Note on a Possible Scheme for the Assignment and Prediction of Radioactive Periods

G. R. DICKSON AND E. J. KONOPINSKI
Indiana University, Bloomington, Indiana

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Families of odd nuclei differing from each other only by α-units show some evidences of a certain type of regularity in their stability against β-processes. The assumption that a similar regularity holds for all such families permits the unique assignment to the correct isotope of many known radioactive periods and the prediction of many yet unknown lifetimes.

BY assuming the existence of certain regularities among the half-lives of the radioactive nuclei as functions of their atomic numbers, the assignment of discovered half-lives to the proper isotopes may be helped and the periods of yet unknown isotopes may be estimated. The existence of such regularities might be expected because of the well-known regularities among the energies of nuclei, if a unique correspondence between life and energy release could be assumed. Such a uniqueness is, of course, actually destroyed by the possibility of "allowed" and "forbidden" transitions. However, one can hope that the nuclei chosen for comparison with each other (henceforth referred to as a "family") will behave so similarly toward such disturbing factors as to result in a dependence on atomic number smooth enough to be useful. The approach is almost entirely empirical; the known half-lives of a family are compared and whatever regularity is found is extrapolated to predictions about unknown and uncertain members.

The criterion we have adopted for the formation of a family is that the members differ only in the number of α-units (of two protons and two neutrons each) they contain. We have chosen this in preference to other possible criteria[1] because of the fact that the occurrence and even the abundance of the stable isotopes shows great similarity for alternating values of the atomic number, Z, throughout the periodic table and makes promising the extensibility of the scheme even to the heaviest nuclei. It also has as a result that the stable isotopes of each family follow each other consecutively as Z increases.[2] The finite lifetimes of the family should then be expected to fall off smoothly as Z increases or decreases from its stable values.

Our specific procedure was to plot the logarithms of the known half-lives against their atomic numbers. Results are shown in the figure for several families for which the data are most abundant. The families are distinguished by such symbols as ($3e$) and ($5o$), in which the number represents the neutron excess (isotopic number) while the letters "e" and "o" denote families with even and odd Z, respectively. The plots show some evidence of the expected behavior, especially among the positron emitters (nuclei with a *larger* than stable Z) of the families ($-1e$), ($-1o$), ($7e$) and among the negatron emitters of ($3e$). All these are families of odd nuclei. All the families of even nuclei without exception display extreme irregularity, even at the beginning of the periodic table as is demonstrated by the family ($0o$) in the diagram. We must, therefore, at the outset confine our method to the odd nuclei. The completely random behavior of the even nuclei serves only to make the few definite evidences of regularity among the odd isotopes appear less accidental.

The diagram shows not only the families of odd nuclei giving the best agreement with our expectations but also those containing the most numerous exceptions to the expected behavior. In the case of every such exception, some question concerning the experimental evidence can be raised, as is shown in the following paragraphs.

[1] Our scheme is consistent with Professor E. Wigner's treatment (Phys. Rev. **51**, 106 (1937)) of nuclei differing by four particles as having the same multiplet structure in a first approximation. This may help in maintaining a similarity of behavior with regard to "forbidden" transitions.

[2] This also is true to a large extent of nuclei differing only by one neutron and one proton, but exceptions are frequent (e.g. $I=1$, 3, etc.,). Moreover, whatever advantage the argument of footnote 1 gives would be lost under this criterion.

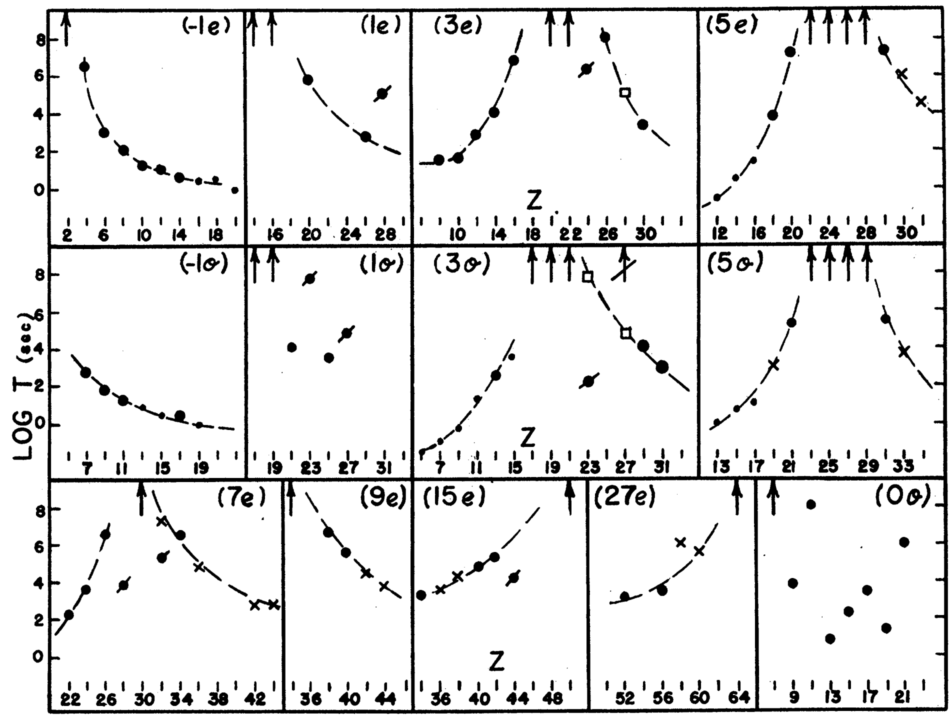

FIG. 1. Logarithms of half-lives, T, as functions of atomic number Z for several families, as denoted by symbols such as $(-1e)$ (i.e. $I=-1$, Z even. To get mass number, double Z and add I). Most of the data are from Livingood and Seaborg's summary (see footnote to Table I). The upward arrows (↑) denote stable isotopes. The full circles (●) represent the best established radioactive isotopes, of classes A and B according to Livingood and Seaborg. The crosses (×) denote isotopes not previously definitely assigned. The assignments best agreeing with our scheme were chosen for these cases (see Table I). The small dots (·) represent estimates from Barkas' masses (Phys. Rev. **55**, 691 (1940)) with the assumption that the transition is "allowed." A diagonal dash through a point signifies that the datum has been put in doubt from the standpoint of our scheme as discussed in the text. The squares are new assignments of some of the newly doubted isotopes. The dashed curves were used in making the predictions of Table II. Cr^{55}, of the family (*7e*), was originally predicted to have a 2- to 3-hour period on the basis of this scheme; the subsequent verification was done at our laboratory by McDaniel and Dickson (Phys. Rev. **57**, 351 (1940)) and also by others (Amaki, Iimori and Sugimoto, Phys. Rev. **57**, 752 (1940)).

The final decisions must, of course, be left to experimental test.

(*1e*).—The activity assigned to Ni^{57} fits better in the family (*3e*) as Ni^{59}. Only the failure to observe it in neutron capture by Ni^{58} seems to have prevented the latter assignment; a low capture cross section may be responsible instead.

(*1o*) *and* (*3o*).—Co^{57} is one of only three exceptions to the rule that stable members of a family follow each other consecutively when ordered according to Z.[3] This makes it desirable to verify further its mass-spectrographic observation,[4] especially since its isobar Fe^{57} is stable. Moreover, the supporting evidence offered by Sampson, Ridenour and Bleakney,[5] that the two negatron periods which arise in Co through neutron capture must be due to *two* stable isotopes, seems now to be nullified. Co^{58} produced in several other ways emits positrons with a totally different period. The existence of Co^{57} as a target of transmutations has, therefore, not yet been proved.

Only the supposition that Co^{57} is stable has prevented the assignment to it of the activity presently given to Co^{55}; the transfer would help the agreement in both the

[3] A second exception is the rare isotope, Rh^{101}, isobaric with Ru^{101}. Only the finding that Ma^{97} is stable would help this case. The third exception among the odd nuclei is due to the absence of Ce^{141} from the stable nuclei of family (*25e*). This rare earth isotope may yet turn up when the mass-spectrographic investigation of Ce is pushed to the accuracy usual in other parts of the periodic table. A similar exception exists in family (*13o*) due to the near-stable isotope Rb^{87}. Only the rather farfetched assumption that this long period is isomeric to a much faster decay from the ground state seems able to make it consistent with our scheme. There may be some support for this in the fact that Sr^{87}, which differs from Rb^{87} only in that a proton replaces a neutron, has isomeric states.

[4] M. B. Sampson and W. Bleakney, Phys. Rev. **50**, 732 (1936).

[5] Sampson, Ridenour, and Bleakney, Phys. Rev. **50**, 382 (1936).

TABLE I. *New or confirmed assignments of known periods.*[1]

Assignment	Period	Formerly
K^{43}	18 min.	$K^{43, 44}$
Ge^{69}	6–10 days	$Ge^{69, 71}$
Ge^{71}	195 days	$Ge^{67, 69, 71}$
Ge^{71*}	37 hr.	Ge^{71}
As^{71}	88 min.	$As^{71, 73}$
Se^{81}	19 min.	$Se^{79, 81}$
Kr^{79}	~1 day	$Kr^{79, 81}$
Rb^{81}	42 min.	$Rb^{79, 81, 83, (87)}$
Rb^{83}	200 hr.	$Rb^{79, 81, 83, (87)}$
Sr^{85*}	70 min.	Sr^{85}
Sr^{91}	6 hr.	Class *D*
Zr^{97}	6 min.	Class *F*
Mo^{91}	17 min.	$Mo^{91, 93}$
Ru^{97}	90 min.	Class *E*
Ag^{107*}	40 sec.	$Ag^{107, 109*}$
Sn^{123}	40 min.	Class *D*
Xe^{133}	9.4 hr.	Class *D*
Er^{169}	12 hr.	$Er^{169, 171}$
Er^{171}	7 min.	$Er^{169, 171}$
Os^{191}	40 hr.	$Os^{191, 193}$
Hg^{203}	25 hr.	$Hg^{203, 205}$

[1] See J. J. Livingood and G. T. Seaborg, Rev. Mod. Phys. 12, 30 (1940).

(3*o*) and (1*o*) families. The agreement would become complete if, further, the activity which has been tentatively assigned to V^{47} were to be attributed to the ground state decay of V^{49} instead. The possibility of this isomerism was recognized by its observers.[6]

(3e) and (7e).—On the basis of our scheme, the ground-state decay of Cr^{51} is expected to be too slow to be easily observed (a period of some decades). That the far shorter period actually observed may be from an isomeric state is supported by the appearance of a highly converted half-million-volt gamma-ray with it. A similar explanation seems also necessary for the too short Ni^{63} period in family (7*e*).

[6] Walke, Williams and Evans, Proc. Roy. Soc. **A171**, 360 (1939). *Note added in proof.*—In agreement with our conclusion is L. A. Turner, Phys. Rev. **58**, 679 (1940).

For most of the families not shown or specifically discussed, the data are not sufficient to make a decision about the validity of our scheme. In four of these families (19*e*, 25*o*, 25*e*, 37*e*) there occur pairs of well established nuclei which in no case conflict with our scheme.

In Table I are listed assignments of known, but previously unassigned, activities made to agree

TABLE II. *Approximate half-lives predicted for yet unknown isotopes.*

Isotope	Period	Isotope	Period	Isotope	Period
B^{13}	0.01 sec.	Ca^{39}	1 sec.	Kr^{77}	1 hr.
C^{15}	20 sec.	Ca^{47}	10 sec.	Kr^{81}	10 yr.
N^{17}	0.1 sec.	Ti^{45}	5 hr.	43^{97}	∞
F^{21}	0.5 sec.	Cr^{49}	1 hr.	Ru^{103}	1 min.
Na^{25}	20 sec.	Cr^{51}	20–200 yr.	Ru^{107}	10 sec.
Mg^{29}	0.5 sec.	Mn^{53}	1 min.	Pd^{101}	1 hr.
Al^{25}	10 sec.	Co^{57}	20 hr.	Pd^{113}	1–60 min.
Al^{31}	1 sec.	Ni^{57}	2 min.	Cd^{121}	3 min.
Si^{33}	5 sec.	Ni^{59}	30 hr.	In^{123}	30 min.
P^{29}	5 sec.	Ni^{63}	20 yr.	Sn^{127}	10–50 min.
P^{33}	10 hr.	Cu^{59}	20 min.	Te^{135}	<20 sec.
P^{35}	5 sec.	Zn^{61}	1 min.	Cs^{135}	3 yr.
S^{31}	2 sec.	Ge^{67}	2 min.	Ba^{143}	<2 min.
S^{37}	10 sec.	Ge^{79}	20 min.	Ce^{141}	∞
Cl^{39}	1 min.	As^{69}	2 min.	Sm^{151}	>1 yr.
A^{35}	1 sec.	Se^{85}	1 min.	Gd^{161}	40 min.
K^{37}	1 sec.	Br^{75}	5 min.	Os^{195}	2 min.
K^{45}	<20 min.				

with our assumptions. Table II contains estimates of yet unknown half-lives as obtained from extrapolations and interpolations along curves such as those shown in Fig. 1. Both tables contain values having varying degrees of certainty, depending on the amount of data available concerning the corresponding families. More assignments and predictions will be possible as more information becomes available.