Abrupt changes in alpha decay systematics as a manifestation of collective nuclear modes *

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It is nearly a century ago that the Geiger-Nuttall law, which was to revolutionize physics by its implications, was formulated based on α decay systematics [1]. Indeed, its explanation by Gamow [2] and also by Gurney and Condon [3] required to accept the probabilistic interpretation of Quantum Mechanics. The Gamow theory reproduced the Geiger-Nuttall law nicely. One can assert that this is an effective theory, where concepts like "frequency of escape attempts" have to be introduced. Yet Gamow's theory is so successful that even today it is applied, with minor changes, in the studies of radioactive decays. One may then wonder why effective approaches have been so successful. The reason is that the α-particle formation probability usually varies from nucleus to nucleus much less than the penetrability. In the logarithm scale of the Geiger-Nuttall law the differences in the formation probabilities are usually small fluctuations along the straight lines predicted by that law for different isotopic chains. The importance of a proper treatment of α decay was attested by a recent calculation which shows that the different lines can be merged in a single line. One thus obtained a generalization of the Geiger-Nuttall law which holds for all isotopic chains and all cluster radioactivities [4,5]. In this universal decay law (UDL) the penetrability is still a dominant quantity. By using three free parameters only, one finds that all known ground-state to ground-state radioactive decays are explained rather well. This good agreement is a consequence of the smooth transition in the nuclear structure that is often found when going from a nucleus to its neighboring nuclei. This is also the reason why, e.g., the BCS approximation works so well in many nuclear regions.

In this work we will show that, when a sudden transition occurs in a given chain of nuclei, departures from the UDL can be seen [6]. Perhaps even more important is that for most cases the UDL predicts the experimental values within a factor of three, except for $N = 126$, where the difference becomes about one order of magnitude. This is so distinct that one may even suspect that the difference in the values of formation amplitudes when going from one nucleus to its neighbors in the vicinity of $N = 126$ overruns the corresponding differences in the penetrability. The difference is explained as a sudden hindrance of the clustering of the nucleons that eventually form the α particle. This is because the clustering induced by the pairing mode acting upon the four nucleons is inhibited if the configuration space does not allow a proper manifestation of the pairing collectivity.

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