S 77. *α-Decay Systematics.*

By Geoffrey Wilkinson.

Recent work in the laboratories at Berkeley is reviewed, and consideration of a large number of isotopes emitting α-particles has enabled many of the phenomena to be correlated. In particular, the relations between α-particle energy and mass number, and between half-life and energy in α-decay, are investigated.

The knowledge of α-particle-emitting isotopes, long confined to the natural decay series of ^{235}U, ^{239}U, and ^{230}Th, has, in recent years, been greatly expanded by the production of many new isotopes by bombardment of the heavy elements with neutrons and high-energy charged particles. The investigations on the artificial neptunium ($4n + 1$) radioactive series, and some of its collateral members, *i.e.*, branch members outside the main line of decay, carried out in the American and Canadian atomic energy projects during the war, have been reviewed by Seaborg (*Chem. Eng. News*, 1948, **26**, 1902). The work on new isotopes produced by cyclotron bombardments of heavy elements with high-energy particles and deuterons at the University of California, has been outlined recently [Templeton and Perlman, *Physical Rev.*, 1948, **73**, 1211 (active Bi isotopes); Templeton, Perlman, and Howland, *ibid.*, 1947, **72**, 758 (artificial radioactive Po isotopes); Ghiorso, Meinke, and Seaborg, *ibid.*, 1948, **74**, 695; 1949, **75**, (artificial collateral chains to the natural radioactive series)]. In all some 100 α-particle-emitting isotopes, the production and properties of which have been recently summarised (Seaborg and Perlman, *Rev. Mod. Physics*, 1948, **20**, 585), are now known, and the new data have permitted a more extensive view of the systematics of α-particle emission than was previously possible, in particular of the correlations between α-particle energy and mass number of the isotope, and the relation between half-life and energy in α-decay.

(*A*) *α-Energy and Mass Number.*—The plot of α-particle energies against the mass number is perhaps the simplest and most direct, if not the most definitive way of correlating α-particle energies. Recent data, not available to previous workers (cf. Schintlemeister, *Wien. Chem.-Ztg.*, 1943, **46**, 106; Berthelot, *J. Phys. Radium*, 1942, **3**, 17; Karlik, *Acta Phys. Austrica*, 1948, **2**, 182) have been treated in this manner by Perlman, Ghiorso, and Seaborg (*Physical Rev.*, 1948, **74**, 1730) and have enabled interesting conclusions to be drawn regarding the nature of the energy surface in the region of the heavy elements, as well as the prediction of properties of unobserved α-particle emitters.

The plot of α-particle energies against mass number can be conveniently divided into two regions.

(i) For the elements from emanation ($Z = 86$) to curium ($Z = 96$) the isotopes of each element can be joined by almost parallel lines, with an increase in α-particle energy for decreasing mass number. No cases have yet been observed where an isotope has a lower decay energy than might be expected, and in the cases of thorium and uranium, the regularity extends through mass-number ranges of 9 and 11, respectively; in uranium, the regularity persists from the heaviest β-stable isotope, ^{238}U, well into the region of instability with respect to orbital-electron capture. The linear trend of increasing α-particle energy with decreasing mass number is explained by Perlman, Ghiorso, and Seaborg from a consideration of an energy-surface diagram. A series of " Bohr–Wheeler parabolas " for mass numbers A, A-2, A-4, etc., are considered, it being borne in mind that in the region from lead to uranium approximately two neutrons are added for each proton in attaining comparable configuration with respect to β-stability. Pairs of elements differing by $Z = 2$ can be compared if it is assumed that a fairly constant packing fraction exists between pairs of nuclear species on the two contours separated by 5—6 mass units. Since α-decay proceeds between points on the two contours differing by 4 mass units, *i.e.*, from (A, Z) to (A-4, Z-2), the energy differences between such pairs of points increase with decreasing mass number.

(ii) For the lower elements, *i.e.*, from bismuth ($Z = 83$) to emanation ($Z = 86$), a different phenomenon appears. The heaviest isotopes follow the same trend as previously at first, but as the mass number decreases, the α-particle energy goes through a maximum, decreases with increasing mass number to a minimum, and then resumes the initial trend of increasing α-particle energy with decreasing mass number.

In order to explain this behaviour, a sharp irregularity in the energy surface, such that a number of isotopes must comprise a localised region of abnormally high stability, must be assumed. Perlman, Ghiorso, and Seaborg point out that ^{209}Bi, ^{210}Po, and ^{211}At, which are situated at or near the minima of their respective curves in the α-energy–mass number plot, contain 126 neutrons, possibly a very stable configuration (Mayer, *Physical Rev.*, 1948, **74**, 235). With such an assumption of abnormal nuclear binding, the trends in α-particle energies can be obtained again from considerations of a series of " Bohr–Wheeler parabolas " as before.

Apart from the information which the plot gives regarding the nature of the energy surface in the region of the heavy elements, it is useful in predicting the properties of unobserved α-particle emitters, and for assisting in the resolution of discrepancies in disintegration schemes of various isotopes.

(*B*) *α-Energy and Half-life.*—Perlman, Ghiorso, and Seaborg have recently extended the work of Berthelot (*J. Phys. Radium*, 1942, **3**, 52) on the correlation between the half-life and α-energy for about 90 α-emitting isotopes. The logarithm of the half-life is plotted against the α-energy, and the results are interpreted with regard to the number of protons (Z) and neutrons (A–Z) in the nucleus.

(*a*) *Even–even nuclei.* Excluding isotopes where the branching ratio for α-particle emission is unknown, all even–even nuclei fall on seven nearly parallel lines corresponding to the elements, Po, Em, Ra, Th, U, Pu, Cm, with an average decrease of about 10 in the probability of α-particle emission for an increase of 2 in Z. This is in agreement with the effect attributable to charge in the Gamow theory of α-particle emission.

(*b*) *Even–odd nuclei.* These lie above the curve for even–even nuclei of the same elements, thus showing abnormally long half-lives, *e.g.*, ^{239}Pu which has a 5·15-Mev. α-particle would cut the line joining ^{238}Pu and ^{240}Pu at a point corresponding to a half-life of 3000 years, whereas the actual half-life is 24,000 years. Even–odd nuclei have, on the average, half-lives longer by a factor of 2 than those that might be predicted on the basis of even–even nuclei.

(*c*) *Odd–even nuclei.* If hypothetical lines are drawn midway between the curves of even–even nuclei, to signify curves for odd Z, then almost all the odd–even isotopes have half-lives greater than those predicted by an average factor of about 5.

(*d*) *Odd–odd nuclei.* Although only six such nuclei are known, the deviations are greater than in other cases, and the half-lives are 10—20 times longer than might be expected.

The exceptions to the general behaviour are found mainly with nuclei whose α-particle energies can be explained by an abnormality in the energy surface, *e.g.*, ^{211}At, polonium isotopes of mass below 212, and the bismuth α-emitters. This suggests that the decreased probability of α-emission, *i.e.*, long half-lives, observed in these cases results from an abnormally small nuclear radius. An attempt to dissociate the effect of a decrease in nuclear radius from the effects due to odd numbers of neutrons and the odd charge for bismuth isotopes, by making corrections based on regularities observed in other elements, leads to the result that discontinuity in radius of the order of 10% is required in this case.

The lengthened half-life for isotopes with odd numbers of protons or neutrons, or both, has previously generally been attributed to abnormal decrease in radii, as is no doubt the factor in the above cases, or to changes in spin between the parent and product nuclei in which the α-particle is emitted with angular momentum. All cases of forbidden transitions, as indicated by abnormally long half-lives, cannot however by explained by these factors. The spin hypothesis in particular would require the alternation of large and small spin numbers down a decay series, and in the case of ^{235}U, the Gamow theory requires a much larger spin change than is known to occur. In view of these difficulties, Perlman, Ghiorso, and Seaborg have suggested that the apparent forbidden nature of all α-decay where nuclei contain an odd number of nucleons may be connected with a greater difficulty in assembling the constituents of the α-particle within the nucleus. The existence of one or more unpaired nucleons may thus hinder the formation and emission with full energy of an α-particle, since the latter must be made up of two neutrons and two protons, each pair having anti-parallel spins.

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