversion coefficient cited (D5) (K8) is somewhat in doubt as the decay scheme is not thoroughly established.

II. The 680-day ground state of $_{69}$Tm^{171} is probably to be identified with an $s_{1/2}$ state, since the logft value of the 0.10 β^- transition to the measured $p_{1/2}$ state of $_{70}$Yb^{171} is 6.3, and the transition is probably 1st forbidden.

III. A decay scheme for $_{68}$Er^{171}, leading by β^- emission to $_{69}$Tm^{171}, has been published (ND p. 201). However, unpublished work (S28) indicates that $\gamma-\gamma$ coincidences between the 0.113 and 0.305 γ-transitions do not occur (to the extent required by the above scheme). Further work on this decay scheme seems essential.

References:

$_{68}$Er^{171}, ND p. 201; $_{69}$Tm^{171}, ND p. 203.
(D5) S. DeBenedetti and F. K. McGowan, Phys. Rev. **74**, 728 (1948).
(K8) B. H. Ketelle and W. C. Peacock, Phys. Rev. **73**, 1269A (1948).
(S28) A. W. Sunyar (private communication, 1951).

A = 176

I. No isomeric transition between the 3.75 hr and 7.2×10^{10} yr $_{71}$Lu^{176} states has been observed (D32) (S3). The long-lived ground state shows a complex γ-ray spectrum (S36). Gamma-rays of about equal intensity of 270 kev, 180 kev, and 90 kev (presumably identical with the 89-kev γ-transition observed to follow a β^- transition from the 3.7-hr isomeric state) were found.‡‡‡

II. β^- transitions of 1.2 and 1.1 Mev of approximately equal intensity to the ground state and an 89-kev excited 2+ state of $_{72}$Hf^{176} (logft $\sim$6.2) identify the 3.75-hr state of $_{71}$Lu^{176} as probably 1−. The β^- transi-

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††† *Note added in proof.*—K-shell conversion coefficients for the isomeric transitions in $_{66}$Dy^{160}, $_{67}$Ho^{165}, $_{68}$Er^{166}, and $_{70}$Yb^{170} have been measured recently by F. K. McGowan (Phys. Rev. **85**, 151 (1952)). These measurements add further support to the present identification of the isomeric transitions.

‡‡‡ *Note added in proof.*—A lifetime of 1.35×10^{-9} sec has been observed for the 89-kev transition (F. K. McGowan, Phys. Rev. **87**, 542 (1952)).

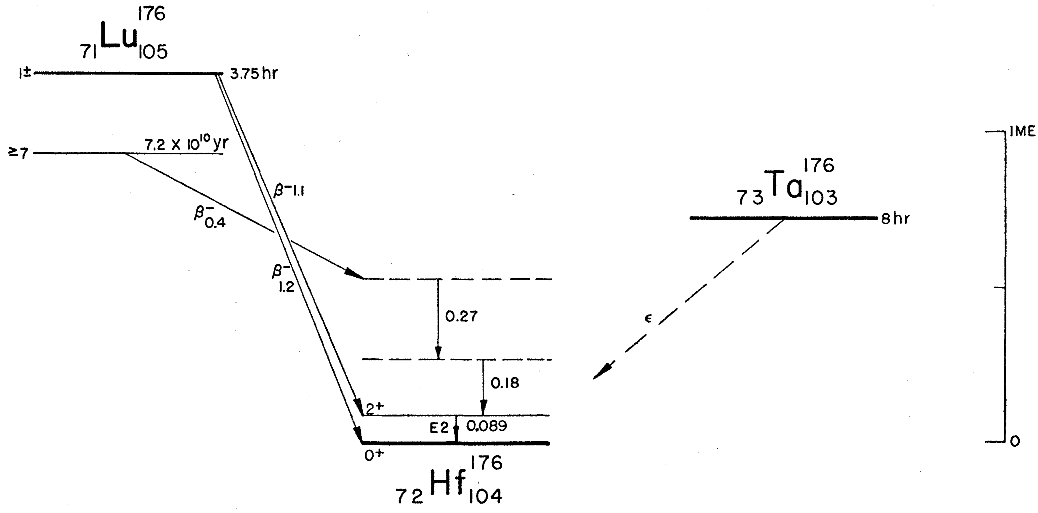

FIG. 56. $A=176$.

tion of 0.4 Mev (F20) (L13) from 7.2×10^{10} yr $_{71}$Lu^{176} has a log*ft* value equal to 18.9 and may therefore be identified as 3rd forbidden, $\Delta I=3$ or 4, yes. The long-lived Lu state has a measured spin ≥ 7. Klinkenberg (K17) suggests (from an analysis of the measured magnetic moment on the basis of $j-j$ coupling) that the spin is 10 ± 1. Such a high spin may be compatible with a 3rd forbidden β-transition in view of the fact that it is probably followed by three successive γ-rays.

References:

$_{71}$Lu^{176}, ND p. 208; $_{73}$Ta^{176}, ND p. 213.
(D32) J. V. Dunworth and B. Pontecorvo, Cambridge Phil. Soc. **43**, 429 (1947).
(S3) G. Scharff-Goldhaber, E. der Mateosian, and J. W. Mihelich, Phys. Rev. **85**, 734A (1952).
(S36) G. Scharff-Goldhaber, unpublished.
(F20) A. Flammersfeld, Z. Naturforsch. **2a**, 86 (1947).
(L13) W. F. Libby (private communication to G. Scharff-Goldhaber).
(K17) P. F. A. Klinkenberg, Physica **17**, 715 (1951).

A = 177

I. The 150-kev I.T. of 1.3×10^{-7} sec $_{71}$Lu^{177} has been tentatively identified as M2 (G10) (M10). The possibility that it is a mixed M1+E2 transition is not excluded.

II. The log*ft* values of the 0.495, 0.366, and 0.17 β^- component spectra of 6.7-day $_{71}$Lu^{177} are 6.8, 6.95, and 5.86, respectively (F4). The 0.495 and 0.366 β^- components are probably 1st forbidden transitions. The measured spin of $_{72}$Hf^{177} is either 1/2 or 3/2, and the level can be characterized as $p_{3/2}$ or $p_{1/2}$ on the basis of nuclear shell theory.

III. If the spin of the ground state of $_{71}$Lu^{177} were $g_{7/2}$, as in the case of $_{71}$Lu^{175}, a 1st forbidden transition to the ground state of $_{72}$Hf^{177} would identify the latter as $p_{3/2}$. However, the log*ft* value of this transition does not agree with that of an α-type, $\Delta I=2$, yes, transition. It may be that the 6.7-day $_{71}$Lu^{177} state has some other spin, such as $d_{3/2}$, $d_{5/2}$, or $s_{1/2}$. If the spins of the ground state and first excited state of $_{72}$Hf^{177} are assumed to be $p_{1/2}$ and $p_{3/2}$, in similarity to $_{72}$Hf^{179}, then the assignment for the 6.7-day $_{71}$Lu^{177} is probably $d_{3/2}$ or $s_{1/2}$.

IV. The log*ft* value of the 1.8-hr $_{70}$Yb^{177} β^- transition is $\sim$6.1.

References:

$_{70}$Yb^{177}, ND p. 205; $_{71}$Lu^{177}, ND p. 209; $_{73}$Ta^{177}, ND p. 213.
(M10) F. K. McGowan, Oak Ridge National Laboratory, ORNL-952 (1950); Phys. Rev. **76**, 1730 (1949).

A = 179

I. The 19-sec $_{72}$Hf$_{179}$ isomer decays by two successive transitions of 160 and 215 kev which have been identified as M3 and probably M1 transitions, respectively (D10).

II. As the ground state of stable $_{72}$Hf^{179} is only known to be either 1/2 or 3/2, we can give the probable assignments of $p_{1/2}$, $p_{3/2}$, and $h_{9/2}$ to the ground state, the 215-, and the 375-kev excited states, respectively. The assignment of $p_{3/2}$ to the ground state would lead either to the probable existence of a 375-kev γ-cross over transition or to inconsistency with present nuclear shell theory.

III. Two other activities have been reported in wolfram and assigned to mass-number 179 (W4). They are activities of half-lives, 30 and 5 min, produced by Ta$-p-3n$ reaction.

References:

$_{72}$Hf^{179}, ND p. 211; $_{73}$Ta^{179}, ND p. 213, NDS p. 39, NDS2 p. 43.
(D10) E. der Mateosian and M. Goldhaber, Phys. Rev. **83**, 843 (1951).
(W4) G. Wilkinson, Phys. Rev. **80**, 495 (1950).

A = 180

$_{72}$Hf$_{108}$ $T_1=5.5$ hr, I.T.,
T_2 (stable).

I. The I.T. associated with the 5.5-hr activity has not yet been identified (B35). Gamma-rays of the

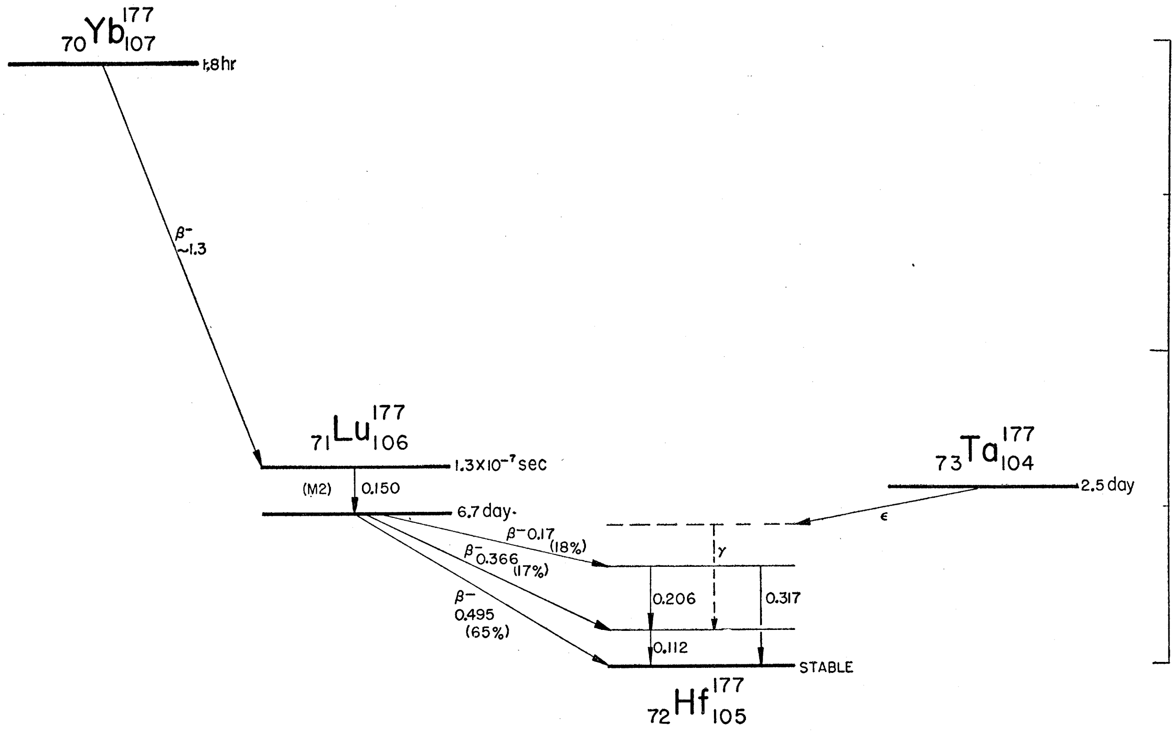

FIG. 57. $A=177$.

following energies have been found associated with this activity: 0.057, 0.093, 0.214, 0.330, 0.442 Mev (B35). A gamma-ray of 0.092 Mev has also been observed following the ϵ-decay of 8-hr $_{73}Ta^{180}$ to $_{72}Hf^{180}$. It has been identified from its K/L ratio as E2 (B6). The 0.057-Mev γ-ray may not be of nuclear origin as the electrons ascribed to this γ-ray may be only Auger electrons. The 0.93 γ-ray is probably the last step in a 4-step isomeric transition (D12). The spin of Hf^{180m} (5.5 hr) must be very large, since no cross-over transition has been observed.

References:

$_{73}Ta^{180}$, ND p. 214, NDS2 p. 43.
(B35) S. B. Burson, K. W. Blair, H. B. Keller, and S. Wexler, Phys. Rev. **83**, 62 (1951).
(B6) W. L. Bendel, H. Brown, and R. A. Becker, Phys. Rev. **81**, 300 (1951).
(D12) E. der Mateosian and M. Goldhaber (unpublished, 1951).

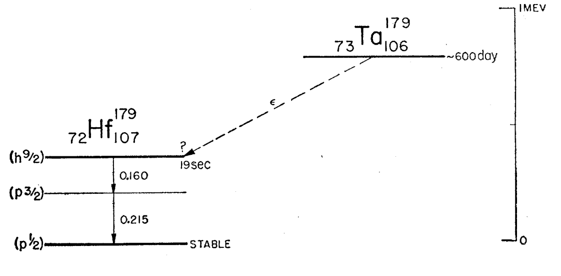

FIG. 58. $A=179$.

A = 181

I. The assignments of 1/2+ and 3/2+ to the 2.2×10^{-5} sec and 1.1×10^{-8} sec isomeric states of $_{73}Ta^{181}$ have been made on the basis of lifetime and conversion data (G10) (B35).

II. The 136-kev excited state has a half-life of $<10^{-9}$ sec (G14), and the transition to the ground state is probably M1. The ground state has a measured spin of 7/2, and its nuclear shell level assignment is probably $g_{7/2}$.

III. The logft value of the 0.42 β^- transition from 45-day $_{72}Hf^{181}$ is 7.2 (F4). An assignment of either 1/2− or 3/2− to the 45-day $_{72}Hf^{181}$ level is consistent with a 1st forbidden transition to the 611-kev excited state of $_{73}Ta^{181}$. An assignment of 1/2− seems rather more likely, since the alternative 3/2− would imply a (~10 percent) β-branch to the ground or excited state of $_{73}Ta^{181}$, which has not been observed.

IV. The 140-day $_{74}W^{181}$ decays to $_{73}Ta^{181}$ by orbital electron capture (W5) showing several associated γ-rays. The 22-μsec state of Ta^{181} is not produced in the decay of W^{181} (D12).

References:

$_{72}Hf^{181}$, ND p. 212, NDS p. 38, NDS2 p. 42; $_{73}Ta^{181}$, ND p. 214; $_{74}W^{181}$, ND p. 216.
(B35) S. B. Burson, K. W. Blair, H. B. Keller, and S. Wexler, Phys. Rev. **83**, 62 (1951).
(G14) R. L. Graham (private communication, 1951).
(D12) E. der Mateosian and M. Goldhaber (unpublished, 1951).
(W5) G. Wilkinson, Nature **160**, 864 (1947).

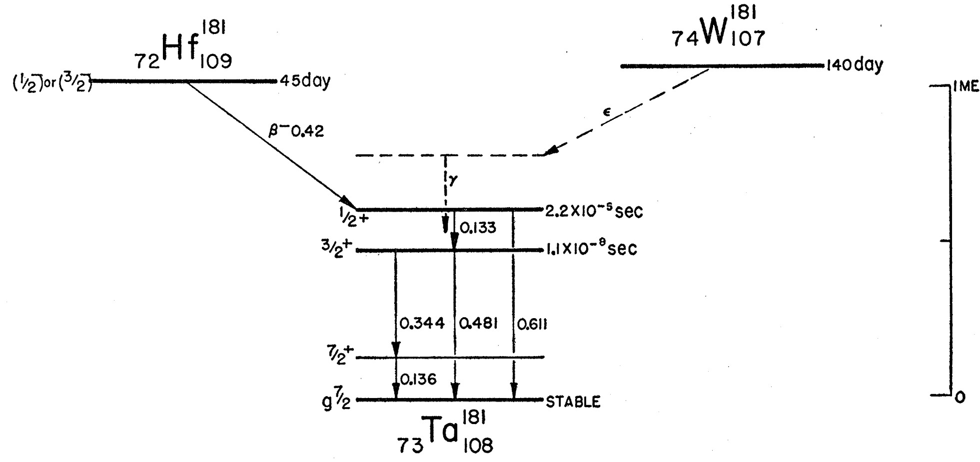

FIG. 59. $A=181$.

A = 182

I. The 180-kev I.T. of 16.4-min $_{73}Ta^{182}$ has been identified from lifetime and conversion data as E3 (G10) (S26).

II. The log*ft* value for the 0.53 β^- transition from 117-day $_{73}Ta^{182}$ is 8.0 (F4). The beta-decay is followed by a complex γ-ray spectrum (NDS p. 39) (ND p. 214). From the fact that there is no beta-transition to the 0+ ground state of $_{74}W^{182}$ we can infer that the spin of the 117-day $_{73}Ta^{182}$ state is high.

III. A third activity of half-life 0.3 sec has also been reported in $_{73}Ta^{182}$, but its mass number has not yet been assigned with certainty (C2).

IV. The activities of 64-hr and 12.7-hr half-lives have been assigned to $_{75}Re^{182}$ (W6).

References:

$_{73}Ta^{182}$, ND p. 214, NDS p. 39, NDS2 p. 43.
(S26) A. W. Sunyar, Phys. Rev. **83**, 864 (1951).
(W6) G. Wilkinson and H. G. Hicks, Phys. Rev. **77**, 314 (1950).
(C2) E. C. Campbell and W. M. Good, Phys. Rev. **76**, 195 (1949).
(G12) M. Goodrich and E. C. Campbell, Phys. Rev. **79**, 418 (1950).
(K1) J. H. Kahn, Oak Ridge National Laboratory, ORNL-1089 (1951); E. C. Campbell, private communication.

A = 183

I. The half-life of 5.5 sec of the 80-kev transition in $_{74}W^{183}$ is compatible with either an E3 or M3 transition (G10). However, experiment indicates that mainly *L* x-rays arise from the conversion. The *K*/*L* ratio is therefore interpreted as being small, and the transition is identified as E3 (D12).

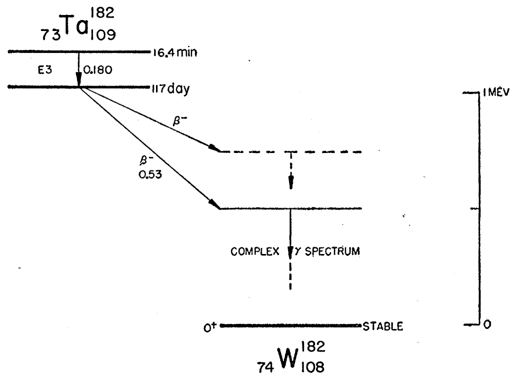

FIG. 60. $A=182$.

II. The measured spin of stable $_{74}W^{183}$ is 1/2 (F11). In this case the assignments for the 5.5-sec and stable $_{74}W^{183}$ levels are 7/2+ and $p_{1/2}$. The 7/2+ assignment is not in accord with the present nuclear shell theory.

III. There is a complex γ-ray spectrum following electron capture from the 240-day $_{75}Re^{183}$ state (W6). A certain number of the transitions appear to occur via the 80-kev state of $_{74}W^{183}$. A second ϵ-capture activity of 67-hr half-life has also been attributed to $_{75}Re^{183}$ (D29).

References:

$_{74}W^{183}$, ND p. 216; $_{75}Re^{183}$, ND p. 218, NDS2 p. 45.
(D8) E. der Mateosian and M. Goldhaber, Phys. Rev. **76**, 187A (1949).
(W6) G. Wilkinson and H. G. Hicks, Phys. Rev. **77**, 314 (1950).
(F11) G. R. Fowles, Phys. Rev. **78**, 744 (1950).
(D29) H. T. Dybvig and M. L. Pool, Phys. Rev. **80**, 126A (1950).

A = 184

$_{75}Re_{109}$ $T_1 = 50$ day, ϵ, e^-, γ,
$T_2 = 2.2$ day, ϵ or I.T., e^-, γ.

References:

$_{75}Re^{184}$, ND p. 219.
(W6) G. Wilkinson and H. G. Hicks, Phys. Rev. **77**, 314 (1950).

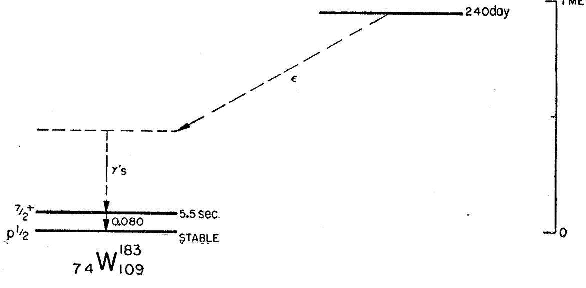

FIG. 61. $A=183$.

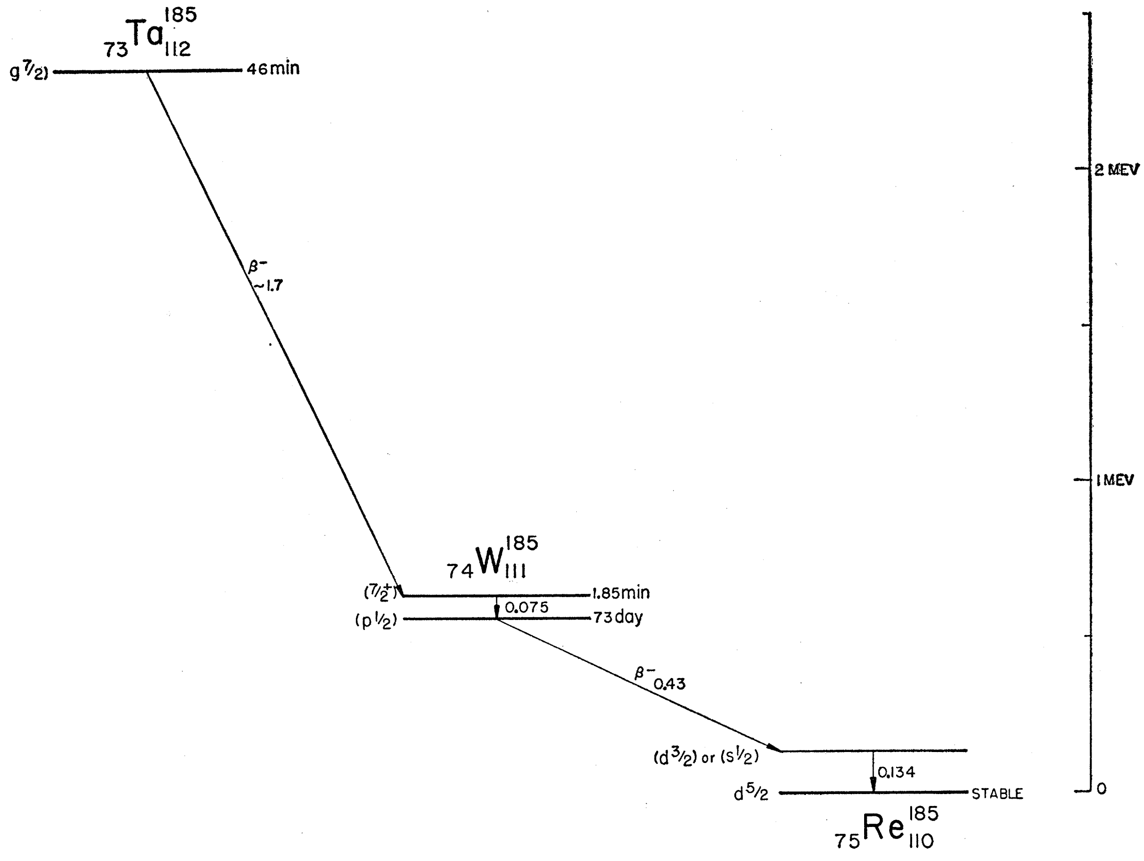

FIG. 62. $A=185$.

A=185

I. The half-life of 1.85 min of the 75-kev transition in $_{74}W^{185}$ is compatible with either an E3 or M3 transition. There is no evidence at present available which enables a decision to be made between these types.

II. The measured spin of Re^{185} is 5/2. The log*ft* value of the 0.43 β^- transition from 73-day $_{74}W^{185}$ to the 134-kev excited state of $_{75}Re^{185}$ is 7.5, and the transition is classified as 1st forbidden. The lifetime of the 134-kev excited state is $<3\times10^{-8}$ sec (M10). These facts are probably consistent with a $p_{1/2}$ assignment to the 73-day $_{74}W^{185}$. By similarity with $_{74}W^{185}$, it is possible that the 1.85-min $_{74}W^{185}$ level is 7/2+.

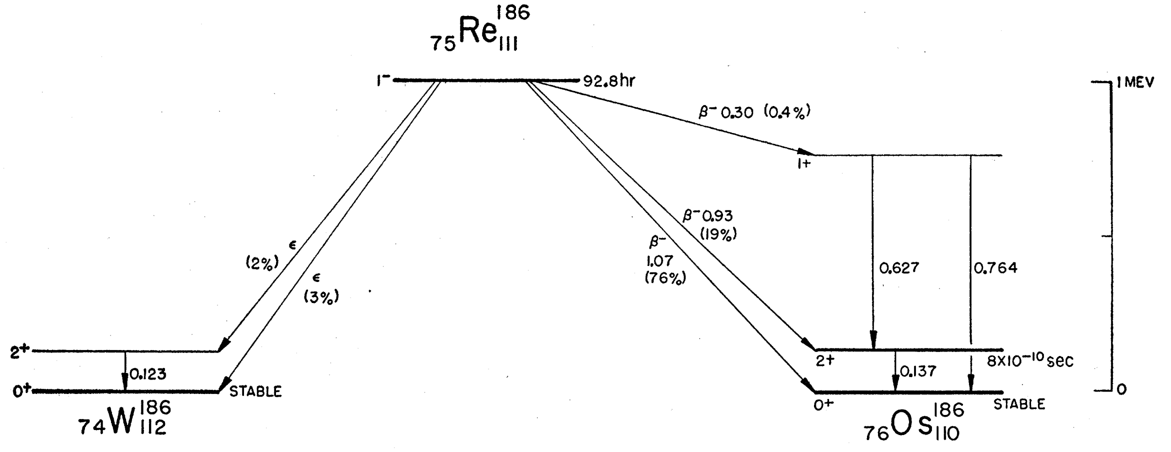

FIG. 63. $A=186$.

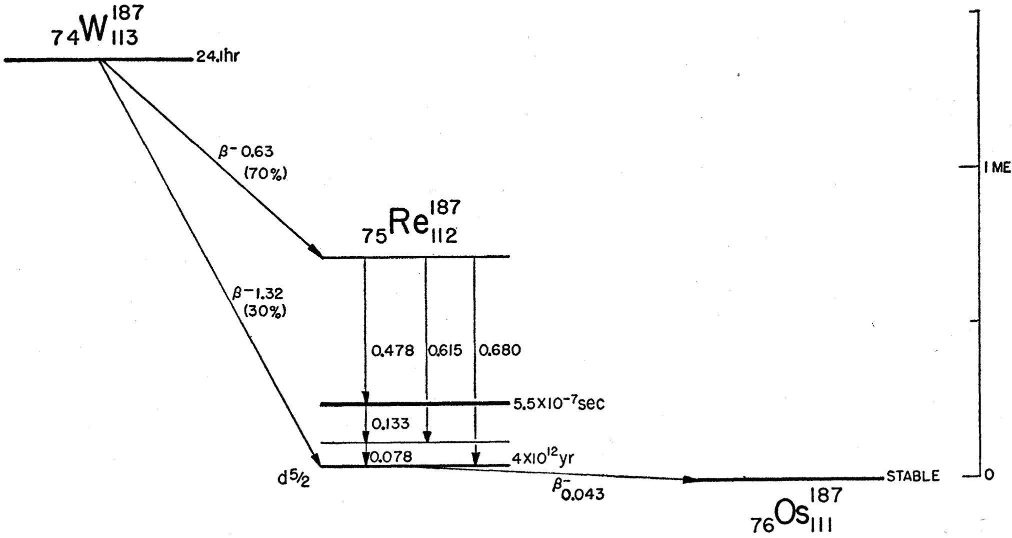

FIG. 64. $A=187$.

III. The log*ft* of the $\sim$1.7 β^- transition from 46-min $_{73}$Ta^{185} is $\sim$6.2.

References:

$_{73}$Ta^{185}, NDS p. 39, NDS2 p. 43; $_{74}$W^{185}, ND p. 217, NDS2 p. 44; $_{75}$Re^{185}, ND p. 219.
(D23) R. B. Duffield, L. Hsiao, and E. N. Sloth, Phys. Rev. **79**, 1011 (1950).
(M10) F. K. McGowan, Oak Ridge National Laboratory, ORNL-952 (1950); Phys. Rev. **76**, 1730 (1949).

A = 186

I. The 137-kev I.T. of 8×10^{-10} sec half-life has been identified from lifetime and conversion considerations as E2 (M15) (M26) (S20).

II. The β^- and electron capture transitions from 92.8-hr $_{75}$Re^{186} have been classified as 1st forbidden (M26), and the assigned spins are shown in the above scheme.

References:

$_{75}$Re^{186}, ND p. 219, NDS2 p. 45.
(M15) F. K. McGowan, Phys. Rev. **81**, 1066 (1951).
(M26) F. R. Metzger and R. D. Hill, Phys. Rev. **82**, 646 (1951).
(S20) R. M. Steffen, Phys. Rev. **82**, 827 (1951).

A = 187

I. The decay from the 5.5×10^{-7} sec $_{75}$Re^{187} state appears to occur by a two-step transition (M10). The 5.5×10^{-7} sec half lifetime is associated with an M2 or (M1+E2) transition of 133 kev (M10) (G10).

II. The probable assignment for the 4×10^{12} yr $_{75}$Re^{187} ground state, which has a known spin and magnetic moment, is $d_{5/2}$. An unequivocal assignment cannot be given for the 5.5×10^{-7} sec state, since information of the multipolarity of the other γ-rays involved in the decay of 24.1-hr $_{74}$W^{187} is lacking.

III. The log*ft* values of the 1.32 and 0.63 β^- transitions from 24-hr $_{74}$W^{187} are 7.88 and 6.35, respectively. The log*ft* value of the 0.043 β^- transition from 4×10^{12} yr $_{75}$Re^{187} is 17.7 (F4). A large spin of $_{76}$Os^{187} (11/2+) would appear to be best consistent with the high *ft* value of the $_{75}$Re^{187} β-transition.

References:

$_{74}$W^{187}, ND p. 217; $_{75}$Re^{187}, ND p. 219.
(M10) F. K. McGowan, Oak Ridge National Laboratory, ORNL-952 (1951); Phys. Rev. **76**, 1730 (1949).

A = 190

$_{77}$Ir$_{113}$ $T_1=3.2$ hr, β^+ 1.7, e^- 0.2, 0.8,
$T_2=12.6$ day, ϵ, e^-, γ.

References:

$_{77}$Ir^{190}, ND p. 223, NDS p. 41.
(C9) T. C. Chu, Phys. Rev. **79**, 582 (1950).
(G11) L. J. Goodman and M. L. Pool, Phys. Rev. **70**, 112 (1946); **71**, 288 (1947).

A = 191

Isomeric activities of 14-hr and 15-day half-lives have been observed in $_{76}$Os^{191}. (J. B. Swan and R. D. Hill, Bull. Am. Phys. Soc. **27**, No. 4, 20, Denver Meeting (1952)). The 14-hr state decays to the 15-day ground state by an M3 transition of 74.2 kev. Assignments of $i_{13/2}$ and 7/2+ have been given to the 14-hr and 15-day states, respectively.

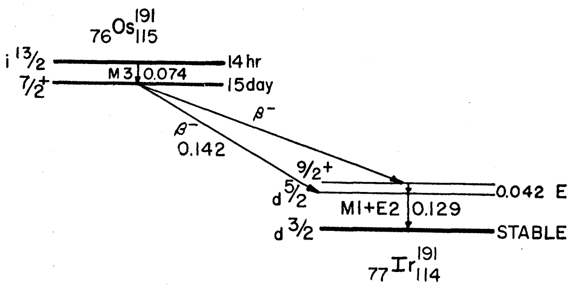

FIG. 64a. $A=191$.

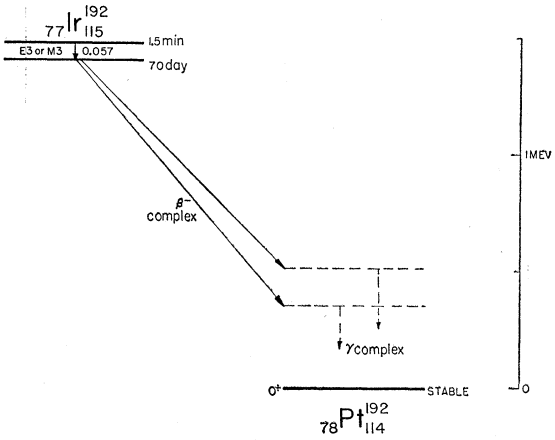

FIG. 65. $A=192$.

A = 192

I. From lifetime considerations the 57.4-kev isomeric transition of $_{77}Ir^{192}$ has been identified as either E3 or M3 (C1) (G10).

II. A γ-ray continuum from 1.5-min $_{77}Ir^{192}$ has also been observed with a maximum intensity distribution at $\sim$30 kev (G8).

III. The beta- and γ-ray spectra associated with 70-day $_{77}Ir^{192}$ are complex and have been the subject of extensive investigations (C15) (S5); but no decay scheme can yet be given.

References:

$_{77}Ir^{192}$, ND p. 224.
(C1) R. L. Caldwell, Phys. Rev. **78**, 407 (1950).
(G8) M. Goldhaber, C. O. Muehlhause, and S. H. Turkel, Phys. Rev. **71**, 372 (1947).
(C15) J. M. Cork, J. M. LeBlanc, A. E. Stoddard, W. J. Childs, C. E. Branyan, and D. W. Martin, Phys. Rev. **82**, 258 (1951).
(S5) W. W. Schoof and R. D. Hill, Phys. Rev. **83**, 892A (1951).

A = 193

I. The half-life of 5.7×10^{-9} sec for the 65-kev transition of $_{77}Ir^{193}$ is consistent with either an E2 or M1 transition (G10). No data are at present available on the L conversion which might help distinguish between these.

II. The measured spin of $_{77}Ir^{193}$ is 3/2, and the nuclear shell theory assignment for the 5.7×10^{-9} sec and stable $_{77}Ir^{193}$ states are accordingly $s_{1/2}$ or $d_{5/2}$, and $d_{3/2}$, respectively.

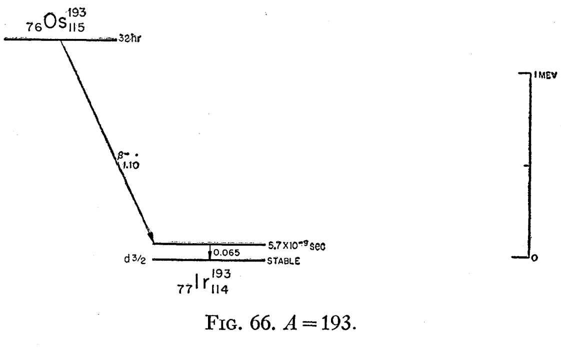

FIG. 66. $A=193$.

III. The logft value of the 1.10 β^- transition of 32-hr $_{76}Os^{193}$ is 7.23 (M12) (B33). The identification of this spectrum as 1st forbidden leads to the assignments of an odd parity state for the 32-hr $_{76}Os^{193}$ which could be $p_{1/2}$, $p_{3/2}$, $f_{5/2}$, or $f_{7/2}$. The assignment of the 32-hr activity to Os^{193} rather than Os^{191} is based on its β-energy (W2).§§§

References:

$_{76}Os^{191}$, ND p. 222, NDS2 p. 45; $_{77}Ir^{191}$, ND p. 223; $_{78}Pt^{191}$, ND p. 225.
(M12) F. K. McGowan, Phys. Rev. **79**, 404 (1950); Oak Ridge National Laboratory, ORNL-952 (1951).
(B33) M. E. Bunker, R. Canada, and A. C. G. Mitchell, Phys. Rev. **80**, 126A (1950).
(W2) K. Way (private communication).

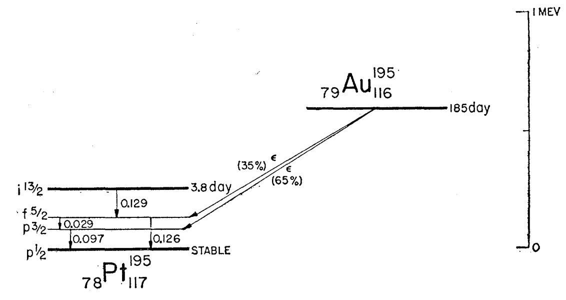

FIG. 67. $A=195$.

A = 195

I. The 129-kev isomeric transition from 3.8-day $_{78}Pt$ which has been previously assigned to $_{78}Pt^{197}$ (H16), or $_{78}Pt^{193}$ (W3), is now assigned to $_{78}Pt^{195}$ (D16). It is consistent with level trends to assign the 3.8-day I.T. to $_{78}Pt^{195}$ and the 80-min I.T. to $_{78}Pt^{197}$ (H9). The 129-kev I.T. has been identified as an M4 transition (G10).

II. The measured spin of $_{78}Pt^{195}$ is 1/2, and a consistent nuclear shell theory assignment would be $p_{1/2}$.

III. The ϵ-capture of 185-day $_{79}Au^{195}$ is followed by the emission of 126-, 97-, and 29-kev γ-rays (S22) (D16), and the assignments of $f_{5/2}$ and $p_{3/2}$, based on conversion coefficients and K/L ratios, have been given for the 126- and 97-kev excited levels, respectively (D16). The 129-kev isomeric transition is therefore attributed to an $i_{13/2}$ to $f_{5/2}$ transition.

References:

$_{78}Pt^{195}$, ND p. 226; $_{79}Au^{195}$, ND p. 228.
(H16) N. Hole, Arkiv Mat. Astron. Fysik **36A**, No. 9 (1948).
(W3) G. Wilkinson, Phys. Rev. **75**, 1019 (1949).
(D16) A. de-Shalit (private communication, 1951).
(S22) R. M. Steffen, O. Huber, and F. Humbel, Helv. Phys. Acta **22**, 167 (1949).
(H9) R. D. Hill, Brookhaven Quarterly Report No. 11, 18 (1951).

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§§§ *Note added in proof.*—This assignment is also consistent with the recent experiments on $_{76}Os^{191}$. (See note added in proof for $A=191$.) Further, it is shown in these experiments (J. B. Swan and R. D. Hill, Phys. Rev., to be published) that the beta-transition to the 65-kev excited state is a relatively weak branch.

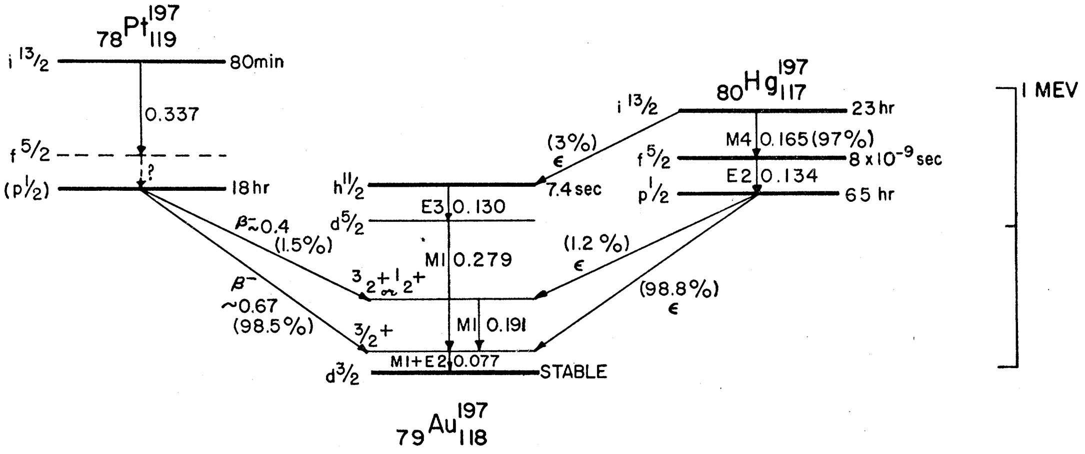

Fig. 68. $A=197$.

A = 196

$_{79}Au_{117}$ $T_1=14.0$ hr, ϵ or I.T.,
$T_2=5.6$ day, ϵ, 0.30 β^-, 0.175 γ.

References:

$_{79}Au^{196}$, ND p. 228.
(W3) G. Wilkinson, Phys. Rev. **75**, 1019 (1949).
(S22) R. M. Steffen, O. Huber, and F. Humbel, Helv. Phys. Acta 22, 167 (1949).

A = 197

I. The 164- and 133-kev transitions of 23-hr and 8×10^{-9} sec $_{80}Hg^{197}$ have been classified from lifetime and K/L ratio considerations as M4 and E2 transitions, respectively (G10) (H18) (D17). On the basis of shell structure theory, the probable assignments to the 23-hr, 8×10^{-9} sec, and 65-hr levels of $_{80}Hg^{197}$ are $i_{13/2}$, $f_{5/2}$, and $p_{1/2}$, respectively.

II. The decay scheme of 7.4-sec $_{79}Au^{197}$ appears to be incomplete (H18). The 279-kev and 191-kev transitions have been shown to be M1 (H18).[|| || ||]

III. The 337-kev isomeric transition of 80-min $_{78}Pt$ (H16) is assigned on the basis mainly of isomer level systematics (H9) to $_{78}Pt^{197}$. This mass assignment is not inconsistent with reactions by means of which the 80-min activity has been produced, namely: Hg$-n-\alpha$, Pt$-d-p$, Pt$-n-2n$, and Pt$-\gamma-n$. The 337-kev isomeric transition has been classified, from lifetime considerations, as M4 (G10). It may be that this transition is followed by at least one other transition as in the case of $_{78}Pt^{195}$. Shell theory would suggest an $i_{13/2}$ to $f_{5/2}$ transition for the 80-min M4 transition. Clearly, further work is required on the 80-min Pt activity, and the scheme shown is given only very tentatively.

References:

$_{78}Pt^{197}$, ND p. 226; $_{79}Au^{197}$, ND p. 229; $_{80}Hg^{197}$, ND p. 231, NDS p. 43, NDS2 p. 47.
(H18) O. Huber, F. Humbel, A. Schneider, A. de Shalit, and W. Zunti, Helv. Phys. Acta **24**, 127 (1951).
(M11) F. K. McGowan, Phys. Rev. **77**, 138 (1950).
(D20) M. Deutsch and W. E. Wright, Phys. Rev. **77**, 139 (1950)
(H16) N. Hole, Arkiv Mat. Astron. Fysik **36A**, No. 9 (1948).
(E1) A. A. Ebel and C. Goodman, Phys. Rev. **82**, 130A (1951).
(H9) R. D. Hill, Brookhaven Quarterly Report No. 11, 18 (1951).
(D17) A. de-Shalit (private communication, 1952).

A = 199

I. The lifetime and conversion data of the 368-kev transition of 44-min $_{80}Hg^{199}$ identify this isomeric transition as M4 (H16) (G10). Similarly the 159-kev transition from the 2.4×10^{-9} sec state of $_{80}Hg^{199}$ has been identified as E2 (S9) (G16).

II. The measured spin of the ground state of $_{80}Hg^{199}$ is 1/2. The other level assignments shown in the decay schemes are consistent with conversion and lifetime data as well as with nuclear shell theory (S9).

III. Logft values for the 0.46, 0.30, and 0.25 β^- spectra from 3.3-day $_{79}Au^{199}$ are 7.8, 6.3, and 6.0, respectively. All transitions are therefore probably 1st forbidden, and the parity of the 3.3-day state of $_{79}Au^{199}$ is even and the spin 3/2, or possibly 5/2 (S9).

References:

$_{79}Au^{199}$, ND p. 230, NDS p. 42, NDS2 p. 46; $_{80}Hg^{199}$, ND p. 232; $_{81}Tl^{199}$, ND p. 234.
(H16) N. Hole, Arkiv Mat. Astron. Fysik **36A**, No. 9 (1948).
(S9) P. M. Sherk and R. D. Hill, Phys. Rev. **83**, 1097 (1951).
(D16) A. de-Shalit (private communication, 1951).
(G16) R. L. Graham and R. E. Bell, Phys. Rev. **84**, 380 (1951).
(S10) K. Siegbahn, M. Siegbahn Commemorative Volume, p. 229 (1952).

A = 204

I. From lifetime and conversion considerations the 905-kev transition from 68-min $_{82}Pb^{204}$ has been identified as an E5 transition, and the 374-kev transition from 3×10^{-7} sec $_{82}Pb^{204}$ as an E2 transition (G10) (S29).

[|| || ||] *Note added in proof.*—A consistent decay scheme of $_{80}Hg^{197}$ and $_{79}Au^{197}$ has been given recently by de-Shalit, Mihelich, and Goldhaber (Phys. Rev., to be published). The 7.4-sec isomeric $_{79}Au^{197m}$ activity has been attributed to a 130-kev γ-transition identified from K/L ratio and lifetime considerations as E3. The spin and parity assignments of the $_{79}Au^{197}$ levels shown in Fig. 68 are those of the above authors.

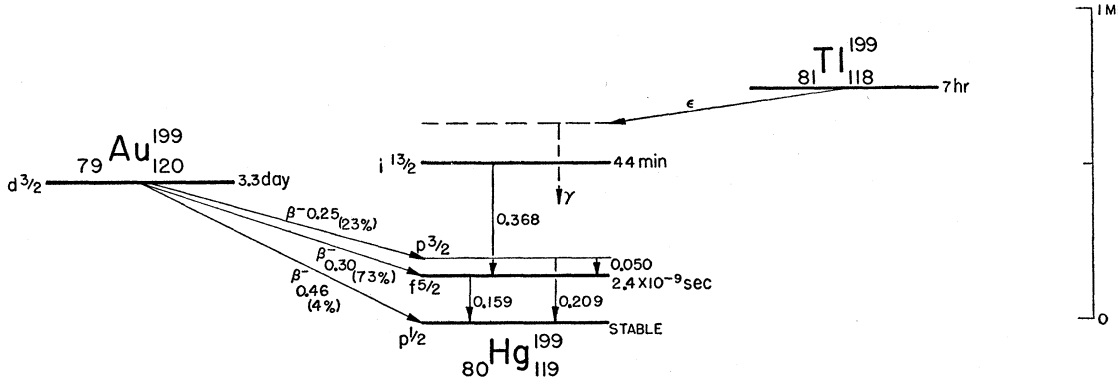

FIG. 69. $A=199$.

The isomeric states of this even-even nucleus are therefore given 2+ and 7+ assignments as shown.

II. The 68-min $_{82}Pb^{204}$ is a daughter product of $_{83}Bi^{204}$. The electron capture may occur to a higher level than the 68-min isomer, since a weak 217-kev γ-radiation has been observed (S29). The 2+ state is also produced directly; i.e., not only through the 68-min state (S29).

III. The most recent value for the half-life of $_{81}Tl^{204}$ is 3.94±0.3 yr (H19). No γ-rays are observed in its decay, the 0.78 β^- transition may therefore be assumed to lead directly to stable $_{82}Pb^{204}$. The logft value corresponding to this transition is 9.69 (F4). This transition has been classified from the shape of the β-spectrum (L14) (D31) as 1st forbidden, $\Delta I=2$, yes, $\log f_1t=8.85$ (D2). In such a case the spin of $_{81}Tl^{204}$ would be 2−, and it would be expected that the β^- transition to the 374-kev excited state of $_{82}Pb^{204}$ would be about 10^2 times more probable than the β^- transition to the ground state. However, the 0.374 γ-ray is not observed in the 3.9-yr β^- transition from $_{81}Tl^{204}$ ($<10^{-4}$ per β^-) (D33).

IV. K-x-rays have been observed in the decay of 3.9-yr Tl^{204} (M38) (L14). The x-rays arise from K-electron capture with an intensity of ~1.5 percent (D31).

V. A second excited state of spin 7− as postulated in $_{82}Pb^{204}$ is a sole exception to the empirical rule (S37) that the second excited state of an even-even nucleus has a spin ≤ 4. It is interesting to note that a spin of 7− can be obtained if an even neutron is removed from the $i_{13/2}$ level and put into a $p_{1/2}$ level.

References:

$_{81}Tl^{204}$, ND p. 235, NDS2 p. 47; $_{82}Pb^{204}$, ND p. 238, NDS2 p. 48, NDS p. 44; $_{83}Bi^{204}$, ND p. 242.
(S29) A. W. Sunyar, D. E. Alburger, G. Friedlander, M. Goldhaber, and G. Scharff-Goldhaber, Phys. Rev. **78**, 326A (1950).
(M38) L. Madansky (private communication).
(L14) L. Lidofsky, P. Macklin, and C. S. Wu, Phys. Rev. **87**, 204A (1952).
(D31) E. der Mateosian (unpublished).
(D33) E. der Mateosian, G. Friedlander, M. Goldhaber, and A. W. Sunyar, unpublished.
(S37) G. Scharff-Goldhaber, Phys. Rev. **87**, 218A (1952).
(H19) G. Harbottle, Quarterly Progress Report, July–September 1951, Brookhaven National Laboratory, BNL-132(S-11), p. 100.

A=207

I. Two γ-transitions of 1.06 and 0.54 Mev are associated with the 0.9-sec isomeric activity in $_{82}Pb^{207}$ (C3). From lifetime and nuclear shell theory considerations these transitions are probably to be identified with M4 and E2 transitions between the levels $i_{13/2}\rightarrow f_{5/2}\rightarrow p_{1/2}$

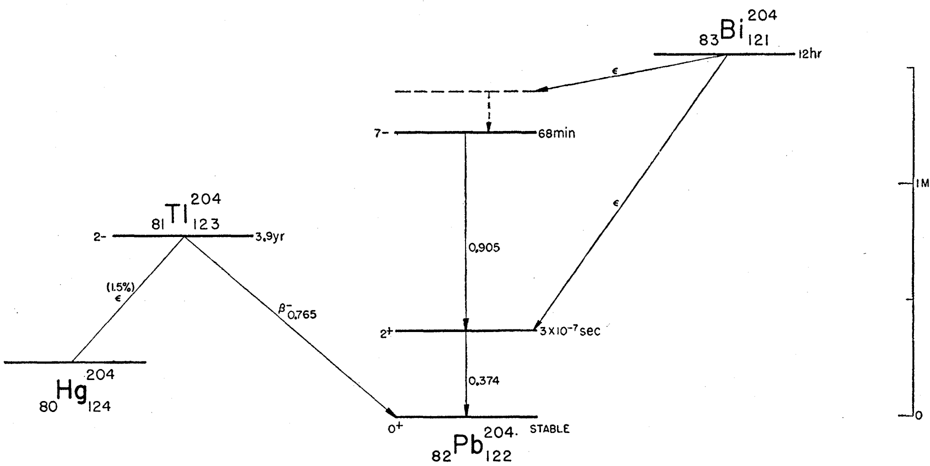

FIG. 70. $A=204$.

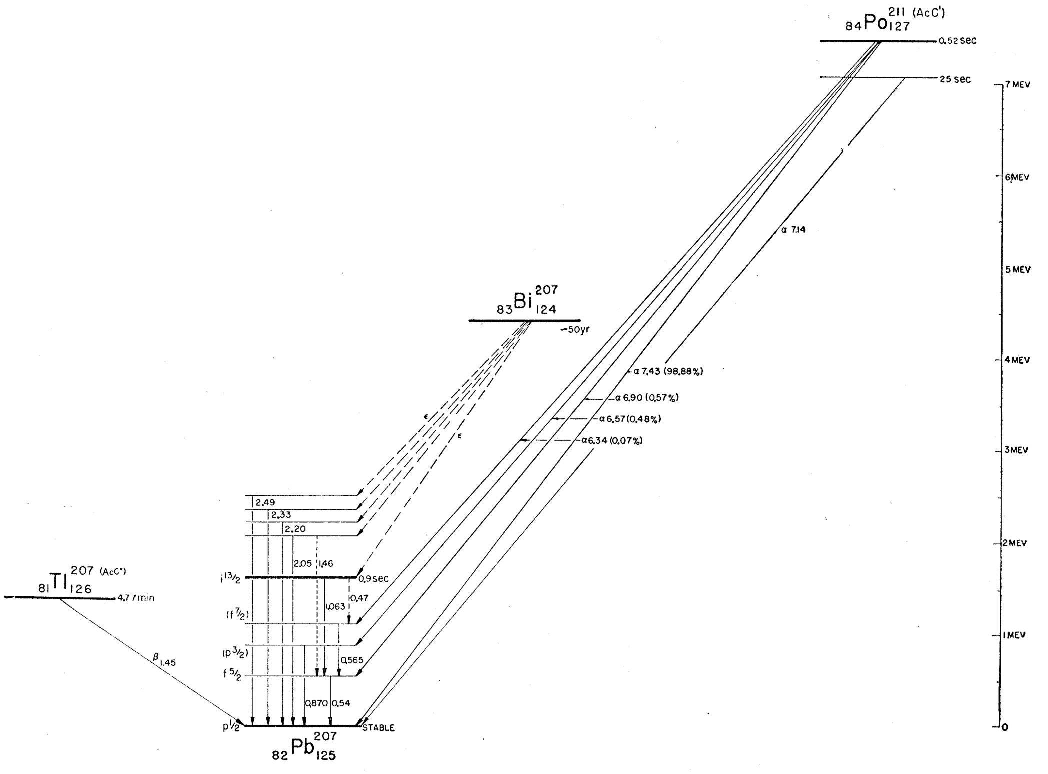

Fig. 71. $A=207$.

(G13). The measured spin of the ${}_{82}Pb^{207}$ ground state is 1/2.

II. The level scheme for ${}_{82}Pb^{207}$ has been constructed (P8) using data also available from the β^- decay of AcC″, the ε-capture of ${}_{83}Bi^{207}$ and the α-decay of ${}_{84}Po^{211}$ (N4) (S33) (H3) (G13) (S19).

References:

${}_{81}Tl^{207}$, ND p. 235; ${}_{82}Pb^{207}$, ND p. 238, NDS p. 44; ${}_{84}Po^{211}$, ND p. 247.
(C3) E. C. Campbell and M. Goodrich, Phys. Rev. **78**, 640A (1950).
(P8) M. H. L. Pryce, private communication (1951).
(N4) H. M. Neumann and I. Perlman, Phys. Rev. **81**, 958 (1951).
(S33) J. Surugue, J. phys. et radium **7**, 145 (1946).
(H3) J. A. Harvey, M.I.T. thesis (1950).
(G13) M. A. Grace and J. R. Prescott, Phys. Rev. **84**, 1059 (1951).
(L6) R. F. Leininger, E. Segrè, and F. N. Spiess, Phys. Rev. **82**, 334A (1951).
(S19) F. N. Spiess, University of California Radiation Laboratory, UCRL-1494.

$A=210$

I. The following energy values are used to determine that the >25-yr ${}_{83}Bi^{210}$ isomer lies 25±45 kev below the 4.85-day ${}_{83}Bi^{210}$ state:

>25-yr ${}_{83}Bi^{210}$, $\alpha=4.93\pm0.02$ (L8),
4.2-min ${}_{81}Tl^{206}$, $\beta^-=1.51\pm0.01$ (A4),
4.85-day ${}_{83}Bi^{210}$, $\beta^-=1.165\pm0.005$ (ND p. 243, NDS p. 46),
138-day ${}_{84}Po^{210}$, $\alpha=5.30\pm0.01$ (ND p. 247).

(The α-particle energies are both uncorrected for nuclear recoil energies.)

II. The spins of ${}_{82}Pb^{206}$, ${}_{82}Pb^{210}$, and ${}_{84}Po^{210}$ ground states are assumed to be 0+. The spin of 2+ for the 803-kev excited state in ${}_{82}Pb^{206}$ is based on the observed $\alpha-\gamma$ angular correlation (D4). The K/L ratio of the 803-kev transition may have been disturbed by the presence of a second γ-ray with a K line superimposed on the L line of the 803-kev transition.

III. The log*ft* values for the various β^- transitions represented in the diagram are: 5.2 (1.51 β^- from 4.2-min ${}_{81}Tl^{206}$), 8.1 (1.165 β^- from 4.85-day ${}_{83}Bi^{210}$), 6.02 (0.029 β^- from 22-yr ${}_{82}Pb^{210}$). The 1.51 β^- transition from 42-min ${}_{81}Tl^{206}$ appears to be allowed, but shell theoretically, an odd parity (0−, 1−) is required for the ${}_{81}Tl^{206}$ state. The 1.165 β^- transition from 4.85-day RaE has a "forbidden" shape and an assignment of 0− has been suggested for the 4.85-day state of ${}_{83}Bi^{210}$ (P6).

IV. The absence of a β^- transition from the >25-yr ${}_{83}Bi^{210}$ state to the 138-day state of ${}_{84}Po^{210}$ would require the log*ft* value of this transition to be $\gtrsim 11$. This is considerably higher than one would expect from a $\Delta I=2$, yes, transition, which should occur if the >25-yr ${}_{83}Bi^{210}$ state had the assignment 2−. Its spin is therefore probably higher.

V. A probable assignment for the 47-kev excited level in ${}_{83}Bi^{210}$ is 1−, in which case the β^- transition from RaD is first forbidden and the transition to the ground state of RaE is an M1 transition, in agreement with the measured L_I/L_{III} ratio (C18) (M28).

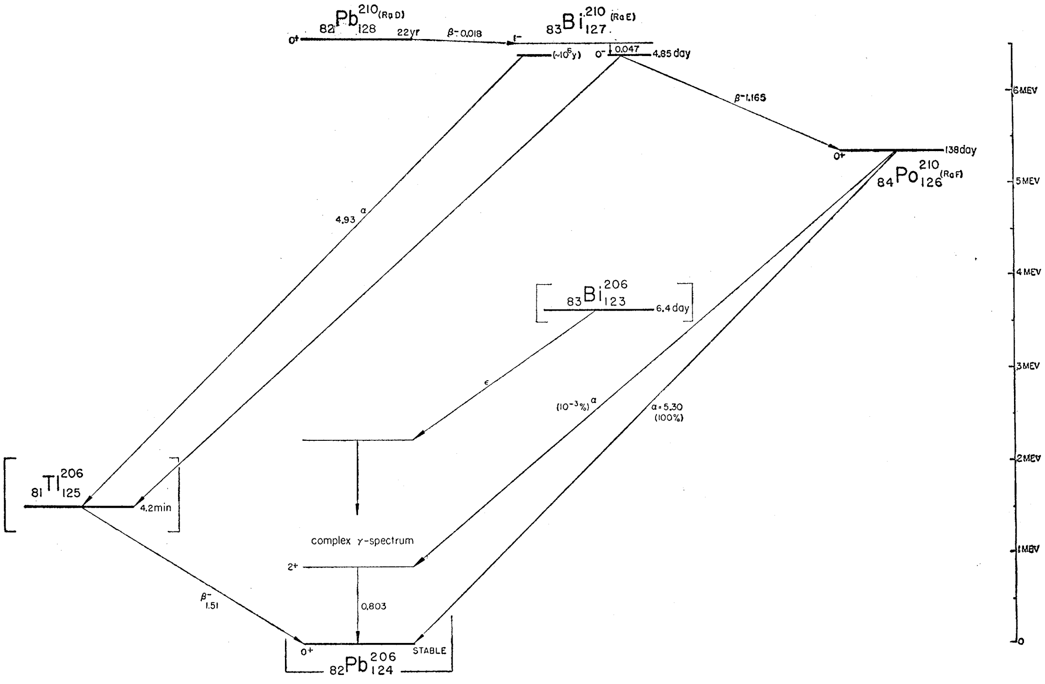

FIG. 72. $A=210$.

References:

$_{83}Bi^{210}$, ND p. 243, NDS pp. 45, 46; $_{81}Tl^{206}$, ND p. 235; $_{84}Po^{210}$, ND p. 247, NDS p. 46; $_{82}Pb^{206}$, NDS p. 44.

(L8) H. B. Levy and I. Perlman, Phys. Rev. **85**, 758A (1952).

(N3) H. M. Neumann, J. J. Howland, Jr., and I. Perlman, Phys. Rev. **77**, 720 (1950).

(A4) D. E. Alburger and G. Friedlander, Phys. Rev. **82**, 977 (1951); **81**, 523 (1951).

(P6) A. G. Petschek and R. E. Marshak, Phys. Rev. **85**, 698 (1952).

(F1) N. Feather, Phil. Mag. **42**, 568 (1951).

(C13) J. M. Cork, C. E. Branyan, A. E. Stoddard, H. B. Keller, J. M. LeBlanc, and W. J. Childs, Phys. Rev. **83**, 681 (1951).

(M7) M. G. Mayer, S. A. Moszkowski, and L. W. Nordheim, Argonne National Laboratory, ANL-4626 (1951); Revs. Modern Phys. **23**, 315 (1951).

(D4) S. DeBenedetti, International Conference on Nuclear Physics, Chicago (1951); S. DeBenedetti and G. H. Minton, Phys. Rev. **85**, 944 (1952).

(C18) L. Cranberg, Phys. Rev. **77**, 155 (1950).

(M28) J. W. Mihelich and E. L. Church, Phys. Rev. **85**, 733A (1952); J. W. Mihelich, Phys. Rev. **87**, 646 (1952).

$A=211$

$_{84}Po_{127}$ $T_1=0.52$ sec, $\alpha=7.434$ (L6),
$T_2=25$ sec, $\alpha=7.14$ (L6) (S19).

References:

AcC′ ($_{84}Po^{211}$), ND p. 247, NDS2 p. 49.

(L6) R. F. Leininger, E. Segrè, and F. N. Spiess, Phys. Rev. **82**, 334A (1951).

(S19) F. N. Spiess, University of California Radiation Laboratory, UCRL-1494.

$A=234$

I. The 394-kev isomeric transition from 1.14-min $_{91}Pa^{234}$ (UX_2) is probably an E4 transition, although E5 is not definitely excluded (G10).

II. The logft value for the 2.32 β^- transition from the 1.14 $_{91}Pa^{234}$ state to the ground state of $_{92}U^{234}$ is 5.6 (F4). Thus the level assignment for the 1.14-min UX_2 ($_{91}Pa^{234m}$) state is probably 1+, and on this basis the assignment for the 6.7-hr UZ ($_{91}Pa^{234}$) state is probably 5+.

III. The assignment of 5+ for the 6.7-hr $_{91}$UZ state is not inconsistent with the ~1.2 β^- transition from the 6.7-hr state to the 782- and 822-kev excited states of $_{92}U^{234}$. The conversion coefficients (B24) of the 782- and 822-kev γ-rays would identify them as M3 and the logft value (=8.03) of the 1.2 β^- transition would identify the β-transition as 1st forbidden, $\Delta I=2$, yes.

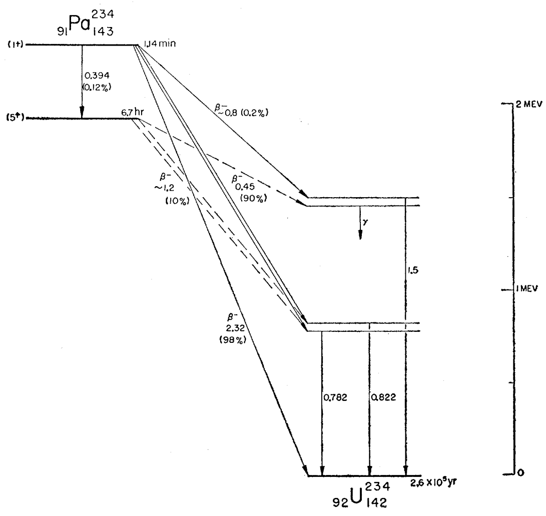

FIG. 73. $A=234$.

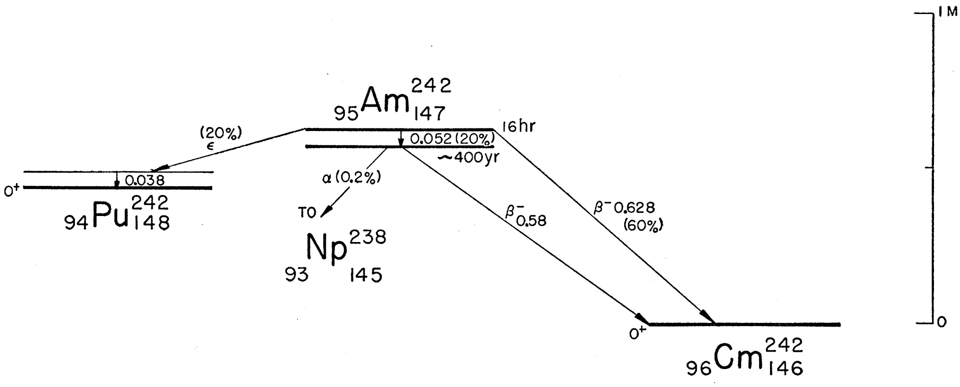

FIG. 74. $A=242$.

IV. The probable allowed character ($\log ft=5.6$) of the 0.45 β^- transition from the 6.7-hr $_{91}\mathrm{Pa}^{234}$ and the probable first forbidden character ($\log ft=6.5$) of the ~0.8 β^- transition from the 1.14-min $_{91}\mathrm{Pa}^{234}$ make it improbable that these transitions occur to the same excited state in $_{92}\mathrm{U}^{234}$. Clearly, the decay scheme is still incomplete.

References:

$_{91}\mathrm{Pa}^{234}$, ND p. 264.
(B25) H. Bradt and P. Scherrer, Helv. Phys. Acta **18**, 405 (1945).
(B24) H. Bradt, H. G. Heine, and P. Scherrer, Helv. Phys. Acta **16**, 455 (1943).
(F2) N. Feather and E. Bretscher, Proc. Roy. Soc. (London) **A165**, 530 (1938).

A = 242

I. The lifetime of the 52-kev isomeric transition in $_{95}\mathrm{Am}^{242}$ is consistent with either an E3 or M3 transition (G10). According to the systematics of $L_I/L_{II}/L_{III}$ ratios (M28) the observed L-radiations (O1) speak in favor of an M3 transition.

II. The $\log ft$ values of the 0.628 β^- transition from 16-hr $_{95}\mathrm{Am}^{242}$ and of the 0.580 β^- transition from ~400-yr $_{95}\mathrm{Am}^{242}$ are 6.6 and 11.75, respectively, thus characterizing these transitions as 1st and 2nd forbidden, respectively.

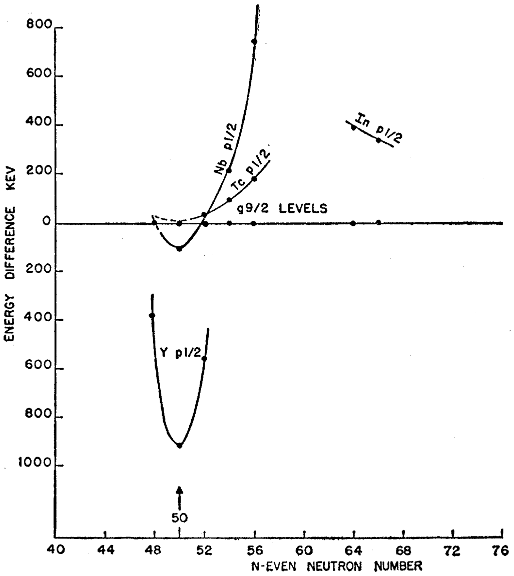

FIG. 75. Energy difference between $2p_{1/2}$ levels and $1g_{9/2}$ levels for odd-proton isomers, plotted as a function of N.

III. If, as is indicated from the energy balance of β^- and isomeric transitions, the two β^- transitions lead directly to the ground state of $_{96}\mathrm{Cm}^{242}$, then the assignments for the 16-hr and ~400-yr levels would be $\leq 1-$ and $\leq 2+$, respectively. (The $\log f_2 t$ value for the 0.58 β^- transition from 400-yr $_{95}\mathrm{Am}^{242}$ is 9.37, thus apparently excluding the assignment 3+.) These assignments are inconsistent with the E3 or M3 character of the 52-kev isomeric transition of $_{95}\mathrm{Am}^{242}$. It is possible that a low energy γ-ray transition may therefore have escaped detection.¶¶¶

References:

$_{95}\mathrm{Am}^{242}$, ND p. 271, NDS2 p. 52.
(O1) G. D. O'Kelley, G. W. Barton, Jr., W. W. T. Crane, and I. Perlman, Phys. Rev. **80**, 293 (1950).
(M28) J. W. Mihelich and E. L. Church, Phys. Rev. **85**, 733A (1952); J. W. Mihelich, Phys. Rev. **87**, 646 (1952).

SYSTEMATICS OF ISOMER LEVELS

The close correlation that has been shown between groups of isomer levels of similar spin assignments, and the magic nucleon numbers of shell theory, naturally leads to an inquiry as to whether there are also correlations of the energies involved in isomeric transitions with nucleon numbers. Such correlations have been found,[22] and are here shown in Figs. 75 to 80, where the energy differences between various levels are plotted as a function of the number of neutrons (N) in the isomeric nucleus. All energy differences are obtained directly from the level schemes discussed earlier in this review article. It is clear that there are regular variations of relative level positions with change of nucleon numbers from one neighboring isotope to another and from one neighboring element to another.

In Fig. 75, the energy differences between the $p_{1/2}$ and $g_{9/2}$ levels of the odd A isomers of $_{39}\mathrm{Y}$, $_{41}\mathrm{Nb}$, $_{43}\mathrm{Tc}$,

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[22] R. D. Hill, Phys. Rev. **79**, 1021 (1950); Brookhaven National Laboratory (S-11) 18 (1951); A. C. G. Mitchell, Phys. Rev. **83**, 183 (1951).

¶¶¶ *Note added in proof.*—A further low energy transition has been observed and included in a revised decay scheme by G. D. O'Kelley (thesis, University of California, 1951).

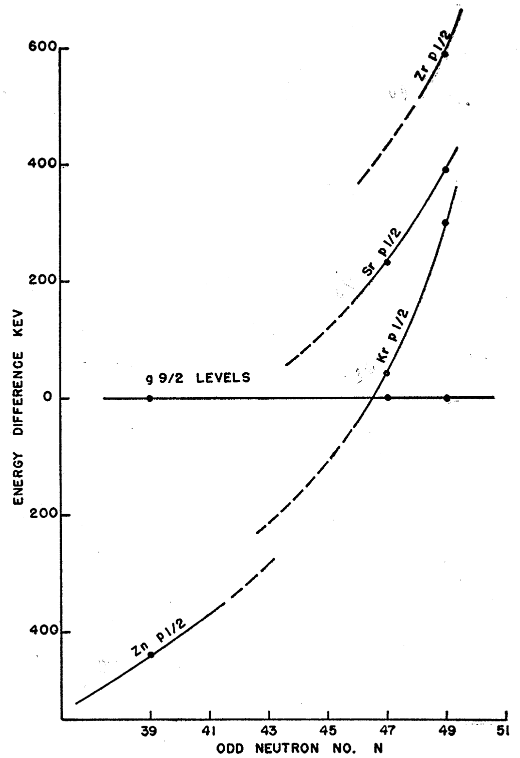

FIG. 76. Energy difference between $2p_{1/2}$ levels and $1g_{9/2}$ levels for odd-neutron isomers, plotted as a function of N.

and $_{49}$In are plotted as a function of their even neutron numbers (N). In each case, except for In for which the known isomers do not extend to sufficiently low N values, there is a minimum in the $p_{1/2}$ curve at the magic number $N=50$. This is probably connected with the contraction of the nuclear core at a magic number (G6). The case of $_{41}$Nb^{93} ($N=52$) is interesting since the $p_{1/2}$ curve is indicated as passing very close to the $g_{9/2}$ level. (The ground state of stable Nb^{93} has a measured spin of 9/2.) This is in agreement with the observation of Glendenin and Steinberg[23] that the isomer of Nb^{93} which they have recently discovered has a low transition energy and comparatively long lifetime.

In Fig. 76, the energy differences between the $p_{1/2}$ and $g_{9/2}$ levels of the odd A isomers of $_{30}$Zn, $_{36}$Kr, $_{38}$Sr, and $_{40}$Zr are plotted against their odd neutron numbers (N). One observes that the $_{36}$Kr and $_{38}$Sr $p_{1/2}$ levels rise with respect to the $g_{9/2}$ levels as the number $N=50$ is approached. There appears also to be a progressive rising of the $p_{1/2}$ levels with respect to the $g_{9/2}$ levels as the atomic number of the element increases. This is consistent too with the rise of the minimum of the $p_{1/2}$ curve with increasing Z, as indicated in Fig. 75.

In Fig. 77, the energy differences between the 7/2+ and $p_{1/2}$ levels are plotted against odd neutron numbers for the odd A isomers of Kr and Se. The 7/2+ curves for both elements show pronounced minima at $N=45$. This behavior is undoubtedly a reflection of the manner in which the 7/2+ states arise from the coupling of $g_{9/2}$ neutrons. The 7/2+ states are only found for 43, 45, or 47 odd particles, corresponding to 3, 5, or 7 $g_{9/2}$ particles in the sub-shell.

In Fig. 78, the energy differences of the $d_{3/2}$ and $s_{1/2}$ levels from the $h_{11/2}$ levels of the odd A isomers of $_{48}$Cd, $_{50}$Sn, $_{52}$Te, $_{54}$Xe, and $_{56}$Ba are plotted against their odd neutron numbers. The $s_{1/2}$ levels of all elements are seen to rise consistently with respect to the $d_{3/2}$ and $h_{11/2}$ levels. This variation is further shown with respect to the $d_{3/2}$ levels in a separate figure (Fig. 79 taken from reference 24). It should be noticed that the values of N at which the $s_{1/2}$ levels cross the $d_{3/2}$ levels increase consistently with increasing Z of the element. It should also be noticed in Fig. 78 that the $d_{3/2}$ levels are displaced slightly toward the $h_{11/2}$ levels immediately following the crossing of the $d_{3/2}$ levels by the $s_{1/2}$ levels. This feature led to the prediction and verification of the existence of a low energy second transition in the decay of the Ba^{133} isomer.[24] The $d_{3/2}$ level curves are observed to fall away steeply from the $h_{11/2}$ levels for values of N increasing towards the magic number 82. Extrapolation of the Te curve to $N=81$ led to a prediction of the approximate energy and lifetime of the Te^{133} isomer[25] which has been confirmed. The energy

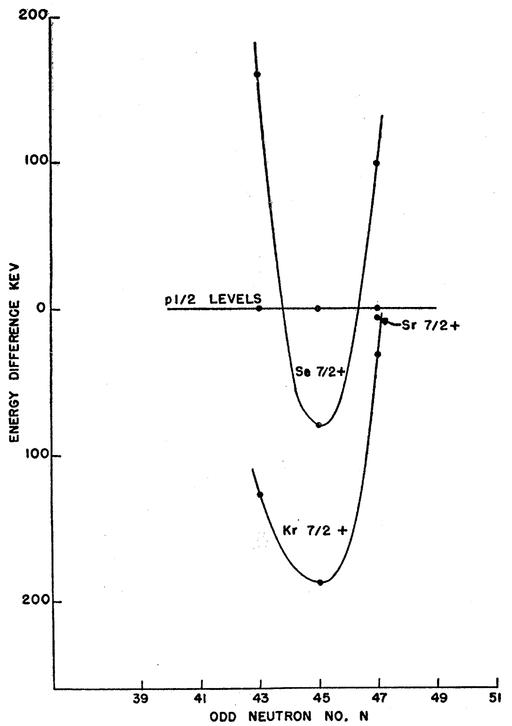

FIG. 77. Energy difference of 7/2+ levels and $2p_{1/2}$ levels for odd-neutron isomers, plotted as a function of N.

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[23] L. E. Glendenin and E. P. Steinberg (private communication, 1951).

[24] Hill, Scharff-Goldhaber, and McKeown, Phys. Rev. 84, 382 (1951).

[25] A. Pappas, Phys. Rev. 87, 162 (1952).

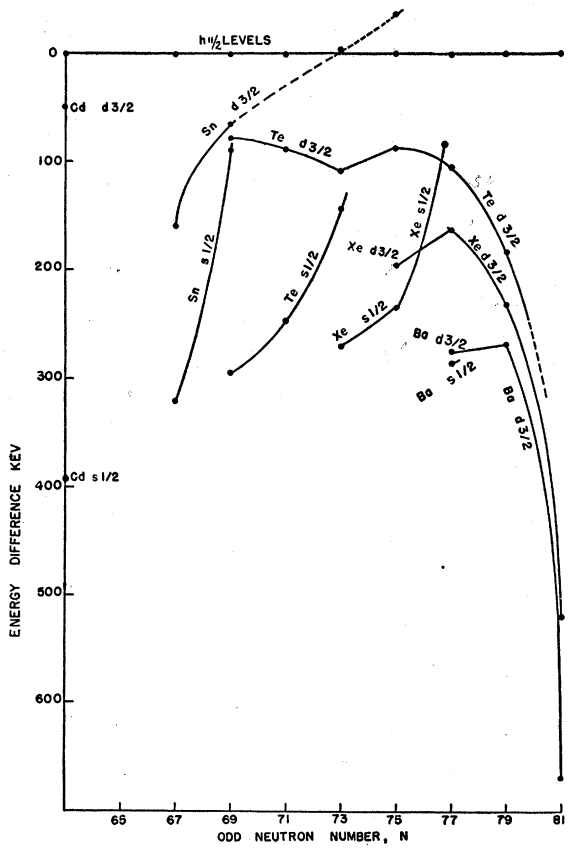

FIG. 78. Energy differences between $2d_{3/2}$ and $3s_{1/2}$ levels and $h_{11/2}$ levels for odd-neutron isomers, plotted as a function of N.

differences between the $d_{3/2}$ and $h_{11/2}$ levels of given N are seen to be consistently larger for higher values of the atomic number of the element. One can interpret the steep drop of the curves as the end of the shell is reached by assuming that the $h_{11/2}$ shell fills as early as possible and that the work done in breaking it to remove a particle from the $h_{11/2}$ shell and to put it into a $d_{3/2}$ shell becomes greater the more completely the $h_{11/2}$ shell is closed. This interpretation is also given by Bohr, Koch, and Rasmussen[26] who find a negative quadrupole moment for $_{54}Xe^{131}$, indicating that this nucleus has in first approximation 10 $h_{11/2}$ neutrons and 1 $d_{3/2}$ neutron rather than 8 $h_{11/2}$ neutrons and 3 $d_{3/2}$ neutrons.

In Fig. 80, the energy differences of the $f_{5/2}$ and $p_{1/2}$ levels from the $i_{13/2}$ levels have been plotted as a function of odd neutron number for the odd A nuclei of $_{78}Pt$, $_{80}Hg$, and $_{82}Pb$. The $f_{5/2}$ and $p_{1/2}$ levels show indications of trends similar to those of Fig. 78. These suggestions have been used to assist in the identification of the mass numbers of the two Pt isomers, but the meager data available for drawing the curves render these conclusions uncertain. The large “breaking energy” for the $i_{13/2}$ levels at the end of the shell is again apparent.

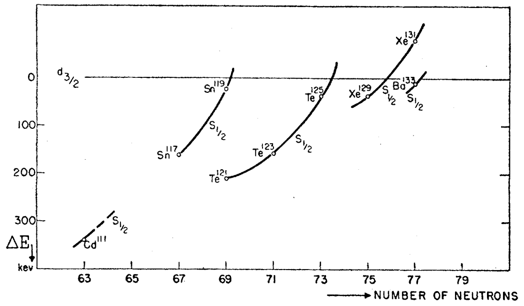

FIG. 79. Energy difference between $3s_{1/2}$ levels and $2d_{3/2}$ levels for odd-neutron isomers, plotted as a function of N.

It is to be hoped that these details of systematic isomer level movements may contribute to a fuller understanding of the factors governing the positions of nuclear energy levels generally.

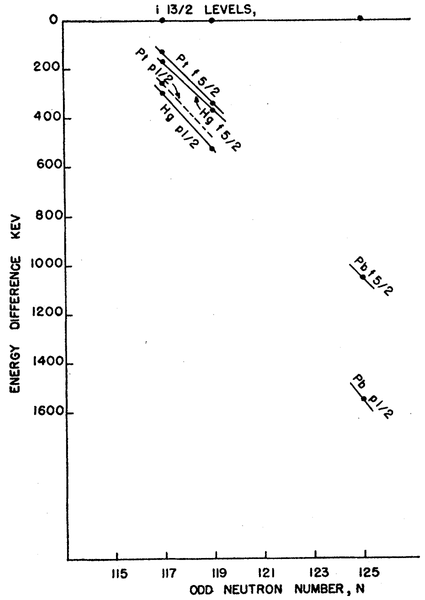

FIG. 80. Energy differences between $2f_{5/2}$ and $3p_{1/2}$ levels and $1i_{13/2}$ levels for odd-neutron isomers, plotted as a function of N.

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BIBLIOGRAPHY

(A1) P. Abelson, Phys. Rev. **56**, 1 (1939).
(A2) H. M. Agnew, Phys. Rev. **77**, 655 (1950).
(A3) D. E. Alburger, E. der Mateosian, and M. Goldhaber, Brookhaven National Laboratory, BNL-64 (1950).
(A4) D. E. Alburger and G. Friedlander, Phys. Rev. **82**, 977 (1951); **81**, 523 (1951).
(A5) O. H. Arroe, Phys. Rev. **79**, 212A (1950).
(A6) O. H. Arroe, Phys. Rev. **79**, 836 (1950).

---

[26] Bohr, Koch, and Rasmussen, M. Siegbahn Commemorative Volume, Uppsala 1951, p. 654.

(A7) P. Axel and J. C. Bowe, private communication (1952).
(A8) P. Axel and S. M. Dancoff, Phys. Rev. **76**, 892 (1949).
(A9) P. Axel and L. Mann, Phys. Rev. **80**, 759 (1950).
(A10) D. Alburger (private communication).
(A11) C. E. Anderson, G. W. Wheeler, and W. W. Watson, Phys. Rev. **87**, 195A (1952).
(A12) H. Aeppli, H. Albers-Schönberg, A. S. Bishop, H. Frauenfelder, and E. Heer, Phys. Rev. **84**, 370 (1951).
(B1) K. T. Bainbridge, M. Goldhaber, and E. Wilson, Phys. Rev. **84**, 1260 (1951).
(B2) P. R. Bell, J. M. Cassidy, and G. G. Kelley, Phys. Rev. **82**, 103 (1951).
(B3) R. E. Bell and R. L. Graham, Phys. Rev. **78**, 490 (1950).
(B4) P. R. Bell, B. H. Ketelle, and J. M. Cassidy, Phys. Rev. **76**, 574 (1949).
(B5) E. H. Bellamy, Nature **168**, 556 (1951).
(B6) W. L. Bendel, H. Brown, and R. A. Becker, Phys. Rev. **81**, 300 (1951).
(B7) I. Bergstrom, Nature **167**, 634 (1951).
(B8) I. Bergstrom and S. Thulin, Phys. Rev. **79**, 538 (1950); I. Bergstrom, Phys. Rev. **81**, 638 (1951).
(B9) I. Bergstrom, Phys. Rev. **80**, 114 (1950).
(B10) I. Bergstrom, Phys. Rev. **81**, 638 (1951).
(B11) I. Bergstrom, Phys. Rev. **82**, 111 (1951).
(B12) I. Bergstrom, Phys. Rev. **82**, 112 (1951).
(B13) I. Bergstrom and S. Thulin, Phys. Rev. **76**, 1718 (1949).
(B14) I. Bergstrom and S. Thulin, Phys. Rev. **79**, 537 (1950).
(B15) A. Berthelot, Ann. phys. **19**, 219 (1944).
(B16) J. Beydon, Compt. rend. **227**, 1159 (1948).
(B17) E. Bleuler, J. W. Blue, and A. C. Johnson, Phys. Rev. **82**, 333A (1951).
(B18) C. J. Berkowski and A. R. Brosi, Oak Ridge National Laboratory, ORNL-607 (1950); quoted by NDS, p. 28.
(B19) J. C. Bowe and P. Axel, Phys. Rev. **84**, 939 (1951).
(B20) J. C. Bowe, M. Goldhaber, R. D. Hill, W. E. Meyerhof, and O. Sala, Phys. Rev. **73**, 1219A (1948).
(B21) G. E. Boyd and Q. V. Larson (private communication to K. Way).
(B22) H. Bradt, P. C. Gugelot, O. Huber, H. Medicus, P. Preiswerk, P. Scherrer, and R. Steffen, Helv. Phys. Acta **20**, 153 (1947).
(B23) H. Bradt, P. C. Gugelot, O. Huber, H. Medicus, P. Preiswerk, and P. Scherrer, Phys. Rev. **68**, 57 (1945); Helv. Phys. Acta **20**, 153 (1947).
(B24) H. Bradt, H. G. Heine, and P. Scherrer, Helv. Phys. Acta **16**, 455 (1943).
(B25) H. Bradt and P. Scherrer, Helv. Phys. Acta **18**, 405 (1945).
(B26) H. L. Bradt and D. J. Tendam, Phys. Rev. **72**, 1117 (1947).
(B27) E. L. Brady and M. Deutsch, Phys. Rev. **78**, 558 (1950); **74**, 1541 (1948).
(B28) P. Brix and A. Steudel, Naturwiss. **38**, 431 (1951).
(B29) A. R. Brosi, T. W. DeWitt, and H. Zeldes, Phys. Rev. **75**, 1615 (1949).
(B30) A. R. Brosi, H. Zeldes, and B. H. Ketelle, Phys. Rev. **79**, 902 (1950).
(B31) J. A. Bruner and L. M. Langer, Phys. Rev. **79**, 606 (1950).
(B32) M. E. Bunker and R. Canada, Phys. Rev. **80**, 961 (1950).
(B33) M. E. Bunker, R. Canada, and A. C. G. Mitchell, Phys. Rev. **80**, 126A (1950).
(B34) W. H. Burgus, J. D. Knight, and R. J. Prestwood, Phys. Rev. **79**, 104 (1950).
(B35) S. B. Burson, K. W. Blair, H. B. Keller, and S. Wexler, Phys. Rev. **83**, 62 (1951).
(B36) S. B. Burson, K. W. Blair, and D. Saxon, Phys. Rev. **77**, 403 (1950).
(B37) S. B. Burson and C. O. Muehlhause, Phys. Rev. **74**, 1264 (1948).
(B38) S. B. Burson and W. C. Rutledge, Phys. Rev. **86**, 633A (1952).
(B39) A. R. Brosi (unpublished work, communicated by K. Way).
(B40) I. Bergstrom, M. Siegbahn Commemorative Volume, Uppsala (1951).
(B41) J. C. Bowe and P. Axel, Phys. Rev. **85**, 858 (1952).
(B42) J. P. Blaser, F. Boehm, and P. Marmier, Helv. Phys. Acta **23**, 623 (1950).
(B43) J. P. Blaser, F. Boehm, P. Marmier, and H. Wäffler, Helv. Phys. Acta **24**, 245 (1951).
(B44) W. L. Bendel, F. J. Shore, and R. A. Becker, Phys. Rev. **83**, 677 (1951).
(C1) R. L. Caldwell, Phys. Rev. **78**, 407 (1950).
(C2) E. C. Campbell and W. M. Good, Phys. Rev. **76**, 195 (1949).
(C3) E. C. Campbell and M. Goodrich, Phys. Rev. **78**, 640A (1950).
(C4) E. C. Campbell (private communication, 1951); J. H. Kahn, Oak Ridge National Laboratory, ORNL-1089 (1951).
(C5) R. Canada, W. H. Cuffey, A. E. Lessor, and A. C. G. Mitchell, Phys. Rev. **82**, 750 (1951); **83**, 955 (1951).
(C6) R. Canada and A. C. G. Mitchell, Phys. Rev. **83**, 76 (1951).
(C7) W. L. Carss, J. R. Gum, and M. L. Pool, Phys. Rev. **80**, 1028 (1950).
(C8) J. M. Cassidy, Phys. Rev. **83**, 483A (1951).
(C9) T. C. Chu, Phys. Rev. **79**, 582 (1950).
(C10) W. H. Cuffey and R. Canada, Phys. Rev. **83**, 654 (1951).
(C11) K. D. Coleman and M. L. Pool, Phys. Rev. **72**, 1070 (1947).
(C12) J. M. Cork, C. E. Branyan, W. C. Rutledge, A. E. Stoddard, and J. M. LeBlanc, Phys. Rev. **78**, 304 (1950).
(C13) J. M. Cork, C. E. Branyan, A. E. Stoddard, H. B. Keller, J. M. LeBlanc, and W. J. Childs, Phys. Rev. **83**, 681 (1951).
(C14) J. M. Cork, H. B. Keller, W. C. Rutledge, and A. E. Stoddard, Phys. Rev. **78**, 95 (1950).
(C15) J. M. Cork, J. M. LeBlanc, A. E. Stoddard, W. J. Childs, C. E. Branyan, and D. W. Martin, Phys. Rev. **82**, 258 (1951).
(C16) J. M. Cork, W. C. Rutledge, A. E. Stoddard, C. E. Branyan, and J. M. LeBlanc, Phys. Rev. **79**, 938 (1950).
(C17) J. M. Cork, A. E. Stoddard, C. E. Branyan, W. J. Childs, D. W. Martin, and J. M. LeBlanc, Phys. Rev. **84**, 596 (1951).
(C18) L. Cranberg, Phys. Rev. **77**, 155 (1950).
(C19) E. C. Creutz, L. A. Delsasso, R. B. Sutton, M. G. White and W. H. Barkas, Phys. Rev. **58**, 481 (1940).
(C20) S. C. Curran, D. Dixon, and H. W. Wilson, Phys. Rev **84**, 151 (1951).
(D1) E. B. Dale and J. D. Kurbatov, Phys. Rev. **80**, 126A (1950).
(D2) J. P. Davidson, Jr., Phys. Rev. **82**, 48 (1951).
(D3) L. Davis, Jr., D. E. Nagle, and J. R. Zacharias, Phys. Rev. **76**, 1068 (1949).
(D4) S. DeBenedetti, International Conference on Nuclear Physics, Chicago (1951); S. DeBenedetti and G. H. Minton, Phys. Rev. **85**, 944 (1952).
(D5) S. DeBenedetti and F. K. McGowan, Phys. Rev. **74**, 728 (1948).
(D6) E. der Mateosian, private communication (1951).
(D7) E. der Mateosian, Phys. Rev. **83**, 223A (1951).
(D8) E. der Mateosian and M. Goldhaber, Phys. Rev. **76**, 187A (1949).
(D9) E. der Mateosian and M. Goldhaber, Phys. Rev. **82**, 115 (1951).
(D10) E. der Mateosian and M. Goldhaber, Phys. Rev. **83**, 843 (1951).
(D11) E. der Mateosian and M. Goldhaber (private communication).
(D12) E. der Mateosian and M. Goldhaber (unpublished, 1951).
(D13) E. der Mateosian, D. Alburger, G. Friedlander, M. Goldhaber, J. W. Mihelich, G. Scharff-Goldhaber, and A. W. Sunyar, Brookhaven National Laboratory, BNL Quarterly Report No. 7 (1950).
(D14) E. der Mateosian, M. Goldhaber, C. O. Muehlhause, and M. McKeown, Phys. Rev. **72**, 1271 (1947), and unpublished data.
(D15) A. de-Shalit (to be published).
(D16) A. de-Shalit (private communication, 1951).
(D17) A. de-Shalit (private communication, 1952).
(D18) M. Deutsch and G. Scharff-Goldhaber, Phys. Rev. **83**, 1059 (1951).
(D19) M. Deutsch, A. Roberts, and L. G. Elliott, Phys. Rev. **61**, 389A (1942).
(D20) M. Deutsch and W. E. Wright, Phys. Rev. **77**, 139 (1950).
(D21) R. B. Duffield (private communication).
(D22) R. B. Duffield and P. Axel (private communication).

(D23) R. B. Duffield, L. Hsiao, and E. N. Sloth, Phys. Rev. **79**, 1011 (1950).
(D24) R. B. Duffield and J. D. Knight, Phys. Rev. **75**, 1613 (1949).
(D25) R. B. Duffield and J. D. Knight, Phys. Rev. **75**, 1967 (1949).
(D26) R. B. Duffield and L. M. Langer, Phys. Rev. **76**, 1272 (1949).
(D27) R. B. Duffield and L. M. Langer, Phys. Rev. **77**, 743A (1950).
(D28) R. B. Duffield and L. M. Langer, Phys. Rev. **81**, 203 (1951).
(D29) H. T. Dybvig and M. L. Pool, Phys. Rev. **80**, 126A (1950).
(D30) E. K. Darby, Can. J. Phys. **29**, 569 (1951).
(D31) E. der Mateosian (unpublished).
(D32) J. V. Dunworth and B. Pontecorvo, Cambridge Phil. Soc. **43**, 429 (1947).
(D33) E. der Mateosian, G. Friedlander, M. Goldhaber, and A. W. Sunyar (unpublished).
(D34) E. der Mateosian and M. Goldhaber, Phys. Rev. **78**, 326A (1950).
(E1) A. A. Ebel and C. Goodman, Phys. Rev. **82**, 130A (1951).
(E2) L. G. Elliott, private communication; Phys. Rev. **85**, 942 (1952).
(E3) L. G. Elliott and R. E. Bell, Phys. Rev. **72**, 979 (1947).
(E4) D. Englekemeir, Phys. Rev. **82**, 552 (1951).
(E5) D. Englekemeir (Argonne National Laboratory, unpublished).
(E6) W. S. Emmerich and J. D. Kurbatov, Phys. Rev. **85**, 149 (1952).
(F1) N. Feather, Phil. Mag. **42**, 568 (1951).
(F2) N. Feather and E. Bretscher, Proc. Roy. Soc. (London) **A165**, 530 (1938).
(F3) E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).
(F4) A. M. Feingold, Revs. Modern Phys. **23**, 10 (1951).
(F5) R. W. Fink, F. L. Reynolds, and D. H. Templeton, Phys. Rev. **77**, 614 (1950).
(F6) A. Flammersfeld and W. Herr, Z. Naturforsch. **5a**, 569 (1950).
(F7) A. Flammersfeld, Z. Naturforsch. **5a**, 687 (1950).
(F8) A. Flammersfeld, Z. Naturforsch. **6a**, 559 (1951).
(F9) R. G. Fluharty and M. Deutsch, Phys. Rev. **76**, 182 (1949).
(F10) G. R. Fowles, Phys. Rev. **76**, 571 (1949).
(F11) G. R. Fowles, Phys. Rev. **78**, 744 (1950).
(F12) S. Frankel, PhD thesis, Illinois (1949).
(F13) J. S. Fraser, Phys. Rev. **76**, 1540 (1949).
(F14) G. Friedlander (private communication, 1951).
(F15) G. Friedlander and J. Miller, Phys. Rev. **84**, 588 (1951).
(F16) G. Friedlander and W. C. Orr, Phys. Rev. **84**, 484 (1951).
(F17) O. Frisch, E. H. Bellamy, and K. F. Smith, International Conference on Nuclear Physics, Chicago (1951).
(F18) O. Frisch, E. H. Bellamy, and K. F. Smith (private communication, 1951).
(F19) E. W. Fuller, Proc. Roy. Soc. (London) **A63**, 1044 (1950).
(F20) A. Flammersfeld, Z. Naturforsch. **2a**, 86 (1947).
(G1) S. Geschwind, H. Minden, and C. H. Townes, Phys. Rev. **78**, 174 (1950).
(G2) P. S. Gill, C. E. Mandeville, and E. Shapiro, Phys. Rev. **80**, 284 (1950).
(G3) M. Glaubman and F. R. Metzger (private communication, 1952).
(G4) L. E. Glendenin, National Nuclear Energy Series **9**, paper 329, page 1936.
(G5) L. E. Glendenin, National Nuclear Energy Series **9**, paper 61, page 596.
(G6) M. Goldhaber, E. der Mateosian, G. Scharff-Goldhaber, A. W. Sunyar, M. Deutsch, and N. S. Wall, Phys. Rev. **83**, 661 (1951).
(G7) M. Goldhaber and C. O. Muehlhause, Phys. Rev. **74**, 1877 (1948).
(G8) M. Goldhaber, C. O. Muehlhause, and S. H. Turkel, Phys. Rev. **71**, 372 (1947).
(G9) M. Goldhaber and A. W. Sunyar, Brookhaven National Laboratory, BNL Quarterly Report No. 7 (1950).
(G10) M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
(G11) L. J. Goodman and M. L. Pool, Phys. Rev. **70**, 112 (1946); **71**, 288 (1947).
(G12) M. Goodrich and E. C. Campbell, Phys. Rev. **79**, 418 (1950).
(G13) M. A. Grace and J. R. Prescott, Phys. Rev. **84**, 1059 (1951).
(G14) R. L. Graham (private communication, 1951).
(G15) R. L. Graham (private communication, 1951); R. L. Graham and R. E. Bell, Phys. Rev. **84**, 380 (1951).
(G16) R. L. Graham and R. E. Bell, Phys. Rev. **84**, 380 (1951).
(G17) P. J. Grant, Nature **165**, 1018 (1950).
(H1) W. Hälg, Helv. Phys. Acta **24**, 641 (1951).
(H2) W. A. Hardy, G. Silvey, and C. H. Townes, Phys. Rev. **85**, 494 (1952).
(H3) J. A. Harvey, M.I.T. thesis (1950).
(H4) R. N. H. Haslam, L. Katz, H. E. Johns, and H. J. Moody, Phys. Rev. **76**, 704 (1949).
(H5) R. W. Hayward, Phys. Rev. **79**, 409 (1950).
(H6) R. W. Hayward and A. C. Helmholz, Phys. Rev. **75**, 1469A (1949).
(H7) A. C. Helmholz, Phys. Rev. **60**, 415 (1941).
(H8) J. M. Hill and L. R. Shepard, Proc. Phys. Soc. (London) **A63**, 126 (1950).
(H9) R. D. Hill, Brookhaven Quarterly Report No. 11, 18 (1951).
(H10) R. D. Hill, Phys. Rev. **76**, 186A, 333 (1949).
(H11) R. D. Hill, Phys. Rev. **83**, 865 (1951).
(H12) R. D. Hill and F. R. Metzger, Phys. Rev. **83**, 455 (1951).
(H13) R. D. Hill, G. Scharff-Goldhaber, and M. McKeown, Phys. Rev. **84**, 382 (1951).
(H14) M. Hoffman, Phys. Rev. **83**, 215A (1951).
(H15) N. Hole, Arkiv Mat. Astron. Fysik **34**, No. 5 (1947).
(H16) N. Hole, Arkiv Mat. Astron. Fysik **36A**, No. 9 (1948).
(H17) E. K. Hyde and G. D. O'Kelley, Phys. Rev. **82**, 944 (1951).
(H18) O. Huber, F. Humbel, H. Schneider, A. de-Shalit, and W. Zunti, Helv. Phys. Acta **24**, 127, 629 (1951).
(H19) G. Harbottle, Quarterly Progress Report July–September 1951, Brookhaven National Laboratory, BNL-132(S-11), p. 100.
(H20) R. W. Hayward (private communication, 1952).
(I1) Iowa State College Report No. 175, G. W. Fox *et al.* (1951).
(J1) S. Johansson, Phys. Rev. **79**, 896 (1950).
(J2) M. W. Johns, C. D. Cox, and C. C. McMullen, Phys. Rev. **86**, 632A (1952).
(K1) J. H. Kahn, Oak Ridge National Laboratory, ORNL-1089 (1951); E. C. Campbell (private communication, 1951).
(K2) D. G. Karraker *et al.*, University of California Radiation Laboratory, UCRL-46 (1950).
(K3) S. Katcoff, O. A. Schaeffer, and J. M. Hastings, Phys. Rev. **82**, 688 (1951).
(K4) H. B. Keller, Argonne National Laboratory, ANL-4595 (1951).
(K5) H. B. Keller and J. M. Cork, Phys. Rev. **84**, 1079 (1951).
(K6) B. D. Kern, A. C. G. Mitchell, and D. J. Zaffarano, Phys. Rev. **76**, 94 (1949).
(K7) B. H. Ketelle, A. R. Brosi, and H. Zeldes, Phys. Rev. **80**, 485 (1950).
(K8) B. H. Ketelle and W. C. Peacock, Phys. Rev. **73**, 1269A (1948).
(K9) B. H. Ketelle and J. W. Ruch, Phys. Rev. **77**, 565 (1950).
(K10) J. D. Knight (private communication, 1951).
(K11) O. Kofoed-Hansen and K. O. Nielson, Phys. Rev. **82**, 96 (1951).
(K12) H. Kuhn and G. K. Woodgate, Nature **166**, 906 (1950).
(K13) H. Kuhn and G. K. Woodgate, Nature **166**, 906 (1950); Proc. Phys. Soc. (London) **A64**, 1090 (1951).
(K14) H. Kuhn and G. K. Woodgate, Proc. Phys. Soc. (London) **A63**, 830 (1950).
(K15) D. N. Kundu, J. L. Hult, and M. L. Pool, Phys. Rev. **77**, 71 (1950).
(K16) B. H. Ketelle, H. Zeldes, A. R. Brosi, and R. A. Dandl, Phys. Rev. **84**, 585 (1951).
(K17) P. F. A. Klinkenberg, Physica **17**, 715 (1951).
(K18) J. J. Kraushaar, Phys. Rev. **85**, 727A (1952).
(K19) R. W. King (private communication).
(L1) L. M. Langer (private communication, 1951).

(L2) L. M. Langer and R. J. D. Moffat, Phys. Rev. **82**, 635 (1951).

(L3) L. M. Langer, R. D. Moffat, and H. C. Price, Jr., Phys. Rev. **79**, 808 (1950).

(L4) L. M. Langer and H. C. Price, Jr., Phys. Rev. **76**, 641 (1949).

(L5) J. C. Lee and M. L. Pool, Phys. Rev. **76**, 606 (1949).

(L6) R. F. Leininger, E. Segrè, and F. N. Spiess, Phys. Rev. **82**, 334A (1951).

(L7) J. S. Levinger, National Nuclear Energy Series **9**, paper 94, page 757.

(L8) H. B. Levy and I. Perlman, Phys. Rev. **85**, 758A (1952).

(L9) W. F. Libby (private communication, 1951).

(L10) I. J. Lidofsky, P. A. Macklin, and C. S. Wu, Phys. Rev. **78**, 318A (1950).

(L11) M. Lindner and I. Perlman, Phys. Rev. **73**, 1124 (1948).

(L12) R. Livingston, O. R. Gilliam, and W. Gordy, Phys. Rev. **76**, 149 (1949).

(L13) W. F. Libby, private communication to G. Scharff-Goldhaber.

(L14) L. Lidofsky, P. Macklin, and C. S. Wu, Phys. Rev. **87**, 204A(1952).

(M1) P. A. Macklin, L. I. Lidofsky, and C. S. Wu, Phys. Rev. **82**, 334A (1951).

(M2) J. Macnamara, G. B. Collins, and H. G. Thode, Phys. Rev. **78**, 129 (1950).

(M3) L. G. Mann and P. Axel, Phys. Rev. **84**, 221 (1951).

(M4) R. Marshak (private communication, 1951).

(M5) E. A. Martell and W. F. Libby, Phys. Rev. **80**, 977 (1950).

(M6) D. S. Martin, Jr., E. N. Jensen, F. J. Hughes, and R. T. Nichols, Phys. Rev. **82**, 579 (1951).

(M7) M. G. Mayer, S. A. Moszkowski, and L. W. Nordheim, Argonne National Laboratory, ANL-4626 (1951); Revs. Modern Phys. **23**, 315 (1951).

(M8) C. L. McGinnis, Phys. Rev. **81**, 734 (1951); **83**, 686 (1951).

(M9) F. K. McGowan (private communication, 1951).

(M10) F. K. McGowan, Oak Ridge National Laboratory, ORNL-952 (1950); Phys. Rev. **76**, 1730 (1949).

(M11) F. K. McGowan, Phys. Rev. **77**, 138 (1950).

(M12) F. K. McGowan, Phys. Rev. **79**, 404 (1950); Oak Ridge National Laboratory, ORNL-952 (1951).

(M13) F. K. McGowan, Phys. Rev. **80**, 482 (1950).

(M14) F. K. McGowan, Phys. Rev. **80**, 923 (1950).

(M15) F. K. McGowan, Phys. Rev. **81**, 1066 (1951).

(M16) F. K. McGowan, Oak Ridge National Laboratory, ORNL-1005 (1951).

(M17) F. K. McGowan, S. DeBenedetti, and J. E. Francis, Jr., Phys. Rev. **75**, 1761 (1949).

(M18) H. A. Medicus (private communication, 1951).

(M19) H. A. Medicus and H. T. Easterday, Phys. Rev. **85**, 735A (1952); private communication of unpublished work by P. Stähelin and P. Preiswerk.

(M20) H. A. Medicus, D. Maeder, and H. Schneider, Helv. Phys. Acta **24**, 72 (1951).

(M21) H. A. Medicus, P. Preiswerk, and P. Scherrer, Helv. Phys. Acta **23**, 299 (1950); H. A. Medicus and P. Preiswerk, Phys. Rev. **80**, 1101 (1950).

(M22) H. A. Medicus, P. Preiswerk, and P. Scherrer, Helv. Phys. Acta **23**, 299 (1950).

(M23) J. Y. Mei, C. M. Huddleston, and A. C. G. Mitchell, Phys. Rev. **79**, 237A (1950); **79**, 429 (1950).

(M24) F. Metzger (private communication).

(M25) F. Metzger and M. Deutsch, Phys. Rev. **74**, 1640 (1948).

(M26) F. R. Metzger and R. D. Hill, Phys. Rev. **82**, 646 (1951).

(M27) J. W. Mihelich (private communication, 1951).

(M28) J. W. Mihelich and E. L. Church, Phys. Rev. **85**, 733 (1952); J. W. Mihelich, Phys. Rev. **87**, 646 (1952).

(M29) J. W. Mihelich and R. D. Hill, Phys. Rev. **79**, 781 (1950).

(M30) J. W. Mihelich, M. Goldhaber, and E. Wilson, Phys. Rev. **82**, 972 (1951).

(M31) J. Miller and G. Friedlander, Phys. Rev. **84**, 589 (1951).

(M32) A. C. G. Mitchell, J. Y. Mei, F. C. Maienschein, and C. L. Peacock, Phys. Rev. **76**, 1450 (1949).

(M33) M. L. Moon, M. A. Waggoner, and A. Roberts, Phys. Rev. **79**, 905 (1950).

(M34) S. A. Moszkowski, Phys. Rev. **83**, 240A, 1071 (1951).

(M35) C. E. Mandeville and E. Shapiro, J. Franklin Inst. **253**, 145 (1952).

(M36) A. C. G. Mitchell and A. B. Smith, Phys. Rev. **85**, 153 (1952).

(M37) F. R. Metzger, Phys. Rev. **86**, 435 (1952).

(M38) L. Madansky (private communication).

(M39) J. Y. Mei, C. M. Huddleston, and A. C. G. Mitchell, Phys. Rev. **79**, 1010 (1950).

(M40) J. W. Mihelich and E. L. Church, Phys. Rev. **85**, 690 (1952).

(N1) V. A. Nedzel, National Nuclear Energy Series **9**, paper 87, page 719.

(N2) C. M. Nelson, G. E. Boyd, and B. H. Ketelle, Oak Ridge National Laboratory, ORNL-828 (1950).

(N3) H. M. Neumann, J. J. Howland, Jr., and I. Perlman, Phys. Rev. **77**, 720 (1950).

(N4) H. M. Neumann and I. Perlman, Phys. Rev. **81**, 958 (1951).

(N5) T. B. Novey, Phys. Rev. **78**, 66 (1950).

(N6) G. J. Nijgh, N. F. Verster, R. H. Nussbaum, R. van Lieshout, and C. J. Bakker, Physica **17**, 658 (1951).

(O1) G. D. O'Kelley, G. W. Barton, Jr., W. W. T. Crane, and I. Perlman, Phys. Rev. **80**, 293 (1950).

(O2) J. S. Osaba, Phys. Rev. **76**, 345 (1949).

(O3) J. Ovadia, Ph.D. thesis, Illinois (1951).

(P1) A. Pappas and C. Coryell, Phys. Rev. **81**, 329A (1951).

(P2) G. W. Parker, National Nuclear Energy Series, Vol. 9, Appendix C, page 2020.

(P3) G. W. Parker, G. E. Creek, G. N. Herbert, and P. M. Lanitz, Oak Ridge National Laboratory, ORNL-286 (1949).

(P4) C. L. Peacock, A. R. Brosi, and A. Bogard, Oak Ridge National Laboratory, ORNL reports, as quoted in ND p. 152.

(P5) C. L. Peacock and A. C. G. Mitchell, Phys. Rev. **75**, 1272 (1949); C. L. Peacock, Phys. Rev. **76**, 186A (1949).

(P6) A. G. Petschek and R. E. Marshak, Phys. Rev. **85**, 698 (1952).

(P7) F. T. Porter and C. S. Cook, Phys. Rev. **81**, 640 (1951).

(P8) M. H. L. Pryce (private communication, 1951).

(R1) W. Rall and R. G. Wilkinson, Phys. Rev. **71**, 321 (1947).

(R2) A. F. Reid and A. S. Keston, Phys. Rev. **70**, 987 (1946).

(R3) G. A. Renard, Ann. phys. **5**, 385 (1950).

(R4) F. L. Reynolds, D. G. Karraker, and D. H. Templeton, Phys. Rev. **75**, 313 (1949).

(R5) R. Richmond and H. Rose, Phil. Mag. **43**, 367 (1952).

(R6) J. R. Risser, K. Lark-Horovitz, and R. N. Smith, Phys. Rev. **57**, 355A (1940).

(R7) B. L. Robinson and L. Madansky, Phys. Rev. **84**, 604 (1951).

(R8) P. Rothwell and D. West, Proc. Phys. Soc. (London) **63A**, 539 (1950).

(R9) L. Ruby and J. R. Richardson, Phys. Rev. **83**, 698 (1951).

(R10) L. I. Rusinov and E. I. Chutkin, Nuc. Sci. Abstracts **4**, No. 1827, 291 (1950).

(S1) A. J. Saur, P. Axel, L. G. Mann, and J. Ovadia, Phys. Rev. **79**, 237A (1950).

(S2) G. Scharff-Goldhaber, E. der Mateosian, M. Goldhaber, G. W. Johnson, and M. McKeown, Phys. Rev. **83**, 480 (1951).

(S3) G. Scharff-Goldhaber, E. der Mateosian, and J. W. Mihelich, Phys. Rev. **85**, 734A (1952).

(S4) D. Schiff, Phys. Rev. **86**, 727A (1952).

(S5) W. W. Schoof and R. D. Hill, Phys. Rev. **83**, 892A (1951).

(S6) J. M. C. Scott, Cavendish Laboratory (unpublished manuscript, 1951).

(S7) E. Segrè and A. C. Helmholz, Revs. Modern Phys. **21**, 271 (1949).

(S8) I. Shaknov, Phys. Rev. **82**, 333A (1951).

(S9) P. M. Sherk and R. D. Hill, Phys. Rev. **83**, 1097 (1951).

(S10) K. Siegbahn, M. Siegbahn Commemorative Volume, p. 229 (1952).

(S11) K. Siegbahn, M. Siegbahn Commemorative Volume, p. 226 (1952).

(S12) K. Siegbahn, Phys. Rev. **77**, 233 (1950).

(S13) K. Siegbahn and W. Forsling, Arkiv Fysik **1**, 505 (1950).

(S14) K. Siegbahn, E. Kondaiah, and S. Johansson, Nature **164**, 405 (1949).

(S15) K. Siegbahn and H. Slätis, Arkiv Fysik **1**, 559 (1950).

(S16) H. Slätis, Arkiv Mat. Astron. Fysik **A33**, No. 17 (1947).

(S17) H. Slätis, S. J. DuToit, and K. Siegbahn, Phys. Rev. **78**, 498 (1950).
(S18) N. R. Sleight and W. H. Sullivan, National Nuclear Energy Series **9**, paper 131.
(S19) F. N. Spiess, University of California Radiation Laboratory, UCRL-1494.
(S20) R. M. Steffen, Phys. Rev. **82**, 827 (1951).
(S21) R. M. Steffen, Phys. Rev. **83**, 166 (1951).
(S22) R. M. Steffen, O. Huber, and F. Humbel, Helv. Phys. Acta **22**, 167 (1949).
(S23) D. T. Stevenson, Phys. Rev. **82**, 333 (1951).
(S24) D. T. Stevenson and M. Deutsch, Phys. Rev. **83**, 1202 (1951).
(S25) K. Strauch, Phys. Rev. **79**, 487 (1950).
(S26) A. W. Sunyar, Phys. Rev. **83**, 864 (1951).
(S27) A. W. Sunyar (private communication, 1952).
(S28) A. W. Sunyar (private communication, 1951).
(S29) A. W. Sunyar, D. E. Alburger, G. Friedlander, M. Goldhaber, and G. Scharff-Goldhaber, Phys. Rev. **78**, 326A (1950).
(S30) A. W. Sunyar, J. W. Mihelich, G. Scharff-Goldhaber, M. Goldhaber, N. S. Wall, and M. Deutsch, Phys. Rev. **86**, 1023 (1952).
(S31) A. W. Sunyar and J. W. Mihelich, Phys. Rev. **81**, 300A (1951); Brookhaven National Laboratory, BNL 82 (S-7) (1950).
(S32) A. W. Sunyar, J. W. Mihelich, G. Scharff-Goldhaber, M. Deutsch, and M. Goldhaber, Phys. Rev. **85**, 734A (1952).
(S33) J. Surugue, J. phys. et radium **7**, 145 (1946).
(S34) F. J. Shore, W. L. Bendel, and R. A. Becker, Phys. Rev. **83**, 688 (1951).
(S35) L. Seren, H. N. Friedlander, and S. H. Turkel, Phys. Rev. **72**, 888 (1947).
(S36) G. Scharff-Goldhaber (unpublished).
(S37) G. Scharff-Goldhaber, Phys. Rev. **87**, 218A (1952).
(S38) R. M. Steffen, Phys. Rev. **86**, 632A (1952).
(S39) K. Siegbahn, M. Siegbahn Commemorative Volume, p. 241 (1952).
(T1) G. M. Temmer, Phys. Rev. **76**, 424 (1949).
(T2) D. A. Thomas, S. K. Haynes, C. D. Broyles, and H. C. Thomas, Phys. Rev. **82**, 961 (1951).
(T3) S. Thulin and I. Bergstrom (private communication, (1952); Phys. Rev. **85**, 1055 (1952).
(T4) S. Thulin, I. Bergstrom, and A. Hedgran, Phys. Rev. **76**, 871 (1949).
(T5) W. A. Thornton, E. der Mateosian, H. T. Motz, and M. Goldhaber, Phys. Rev. **86**, 604A (1952).
(V1) N. F. Verster, G. J. Nijgh, R. van Lieshout, and C. J. Bakker, Physica **17**, 637 (1951).
(W1) M. A. Waggoner, Phys. Rev. **80**, 489 (1950).
(W2) K. Way (private communication).
(W3) G. Wilkinson, Phys. Rev. **75**, 1019 (1949).
(W4) G. Wilkinson, Phys. Rev. **80**, 495 (1950).
(W5) G. Wilkinson, Nature **160**, 864 (1947).
(W6) G. Wilkinson and H. G. Hicks, Phys. Rev. **77**, 314 (1950).
(W7) R. R. Williams, Jr., J. Chem. Phys. **16**, 513 (1948).
(W8) L. Winsberg, National Nuclear Energy Series **9**, paper 60, page 593.
(W9) C. S. Wu, International Conference on Nuclear Physics, Chicago, Illinois (1951).
(W10) C. S. Wu and L. Feldman, Phys. Rev. **82**, 332 (1951).
(W11) A. C. Wahl and N. A. Bonner, Phys. Rev. **85**, 570 (1952).
(W12) R. W. Wilson, Phys. Rev. **79**, 1004 (1950).
(Y1) Fu-Chun Yu and J. D. Kurbatov, Phys. Rev. **74**, 34 (1948).
(Z1) H. Zeldes, A. R. Brosi, and B. H. Ketelle, Phys. Rev. **81**, 642 (1951).
(Z2) H. Zeldes, B. H. Ketelle, and A. R. Brosi, Phys. Rev. **79**, 901 (1950).
(Z3) A. Zucker and W. W. Watson, Phys. Rev. **80**, 966 (1950) .