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GEIGER-NUTTALL RELATION FROM FISSION-CHARACTER OF α-DECAY

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Abstract : Basic limitations of the one-body theory of α-decay are first pointed and then the essential features of the recent theory due to the present author are described. The Geiger-Nuttall relation is then derived from the fission-character of α-decay as revealed by the recent theory. The relation turns out to be $\log T_{\frac{1}{2}}(\text{expt.}) = C - DE_K(\alpha)$.

Key-words : α-decay, recent theory of α-decay, fission-character of α-decay, Geiger-Nuttall relation

Introduction

As is well known, the Geiger-Nuttall (GN) empirical relation is the first significant study in the field of α-decay. This relation is said to have found, long after two decades of its finding, its theoretical justification in the one-body theory of α-decay due to Gamow-Condon-Gurney. But this theory met with serious objections soon in the wake of neutron-discovery and consequent knowledge of the neutron-proton (n-p) composition of the nucleus which ruled out, as a logical consequence, the theory's basic postulate of pre-existence of α-particles as permanent substructures inside the emitter prior to emission. Neutron-discovery prompted Bethe[1] and Frenkel[2] to remark that an α-particle, instead of pre-existing as a permanent entity inside the emitter, is formed out of (2n-2p) nucleons in the process of emission. In other words, α-formation and α-emission are, according to them, one and the same process. Frenkel further adds that α-decay is a distinct type of asymmetric spontaneous fission. Again, according to Kaplan[3], a fundamental revision of the one-body theory, perhaps affecting one's idea about the coulomb-barrier penetrability, can take into account the probability of α-formation out of (2n-2p) nucleons. These serious objections and criticisms not-withstanding , the one-body theory of α-decay with its different variants still continues to be the guiding theory in the field of α-decay studies.

Knowledge of (n-p) composition of a nucleus requires, of logical necessity, a theory of α-decay to be based on this knowledge and to evolve, as suggested by Bethe and Frenkel and as realised in the recent theory due to Basu[4,5], out of consideration of α-formation from (2n-2p) nucleons of the emitter. The one-body theory is, at best, a description of the post-α-formation aspect of the α-decay phenomenon to the complete exclusion of its nuclear aspect. In the post-neutron-discovery era, however, attempts have persistently been made to introduce the nuclear aspect as an after-thought through consideration of α-formation within the frame-work of the very post-α-formation picture. As α-formation and α-emission are one and the same process and not two separate processes, it is obviously fallacious to consider the question of α-formation out of (2n-2p) nucleons in the post-α-formation picture. One thus comes across a serious logical inconsistency in the body theoretic of the existing model. It is also here that one feels badly the necessity, as expressed by Kaplan[3], for a fundamentally revised theory of α-decay. If, however, one undertakes an *ab initio* investigation into the process of α-formation out of (2n-2p) nucleons, the emergent picture of α-decay, as shown by Basu[4,5], is fundamentally different from and, in fact, diametrically opposite to the one-body model of α-decay and reveals the following essential features of the decay mechanism. (1) Instead of pre-existing as a permanent entity inside the emitter, an α-particle is formed, as remarked by Bethe[1] and Frenkel[2], out of the last (2n-2p) nucleons of the emitter in the process of emission[6]. (2) α-Emission takes place over the so-called coulomb-barrier[6] rather than tunnel through it. Kaplan's hint at a possible change of one's idea about coulomb-barrier penetrability may be recalled here. (3) The repulsive coulomb energy emerging between the α-cluster and virtual daughter in the process of their transformation into real entities is rather the cause of the α-decay process than a barrier to it.[7] As the cause of a certain process can never act as a barrier to the same process, this finding rules out the role of the coulomb repulsive energy as a barrier and the concept of tunnelling in the α-decay process and thus lends final confirmation to the feature (2) mentioned above. As suggested by the above-mentioned features and as shown by Basu[8], α-decay is, true to the prediction of Frenkel[2], a case of spontaneous fission. It can also be easily shown[9] that the Gamow theory of α-decay is actually an antithesis of fission and hence incapable of reproducing the recently discovered fission-character of α-decay. In short, this new theory of α-decay fully vindicates the suggestions of Bethe[1] and Frenkel[2], and fulfills the need, as advocated by Kaplan[3], for a fundamentally revised theory of α-decay.

The original G-N relation expresses a connection between the life-time of an α-emitter and the range in air of the α-particle emitted by it. Its derivative relation connecting the life-time ($T_{\frac{1}{2}}$) of an emitter with the kinetic energy $E_K(\alpha)$ of the α-particle emitted by it is far more significant. To explore this connection, Gamow[10] and others[11] plotted $\log T_{\frac{1}{2}}$(expt) vs. $E_K(\alpha)$ which yielded a set of curves, each representing a series ($Z = \text{constant}$) of even-even (e-e) isotopes of an α-emitter in their g.s. to g.s. decay. The GN relation corresponding to these curves is yet to be derived from a theory of α-decay. There are, then, other workers [3,12] who plotted $\log T_{\frac{1}{2}}$(expt.) vs. $E_K^{-\frac{1}{2}}(\alpha)$ which, true to the Gamow theory of α-decay, yielded a set of straight lines, each representing an (e-e) isotopic series in their g.s. to g.s. decay. This is where the GN relation is said to have found its theoretical justification. But this agreement between theory and experiment, according to Kaplan[3], simply testifies to the validity of barrier-tunnelling concept in the one-body model but does not imply anything concerning the validity of the model itself. This naturally gives rise to questions about the one-body theoretical justification of the GN relation. The present work is, therefore, an attempt to derive the GN relation from the fission character of α-decay as revealed by the new theory.

Theory, Results And Discussions

As shown by Basu[7,8] on the basis of Bohr-Wheeler theory of fission and then on the independent basis of his own theory of α-decay, α-decay is a distinct case of spontaneous fission. The fission-character of α-decay is best expressed by the following relation[9] for a series of (e-e) isotopes in their g.s. to g.s. decay.

$$\log T_{\frac{1}{2}}(\text{expt.}) = A-B\left[E_{\text{coul}}(\text{max})/|E_{\text{core}}|\right] \quad \ldots(1)$$

where A & B are characteristic constants of the series and other symbols have their usual significances and methods of evaluation as in references 6 & 7.

Equation (1) can be rewritten in the following convenient form.

$$\log T_{\frac{1}{2}}(\text{expt.}) = (A-B)-B\left[E_K(\alpha)/|E_{\text{core}}|\right] \quad \ldots(2)$$

where use has been made of the following relation in a previous work[7] with E_{core} in its usual negative sense.

$$E_K(\alpha) = E_{\text{coul}}(\text{max}) + E_{\text{core}} = E_{\text{coul}}(\text{max.}) - |E_{\text{core}}| \quad \ldots(3)$$

Relation (2) may as well be treated as the GN relation between the expt. $T_{\frac{1}{2}}$ and expt. kinetic energy $E_K(\alpha)$ but for the presence of E_{core}, the attractive core-interaction, which is not amenable to experimental determination, It may, however, be absorbed in B of eqn.(2) where it will be free to operate in the back-ground. Eqn.(2) in that case reduces to the following form yielding the desired GN relation between $T_{\frac{1}{2}}$ and $E_K(\alpha)$.

$$\log T_{\frac{1}{2}}(\text{expt.}) = C-DE_K(\alpha) \quad \ldots(4)$$

where C = (A-B) = a characteristic constant of the series and $D = B/|E_{\text{core}}|$.

As D is a function of $|E_{\text{core}}|$ it varies, increasing monotonically with monotonic decrease of $|E_{\text{core}}|$ from one member to another down an (e-e) series while corresponding $E_K(\alpha)$'s increase monotinically (barring shell-closure) down the same series. This variation of D, co-efficient of $E_K(\alpha)$ in eqn. (4), will make a plot of log $T_{\frac{1}{2}}$ vs. $E_K(\alpha)$ for a series deviate from linearity to a curve. In other words, according to eqn.(4), a plot of log$T_{\frac{1}{2}}$ vs. $E_K(\alpha)$ should yield a set of curves, each curve being representative of a series of (e-e) isotopes of an emitter in their g.s. to g.s. decay. This suggestion is, in fact, remarkably borne out by numerous experimental plots in literature by different workers[10,11,13]. Relation (4) may, therefore, be rightly looked upon as the required GN relation between the α-decay life-time of an emitter and the kinetic energy of an α-particle emitted by it. The one-body theory, on the contrary, is incaple of yielding a relation of the type of eqn.(4) but yields, instead, a GN relation of doubtful theoretical origin. This is not surprising as the theoretical foundation of the one-body model is, as dsicussed in the introduction, far from being valid. As is obvious from the above study, the empirical GN relation follows smoothly as a corollary to the fission character of α-decay as discovered by the present theory whereas the Gamow theory of α-decay is basically an anti-thesis of fission mechanism of α-decay.

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