Nuclear Structure and Two-proton, One-proton Decay Studies of Light, Medium, Heavy and Superheavy Nuclei

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Nuclei in nature are either stable or unstable. A sudden and discontinuous behavior at particular number of protons and neutrons is noted and those numbers are called magic numbers and the nuclei with magic number of protons or neutrons or both, seem to be stable against radioactive decay. For the unstable nucleus, nuclear force is no longer able to hold the nucleons inside the nucleus and it decays by the emission of particles or radiation. These unstable nucleus usually undergoes basic decays such as alpha, beta and gamma decays. In addition to that, with the advancement in experimental techniques and the identification of new isotopes beyond the limit of stability paved a way for the observation of exotic decays such as two-proton emission and one-proton emission, cluster decay and neutron emission.

This thesis deals with two works. One is related to nuclear structure and another one is related to nuclear decay. The objectives of this thesis are to study the evolution of new magic numbers and to study exotic decay modes such as two-proton emission and one-proton emission of nuclei in light, medium, heavy and superheavy mass region of the nuclear chart. Yukawa-plus-exponential macroscopic mass formula, derived by Krappe, is used to calculate the binding energy of the magic and its adjacent nuclei. Exotic decay such as two-proton emission and one-proton emission are analysed within Yukawa-plus-exponential model (YEM) which has been developed by Krappe and used by Shanmugam and Kamalakaran, for both spherical and deformed configurations.

The magic numbers have played a significant role in development and understanding of the structure of nucleus. Yukawa-plus-exponential macroscopic mass formula (temperature independent) is used to calculate the binding energy of the nucleus. Here a_V and a_S are used as a fitting parameter to obtain best matching binding energies with the experimental binding energies. Binding energies of the core and core ± nucleon are used to evaluate the single particle energies (SPEs). The SPE level calculation of the nucleus ^{40}Ca shows the occurrence of shell gap at $N, Z = 14$ and 16. This motivated to extend the SPE level calculation for the superheavy mass region. Gap at $Z = 92$ and 114 shows the occurrence of new magic numbers, whereas the gap at $N = 164$ and 184 are predicted as a magic number in superheavy mass region. There exists a good match between the spin-orbit splitting (SOS) of protons and neutrons of the present calculation and other reported values for a few levels. The difference is found to be higher for the case of light nuclei and it is found to reduce as the mass number increases. Reduced SOS of both protons and neutrons is found to depend on $A^{2/3}$ [1].

Two-proton ($2p$) emission for the spherical nuclei are analysed using Coulomb-plus-Yukawa-plus-exponential potential for the non-overlapping region and the spectroscopic factor is calculated which accounts for preformation probability [2]. By varying a factor in the expression for spectroscopic factor, a good match is arrived for the half-lives of the experimentally observed $2p$ emitters with the experimental values. A relation has been ar-

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rived for the spectroscopic factor with respect to macroscopic quantities such as Z and A of parent nucleus. Half-lives of their competing decay mode ($1p$ emission) are also calculated, for the determination of preferred decay mode. From the experimentally identified $2p$ emitters, three candidates such as ^{8}Be, ^{19}Mg and ^{45}Fe are proven to be true $2p$ emitters, because their Q_{1p}-values are found to be negative. $2p$ emission serves as a dominant decay mode compared to $1p$ emission for the remaining three cases such as ^{12}O, ^{16}Ne and ^{54}Zn. From the analysis, it is found that there exists a linear dependence between the reduced decay width and physical parameters such as fragmentation potential and pairing gap. It is found similar to alpha decay and $2p$ decay can be considered as two-body decay. The calculation is extended to predict the $2p$ emitters from $8 \leq Z \leq 54$ and $11 \leq A \leq 108$. Nearly 44 candidates, which are having positive Q_{2p} values are chosen and its decay characteristics are calculated. Branching ratio between 2p and 1p emission has confirmed that 12 nuclei are proven to be true $2p$ emitters and remaining 32 cases are having competition between $2p$ and $1p$ decay.

Half-lives of deformed $2p$ emitters [3] are calculated using CYEM, with the inclusion of deformation and it is the extension of the earlier work. The same fitted relation for spectroscopic factor is used here for the calculation of preformation probability. Out of eight experimental $2p$ emitters, three cases such as ^{45}Fe, ^{54}Zn and ^{67}Kr are having prolate deformed daughter nucleus. Computed half-lives show good match with the experimental values compared to the spherical one. Since, it is established that there exists a competition between the $2p$ and $1p$ emission, branching ratio between $2p$ and $1p$ emission is calculated. ^{45}Fe is proven to be true $2p$ emitter because of its negative Q_{1p} value. ^{48}Ni and ^{67}Kr are having competition between $2p$ and $1p$ emission. From the analysis, it is found that for the prolate deformed daughters, the area under the potential curve reduces, the penetrability increases and therefore the half-life is reduced, whereas for oblate cases, it is vice-versa.. Further, the study has been extended to predict twenty-one $2p$ emitters. The results confirm that $2p$ emission preferably happens in prolate shaped daughter nucleus, irrespective of the parent nucleus being prolate or oblate. Further, the analysis confirms that $2p$ emission is similar to other binary decay processes.

Cubic-plus-Coulomb-plus-Yukawa-plus-exponential model (CCYEM) is used to compute the half-lives of $1p$ emitters for both spherical and deformed configuration. For the spherical case, the computed half-lives matches with the experimental values for majority of the cases, whereas for a few cases, a significant difference is found. On comparing the half-live of spherical case with deformed case, it is found that for prolate case, half-life is found to be low and whereas for the oblate case, it is increased. Since, there exist a competition between $1p$ and α decay, branching ratio is calculated between the $1p$ emission and alpha decay. Present calculated preferred decay mode of both spherical and deformed configuration matches well with that calculated using experimental one. For most of the cases, $1p$ emission is the preferred decay mode. The study has been extended to predict $1p$ emitters and its competitive decay mode in the medium and heavy mass region. The analysis has been extended further to predict the $1p$ emitters in the superheavy mass region for both spherical and deformed configuration. From the analysis, it is found that $1p$ emission occurs in the nuclei lying near the proton-rich drip line.

References

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