From fourth kind of Natural Radioactivity to the Extension of Periodic Table to Super Heavy Nuclei: Indian Contribution to Cold Nuclear Phenomena

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Introduction

These days most of the scientists around the globe consider that the basic phenomena related to the low energy heavy-ion nuclear physics are already discovered and their better description should now be further provided by the theoretical researchers. Almost forty years ago this type of status quo was prevailing when Prof. Raj K. Gupta and collaborators, during 1974-76, laid the foundation, in a series of works based on the Quantum Mechanical Fragmentation Theory (QMFT) where the "cold reaction valleys" were first calculated [1, 2], for the prediction of cluster radioactivity (CR) on theoretical grounds by Sặndulescu, Poenaru and Griener in 1980 [3]. This phenomenon was later established by Rose and Jones [4] experimentally.

The discovery of CR or fourth (other than α, β and γ) /new kind of radioactivity, after almost 50 years of the pioneering experiments of Becquerel and Rutherford, followed by extensive theoretical and experimental research, is an another exceptional evidence of atomic nucleus as a continuous source of novel as well as unexpected phenomenon. CR is the spontaneous emission of clusters heavier than α-particle, also, sometimes referred to as "magic radioactivity" because cluster decays in trans-Lead region have always a doubly magic nucleus ^{208}Pb (Z=82, N=126) or a nucleus close to it. One may also relate this phenomenon to α-decay, in which much lighter doubly magic nucleus ^{4}He (Z=2, N=2) is emitted, and term it as Pb-radioactivity. As noted above, its theoretical prediction was actually based on the fragmentation potentials or cold valleys (calculated by using the QMFT by Gupta and collaborators) of those binary decays containing a partner ^{208}Pb or close to it (see Fig. 1 of Ref. [5]). The fact that daughter nuclei are always the spherical closed shell ^{208}Pb or neighbouring nuclei is the fundamental result of the QMFT that led authors of Ref. [3] to predict it. It is now well established, and the cluster-decay half-lives (and its branching ratios with respect to α decay) for spontaneous emissions of some 13 to 14 heavy clusters, ranging from ^{14}C up to ^{34}Si, are measured for the ground-state decays of certain parent nuclei in trans-Lead region, specifically from ^{221}Fr to ^{242}Cm [6, 7], including, recent observation of ^{14}C and ^{15}N decays of ^{223}Ac and ^{34}Si decay of ^{238}U [8].

For understanding the CR phenomenon, the unified fission models (UFM) such as the analytic super-asymmetric fission model (ASAFM) [3], and the preformed cluster models (PCM) like that of Gupta and collaborators [9] have been advanced. They differ from each other for their non-inclusion or inclusion of the preformation probability/ spectroscopic factor P_0 of the cluster being pre-formed before penetrating the confining nuclear interaction barrier with certain penetration probability P. In PCM, for the first time, Gupta and collaborators [9] assumed the clusters to be pre-born in the parent nucleus with certain P_0's, calculated by solving the stationary Schrödinger equation for the dynamical flow of mass and charge, the only available method to-date to calculate P_0. It may be noted here that the mass and charge densities calculated by using the RMF theory are also known to support the clustering effects in various heavy parents with observed cluster decays [10].

The study of "cold reaction valleys" by Prof. Raj K. Gupta and collaborators almost forty years ago also led to an idea of cold fusion (reaction partners) and succeeded in extending our known periodic table of elements up to Z=118. For the last three decades, exciting area of research in nuclear physics is the extension of the periodic table of elements in the super heavy mass region due to the advanced experimental facilities with high precision, further supported by the theory given almost four decades backing, explaining the underlying physics much better [2]. It was predicted that for production of nuclei with Z $\geq$ 102 there is a necessity to bombard suitable projectile on doubly magic nuclei and it was further shown that the most favourable combinations are related to the valley of heavy cluster emission, i.e., the so-called Pb potential valley [2]. Evidently, due to the double magicity of ^{48}Ca, it became possible to set up and perform a new generation of experiments in order to hunt for new super heavy elements (SHE), and to further explore the prospects to reach the boundary of the proposed "island of stability". It is now recognized world-wide that these predictions made possible the production of all SHE Z $\leq$ 118 in Darmstadt and Dubna [11], based on the idea of cold reaction valleys.

Moreover, Gupta and collaborators developed the so-called dynamical cluster decay model (DCM) [12] to study the decay of excited compound nuclei as a collective clusterization process for emissions of the light particles LPs, as well as the intermediate mass fragments IMFs and heavy mass fusion-fission fragments FFs, in contrast to the statistical models in which each type of emission is treated on different footing. Number of compound nuclei from very light ^{28}Al* to super heavy ^{297}117* nuclei have been studied successfully [12], using the DCM.

Further details of the comprehensive study will be presented at the symposium.

The idea of "cold reaction valleys" led to the prediction and verification of very rare (fourth) kind of natural radioactivity along with the extension of periodic table (with the production of SHE). It also led to the development of dynamical theories (PCM and DCM) to successfully explain the ground-state as well as excited-state decays of nuclei. For sure, these are among the most substantial accomplishments of Indian Physics, and we owe them to Prof. Raj K. Gupta who celebrates his **75th** Birthday this year, dynamic as ever.

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