PHYSICAL REVIEW VOLUME 75, NUMBER 7 APRIL 1, 1949

# Relation Between Half-Life and Energy in Alpha-Decay

I. PERLMAN, A. GHIORSO, AND G. T. SEABORG
*Department of Chemistry and Radiation Laboratory, University of California, Berkeley, California*
(Received February 21, 1949)

THE great number of new alpha-particle emitters has recently made possible the observation of new and interesting systematics in the alpha-decay process. For example, a plot of alpha-energy *versus* mass number for about 90 alpha-emitters has led to interesting conclusions as to the nature of the energy surface in the region of the heavy elements.[1] The present note contains some correlations between alpha-energy and half-life which have resulted in some new conclusions regarding the effect of nuclear type on this relationship.

Figure 1 shows a plot of the logarithm of the half-life *versus* the alpha-energy for the nuclear species of the even-even type. Berthelot[2] had previously treated a more limited amount of alpha-decay data in this manner and reached some of the same deductions that will be noted here. It is not possible to give references for the many recently prepared isotopes which are shown here but, with a few exceptions, the information which is used here may be found in a review article covering all of the isotopes.[3] All of the even-even alpha-emitters for which both the alpha-half-life and the energy are known are included in Fig. 1 while those species which exhibit branching decay with an unknown proportion of orbital electron capture are excluded.

It will be seen that all of the even-even species as reported in Fig. 1 fall on seven nearly parallel lines corresponding to the seven elements polonium, emanation, radium, thorium, uranium, plutonium, and curium. (The three exceptions, $Po^{206}$, $Po^{208}$, and $Po^{210}$, will be discussed below.) The positions of these lines are such as to indicate an average decrease of about a factor of ten in the probability for alpha-emission with an increase of two in atomic number. This displacement is in agreement with the effect attributed to $Z$ in the Gamow formula.[4]

Other nuclear types, even-odd, odd-even, and odd-odd have not been entered in Fig. 1 because the large number of points would obscure the regularities of the even-even isotopes. However, keeping as reference the positions of the lines for the even-even isotopes it is possible to observe some definite departures for the other nuclear types.

Even-odd nuclei (even protons, odd neutrons) of an element lie above the curves for the even-even isotopes of that element signifying abnormally long half-life. As an example $Pu^{239}$ with its 5.15-Mev alpha-particle would cut the line joining $Pu^{238}$ and $Pu^{240}$ at a half-life of 3000 years whereas its actual half-life is 24,000 years. On the average the even-odd nuclei have longer half-lives by a factor of about five over what might be predicted on the basis of the even-even nuclei. The greatest deviation noted was a factor of 10, the least was a factor of 2.

If one draws lines midway between each pair of lines in Fig. 1 to signify hypothetical half-life-energy curves for the odd $Z$ elements, it is found that the odd-even isotopes have longer half-lives than would be predicted. The half-life deviation from prediction for the 15 odd-even isotopes is about fivefold on the average.

In examining the odd-odd species of which six are known, it is found that the deviations are much greater than for the even-odd or odd-even types. On the average these isotopes have longer half-lives by a factor of some 10 to 20 than indicated by predictions from the hypothetical curves.

In all of these correlations, in the cases of isotopes with more than one alpha-group, partial alpha-half-lives have been calculated and the deviations noted are for the least forbidden group. As an example the short-range alpha-group of $Pa^{231}$ has a half-life three times too long while the long range group is thirty times too long.

The above correlations do not include $At^{211}$, polonium isotopes below 212, and all naturally occurring bismuth alpha-emitters. In all of these cases half-lives are abnormally long and this includes the even-even nuclei. Since these are just the nuclei whose alpha-energies are explained by a depression in the energy surface[1] it is suggested that the decreased probability of alpha-emission is due to the attendant shrunken nuclear radius. If we attempt to dissociate the effect of decrease in radius from the effects due to odd protons and neutrons for bismuth isotopes by making corrections based on regularities observed in the other elements, it is found that a discontinuity in radius of about 10 percent is required for these bismuth isotopes.

It is remarkable that all nuclei with odd protons or odd neutrons have abnormally long half-lives

[1] I. Perlman, A. Ghiorso, and G. T. Seaborg, Phys. Rev. **74**, 1740 (1948).
[2] A. Berthelot, J. de Physique (Ser. VIII) **3**, 52 (1942).
[3] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).
[4] G. A. Gamow, *Structure of Atomic Nuclei and Nuclear Transformations* (Clarendon Press, Oxford, 1937).

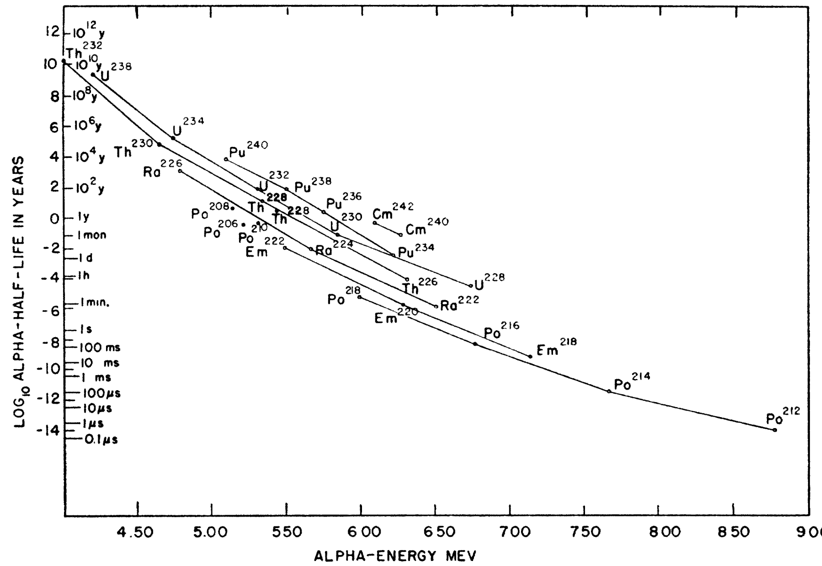


FIG. 1. Plot of log of alpha-half-life *versus* alpha-energy for even-even nuclei.

with the apparent exceptions $At^{217}$, $Po^{215}$, and $Po^{213}$. It is perhaps noteworthy that all of these have high decay energies, 7 Mev or greater. In addition the "normal" for comparison is the line connecting $Po^{216}$, $Po^{214}$, and $Po^{212}$, and it cannot be known for sure that these nuclei are not already beginning to show the effect which becomes so pronounced for $Po^{210}$ and thus are themselves abnormally long-lived.

The generally lengthened half-life for any isotope with odd neutron, odd proton, or both is probably not explicitly explained by existing alpha-decay theory. The occurrence of abnormally long half-lives has been generally attributed to an actual abnormal decrease in nuclear radius (as is no doubt the important factor for $At^{211}$, the light polonium isotopes, and the bismuth isotopes as mentioned above) and to changes in spin between parent and product nuclei in which the alpha-particle is emitted with angular momentum. Although spin changes of this kind may contribute in some cases it is probably impossible to explain all of the forbidden transitions in this way. In the first place this would demand regular alternation of large and small spin numbers down a decay series. Furthermore in a case like $U^{235}$ alpha-decay, the ground state transition would require a spin change of the order of some 10 units according to Gamow's relationship[3] while the measured values[5,6] for $U^{235}$ and $Pa^{231}$ are 5/2 (or 7/2) and 3/2, respectively, corresponding to a change of only 1 unit (or 2 units). To explain the apparent forbidden nature of all alpha-decay processes in which there is an odd neutron, odd proton, or both it may be necessary to turn to the coefficient of the exponential term and connect the prohibition with a greater difficulty in assembling the components of the alpha-particle in these cases. In this sense one may consider that the existence of one or more unpaired nucleons presumably in the highest quantum states will hinder the formation and emission with full energy of an alpha particle since it must be made up of two neutrons and two protons each pair having antiparallel spins.

All of the data on alpha-emitters will be presented in a forthcoming paper in which will be included further discussion of the regularities.

This work was performed under the auspices of the AEC.

[5] O. E. Anderson and H. E. White, Phys. Rev. **71**, 911 (1947).

[6] H. Schüler and H. Gollnow, Naturwiss. **22**, 511 (1934).