REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Alpha decay is a kind of radioactive decay in which parents mass number reduced by 4 and its atomic number is reduced by 2 and it leads to give an alpha particle. An alpha particle is identical to a helium nucleus having two protons and two neutrons. It is a relatively heavy, high-energy particle, with a positive charge of +2 from its two protons. Alpha particles have a velocity in air of approximately one-twentieth the speed of light, depending upon the individual particle's energy. Alpha decay is used in many areas like smoke detectors, artificial pace makers, static eliminators etc.

The dynamical cluster decay model was based on Quantum Mechanical Fragmentation Theory (QMFT). The QMFT works on the collective co-ordinates of mass and charge symmetry and with relative separation R. These two co-ordinates refers to the nucleon division or exchange between the outgoing fragments and the transfer of kinetic energy of incident channel to internal excitation or total kinetic energy of the outgoing channel. The dynamic cluster decay model basically developed in order to find the cross sections of compound nucleus by using the partial wave analysis with respect to its co-ordinates. It is used to study the decay of hot rotating compound nuclei.

2.1 Review on alpha decay:

2.1.1 Review on experimental studies on alpha decay:

E. Behnkeet al., (2012) has reported from the operation of a 4.0-kg CF3I bubble chamber in the 6800-foot-deep SNOLAB underground laboratory. The effectiveness of ultrasound analysis in discriminating alpha-decay background events from single nuclear recoils has been confirmed, with a lower bound of >99.3% rejection of alpha-decay events. Twenty single nuclear recoil event candidates and three multiple bubble events were observed during a total exposure of 553 kg-days distributed over three different bubble nucleation thresholds. The effective exposure for single bubble recoil-like events was 437.4 kg-days. A neutron background internal to the apparatus, of known origin, is estimated to account for five single nuclear recoil events and is consistent with the observed rate of multiple bubble events. The remaining excess of single bubble events exhibits characteristics indicating the presence of an additional background. These data provide new direct detection constraints on WIMP-proton spin-dependent scattering for WIMP masses >20 GeV/c2 and demonstrate significant sensitivity for spin-independent interactions.

V. Barci et al., (2003) in his experiment the level structure of ^{229}Th, produced by α-particle decay of ^{233}U, was studied with γ-ray spectroscopy measurements. The sources were continuously separated from daughters with ion-exchange chromatographic methods. Singles and coincidence measurements were performed with high-purity germanium detectors. Energies and intensities of about 220 γ rays were accurately determined. About 70 transitions was reported for the first time, especially in the 300–700 keV energy range. A ^{229}Th level scheme was proposed, accounting for 220 transitions among 47 excited states. Alpha-particle feeding intensities and hindrance factors were deduced and compared to direct α-particle measurements; the agreement was found to be relatively good. The level structure was interpreted in the framework of rotational and/or reflection asymmetric models. The agreement with experimental data was shown to be satisfactory.

C. F. Liang et al., (2000) in his work alpha decay from ^{225}Ra has been observed for the first time. 5006±5keV and 4976±5keV alphas with intensities $2.0\pm0.5\times10^{-5}$ and $6\pm3\times10^{-6}$ and alpha decay hindrance factors 40±10 and 70±35, respectively. The corresponding levels in ^{221}Rn are the ground state (7/2+) and 30±10keV excited state (tentatively 3/2+) with the octupole deformed configurations 3/2(-0.1 0.6) mixed with 1/2(-0.1 0.5 -2).

Eugene V. Tkalya (1999) calculated the spectrum of bremsstrahlung in alpha decay within the framework of quantum and classical electrodynamics. The formulas for the spectra of E1 and E2 radiation are obtained. The bremsstrahlung was evaluated for the Coulomb barrier and for the spherical symmetry rectangular potential barrier.

Experimental results for the nuclei $^{210,214}Po$ and ^{226}Ra were analyzed. A concept of interference of the space regions in the emission amplitude was discussed.

G. L. Poli, et al .,(1999) has investigated the Ground and isomeric proton and alpha decay branches the new isotope ^{177}Tl, which was produced by bombarding a ^{102}Pd target with a 370 MeV beam of ^{78}Kr ions. The ground state is assigned as a πs1/2 configuration and the high spin isomer is assigned as a (πh11/2)-1 configuration. The ground-state proton decay of ^{171}Au has been identified for the first time, produced by bombarding a ^{96}Ru target with ^{78Kr} ions. The ^{171}Au ground state is also assigned as a πs1/2 configuration. Spectroscopic factors, masses, and proton separation energies are derived using these new proton decay measurements. New ground-state αdecays for ^{169}Ir and ^{173}Au are also reported.

C. F. Liang, et al., (1999) the level structure of ^{215}Po has been studied by observing the alpha decay of ^{219}Rn and coincident gamma rays and electrons. In addition to some new levels, some additional tentative spin and parities are observed. Quite different alpha decay hindrance factors make possible the assignment of π(h9/2)2ν(g9/2)5 plus residual reflection asymmetric configurations to one set of states and π(h9/2)2ν(g9/2)4i11/2 plus residual configurations to another set of states. These configuration assignments are further studied by a comparison of the systematics of the ^{215}Po levels with those of neighboring odd neutron nuclei. In this way the nature of the collapse of the reflection asymmetric configurations into the less degenerate shell model configurations can be studied.

R. K. Sheline, et al., (1998) the level structure of ^{219}Rn has been studied using the alpha decay of ^{223}Ra and coincident gamma rays. While only modest changes are required in the level structure, and only above 342.8 KeV, severe changes are required throughout the level scheme in the spin assignments. These changes allow the assignment of two sets of anomalous bands with K=5/2± and K=3/2±. The K=5/2± bands have configurations intermediate between the reflection asymmetric configuration and the g9/2 shell model configuration, while the K=3/2± bands have configurations intermediate between the mixed reflection asymmetric configuration and the i11/2 shell model configuration. Comparison of the systematics of ^{219}Rn with neighboring isotones, isobars, and isotopes shows clearly the collapse of the quadrupole-octupole-type configurations into the less degenerate shell model configurations.

F. Bourgine et al., (1997) has used the 4π light charged-particle detector DIAMANT in combination with the γ-ray spectrometer EUROGAM II the decay of the ^{90}Ru compound nucleus via the pα channel was studied. These nuclei were produced at excitation energy of 54.9 MeV and with a maximum angular momentum of 37ħ by the 120 MeV ^{32}S + ^{58}Ni reactions. The measurement of the energy of the two particles allowed the determination of the energy distribution of the entry states. A particular behavior of the sharing of the available energy between the two particles was found: For increasing values of the entry-state energy, the mean energy for protons remains almost constant while for alpha particles it decreases. This behavior was well reproduced by the evaporation code LILITA_N95. The physics underlying the decay was discussed in the framework of the statistical model which predicts a strong correlation between the excitation energy and the angular momentum of the evaporation residue. This result encourages the use of the pα channel to select the excitation energy and the angular momentum of the evaporation residue for super deformed band studies.

C. F. Liang et al.,(1994) the level structure of ^{212}Bi was found by observing the alpha decay of ^{216}At which is in secular equilibrium with ^{220}Fr and ^{224Ac}. Eight states are observed and tentatively assigned to the configuration πh9/2v(g9/2)3 and three to the configuration πh9/2v(g9/2)2i11/2. These two lowest configurations in ^{212}Bi are compared with the corresponding configurations in ^{210}Bi and the calculations of Warburton.

C. F. Liang et al., (1994) the fine structure in the alpha decay of ^{231}U has been studied for the first time. The alpha branching ratio in ^{231}U was determined as (4±1) ×10-5. Levels in ^{227}Th are deduced and tentative spins and parities suggested.

2.1.2 Review on theoretical studies on alpha decay:

G. Royer (2013) has Investigated that the potential barriers governing the reactions ^{58}Fe+^{244}Pu, ^{238}U+^{64}Ni, and ^{238}U+^{72}Ge and that have been determined from a liquid-drop model taking into account the proximity energy, shell energies, rotational energy and deformation of the incoming nuclei in the quasimolecular shape valley. Double-humped potential barriers appear in these entrance channels. The external saddle-point corresponds to two touching ellipsoidal nuclei when the shell and pairing effects are taken into account, while the inner barrier was due to the shell effects at the vicinity of the spherical shape of the composite system. Between them, a large potential pocket exists and persists at very high angular momenta allowing the capture of very heavy ions at high excitation energies.

D. N. Poenaru, et al., (2012) has found that the calculations of half-lives of super heavy (SH) nuclei showed an unexpected result: for some of them cluster radioactivity (CR) dominates over α decay. So that they changed the concept of CR to allow emitted particles with Ze>28 from parents with Z>110 (daughter around ^{208}Pb). Then they found a trend toward shorter half-lives and larger branching ratios relative to α decay for heavier SHs.

T H. F. Zhang, et al., (2012) introduced the "island of stability" of superheavy nuclei due to shell effects and the α-decay half-lives of these nuclei were predicted. The calculations of the binding energies within a new macroscopic-microscopic model (MMM) were performed and compared with the experimental data for heavy nuclei from Md to the Z=118 element. The agreement was excellent. The data confirm that the ^{270}Hs was a deformed double submagic nucleus beyond ^{208}Pb. The features of α-decay energies and one-proton-separation energies from the MMM reveal that the next double magic nucleus after ^{270}Hs should be ^{298}114. The potential energy surfaces calculated within the constrained relativistic mean-field (CRMF) theory showed that the ^{270}Hs was a deformed double magic nucleus, but ^{298}114 is a spherical double magic nucleus. The α-decay half-lives are determined using a generalized liquid drop model (GLDM) with the Qα from the MMM for Hs and Z=114 isotopes, respectively.

H. F. Zhang, et al., (2011) has determined the assault frequency and preformation factor of the α-decay description from the experimental α-decay constant and the penetration probabilities was calculated from the generalized liquid-drop model (GLDM) potential barriers. In order to determine the assault frequency a quantum-mechanical method using a harmonic oscillator was introduced and leads to values of around 10^{21} s^{-1}, similar to the ones calculated within the classical method.

The preformation probability was around 10^{-1}–10^{-2}. The results for even-even Po isotopes were discussed for illustration. While the assault frequency presents only a shallow minimum in the vicinity of the magic neutron number 126, the preformation factor and mainly the penetrability probability diminish strongly around N=126.

D. N. Poenaru et al., (2011) has estimated the single line of universal (UNIV) curve for α decay and cluster radioactivities was obtained by plotting the sum of the decimal logarithm of the half-life and cluster preformation probability versus the decimal logarithm of the penetrability of external barrier. This fission-like theory was compared to the universal decay law (UDL) derived using α-like R-matrix theory. The experimental data on heavy cluster decay in three groups of even-even, even-odd, and odd-even parent nuclei were reproduced with comparable accuracy by both types of universal curves, UNIV and UDL

G. Royer et al., (2008) in his work new recent experimental α decay half-lives have been compared with the results obtained from previously proposed formulas which depends only on the mass and charge numbers of the α emitter and the Qα value. For the heaviest nuclei they compared with calculations using the Density-Dependent M3Y (DDM3Y) effective interaction and the Viola-Seaborg-Sobiczewski (VSS) formulas. The correct agreement allows them to make predictions for the α decay half-lives of other still unknown superheavy nuclei from these analytic formulas using the extrapolated Qα of G. Audi, A. et al. mass table

H. F. Zhang et al., (2007) has determined the theoretical α decay half-lives of the heaviest odd-Z nuclei are calculated by using the experimental Qα value. The barriers in the quasimolecular shape path were determined within a Generalized Liquid Drop Model (GLDM) and the WKB approximation was used. The results were compared with calculations using the Density-Dependent M3Y (DDM3Y) effective interaction and the Viola-Seaborg-Sobiczewski (VSS) formulas. Thus the calculations provided consistent estimates for the half-lives of the α decay chains of these superheavy elements. The experimental data stand between the GLDM calculations and VSS ones in the most time. Predictions were provided for the α decay half-lives of other super heavy nuclei within the GLDM and VSS approaches using the extrapolated Qα of Audi, et al mass table which may be used for future experimental assignment and identification.

Hongfei Zhang et al., (2006) the α decay half-lives of the recently produced isotopes of the 112, 114, 116 and 118 nuclei and decay products have been calculated in the quasi-molecular shape path using the experimental Qα value and a Generalized Liquid Drop Model including the proximity effects between nucleons in the neck or the gap between the nascent fragments. Reasonable estimates are obtained for the observed α decay half-life. The results were compared with calculations using the Density-Dependent M3Y effective interaction and the Viola-Seaborg-Sobiczewski formulae. Generalized Liquid Drop Model predictions are provided for the α decay half-lives of other super heavy nuclei using the Finite Range Droplet Model Qα and compared with the values derived from the VSS formulae.

2.2 Review on dynamic cluster decay model:

2.2.1 Review of theoretical studies on DCM model:

Raj Kumar et al., (2013) has estimated the decay of the Z=115 super heavy nuclear system, formed in the ^{243}Am+^{48}Ca reaction, by using the dynamical cluster-decay model. The calculated excitation functions of 2n-, 3n-, and 4n-evaporation channels, for the excitation energy range E_{CN}*=31–47 MeV, are compared with the recent experimental data. The deformation effects are included up to β2, within the hot optimum orientation approach, and a comparative analysis of spherical versus static and dynamic deformations was investigated explicitly for the 2n-evaporation residue, as only 2n-decay responds to spherical fragments. The 3n- and 4n-decay cross sections could be fitted only after the inclusion of deformation effects. The variation of preformation probability, barrier penetrability, and barrier modification was investigated in order to extract a better picture of the dynamics involved in the reaction under consideration. It was observed that, for the 3n-evaporation channel, the barrier modification at E_{CN}*=36.15 MeV is the smallest and hence supports the experimental observation of maximum cross section (8.5 pb) at this energy. The role of isospin (N/Z ratio) was also investigated for the decay of various isotopes of Z=115 formed in ^{48}Ca + ^{241,243,245}Am reactions. Furthermore, the evaporation cross sections of 2n, 3n, and 4n channels are also estimated at the Bass barrier by interpolating the neck-length parameters fixed in reference to available data at above-barrier energies. Finally, the α-decay chains are analyzed by using the preformed cluster model. It is shown that the present data of α-decay half-lives support "hot" optimum orientations of nuclei, rather than the usual "cold" ones, within a constant empirical factor in penetrability.

C. Karthikraj et al., (2013) in his work DCM was applied to study the decay of odd- A and non-α structured $^{59}Cu^*$ formed in the $^{35}Cl+^{24}Mg$ reaction at E_{lab}=275 MeV. Here, the temperature (T)–dependent binding energies due to Krappe is used. The roles of Wigner and pairing energies in the fragmentation potential are explicitly shown in this work. For the temperature T=4.1898 MeV corresponding to E_{lab}=275 MeV, the contribution of pairing vanishes and the resulting structure of the fragmentation potential due to Wigner term was shown. In addition to this, they also studied the role of factor α appearing in the inertia part of the equation of motion dictating the mass-transfer process. It is shown that this factor has significant effect in the structure of preformation probability values and hence in turn there is a significant change in the cross sections. After that they compared the cross sections of the measured charge distributions of the fission fragments for two limiting values of the parameter α with the experimental data. In order to fit the total cross-section values, a linear relation is obtained between the free parameter of the model Δ R and the factor α appearing in the hydrodynamical mass.

Manoj K. Sharma et al., (2012) has estimated the odd-mass nuclear systems $^{213}Fr^*$ (with N=126) and $^{217}Fr^*$ (with N=130) formed in ^{19}F + $^{194,198}Pt$ reactions by using DCM model. The measured anomaly in fission anisotropy for $^{213}Fr^*$ in this reaction was said to be due to either the possible role of the magic N=126 shell of the compound nucleus (CN) or the presence of a non-compound nucleus component, such as quasifission, in the fission cross section. Their calculations were made within the DCM for the fragments having quadrupole (β2) deformations with orientations of compact, hot configurations, compared with spherical as well as β2–β4 deformed considerations.

For quadrupole deformed fragments (with "optimal" orientations), the calculated fission cross-sections (as well as the evaporation residue cross-sections) match the data nearly exactly, without invoking a significant contribution from quasifission. The calculated fission mass distribution for the two systems was quite similar for either of the spherical, β2-alone deformed, and β2–β4 deformed choices of fragments. A small hump or shoulder was seen in fragment preformation yields for the deformed case (β2 or β2–β4) in both the systems due to a deformed closed shell around Z2=36 and a spherical magic shell around Z1=50, which for ^{213}Fr* (N=126) decay is somewhat more pronounced as compared to ^{217}Fr* (N=130). Note that the magic shell of the CN proton/neutron number plays no role in DCM.

Kirandeep Sandhu et al., (2012) has made a study on a dynamical cluster decay model (DCM) in order to find the decay of the ^{268}Sg* compound nucleus formed in the ^{30}Si+^{238}U reaction at above and below the Coulomb barrier energies. The neutron evaporation residues and fission cross sections were calculated in reference to the available data, including β2i-static deformations with 'optimum' orientations. The role of spherical and the β2i-dynamic deformed choices of fragmentation were also studied explicitly at the highest 169 MeV energy. The fission fragment distribution was symmetric at above-barrier energies, where equatorial collisions are preferred, but becomes asymmetric when the nuclei approach in pole-to-pole configuration at sub-barrier energies. Therefore, at above-barrier energies the calculations were carried out by considering 'hot fusion', equatorial collisions, whereas at sub-barrier energies the 'cold fusion', polar configuration was considered.

The asymmetric peaks at sub-barrier energies may be associated with some competing process, like quasifission. The analysis of polar and equatorial configurations suggests that larger barrier modification was required at sub-barrier energies for neutron evaporation residue and fission fragments, i.e., the contribution of barrier modification at sub-barrier energies is relatively higher for a cold elongated polar configuration as compared to a hot compact equatorial configuration. Finally, the potential energy surfaces for the Si-induced reaction are compared with the S-induced reaction on the 238U target, at comparable center of mass energies.

C. Karthikraj, et al. (2012) has observed the effect of temperature-dependent binding energies. In earlier works on the DCM, the temperature-dependent liquid drop energy from Davidson et al.'s work with two of its constants refitted for each isotopic chain to reproduce ground-state experimental binding energies is used. In their work, the temperature-dependent binding energy formulas of Krappe H and Guet et al. are used in the DCM without any refitting of the coefficient of the liquid drop needed to study the decay of the hot and rotating ^{56}Ni* system formed in the ^{32}S+^{24}Mg reaction at two incident energies, $E_{c.m.}$=51.6 and 60.5 MeV. The use of Krappe's formula results in the explicit preference of a four-nucleon transfer, indicating strong minima in the potential energies corresponding to α-structured nuclei as well as exhibiting structural effects in the preformation calculations favoring α-structured nuclei.

The overall cross sections for the light particles and intermediate mass fragments are nicely reproduced by the use of Krappe's formula. However, the individual channel cross-sections exhibit a strong distribution only for α nuclei, and for other fragments the results are lower by a factor of 2 to 3. The use of Guet et al.'s formula though does not show any explicit structure effects in the potential energy calculations or the Preformation calculations; the overall cross sections was calculated for light particles and intermediate mass fragments compare well with the experimental data.

The results of individual channel cross-sections, however, do not exhibit any explicit preference for the α-structured nuclei; rather, the individual channel cross sections decreases with an increase in the mass number of the fragments. The calculated average kinetic energies using both formulas for the favored αfragments compares well with experimental values. Without any refitting of the coefficients of the temperature-dependent binding energies, the DCM works out well and the explicit preference of α structure depends mainly on the choice of formula.

Manpreet Kaur et al., (2012) has used the dynamical cluster decay model (DCM), to study the decay of actinide nuclear system $^{254}Fm^*$ formed in ^{11}B +^{243}Am reaction with choices of spherical, quadrupole deformation β2 alone and higher multipole deformations β2–β4. For β2 deformations, the optimum orientations θiopt were used whereas for higher multipole deformations the compact orientations θic of decaying fragments were taken in to account. Besides static-β2 deformations, the effects of dynamical-β2 deformations are also explored. The calculated cross sections found excellent agreement with the available experimental data with spherical as well as deformed choices of fragmentations, which enables them to account for the role of important nuclear deformation effects in the ^{11}B-induced nuclear reaction. Spontaneous decay of ^{254}Fm with cold elongated configuration and optimum orientation was also worked out. The mass distributions of excited fermium isotopes in the neighborhood of $^{254}Fm^*$ are also explored. In addition, the roles of temperature, angular momentum, and fission fragment anisotropies are investigated in the context of the chosen reaction.

Manpreet Kaur et al., (2012) the dynamical cluster decay model (DCM) was applied in reference to recent data on $^{78,82}Kr$ + ^{40}Ca reactions at a bombarding energy of 5.5 MeV/nucleon. For the nuclear systems $^{118,122}Ba^*$, Within the DCM approach, they fit the total fission and evaporation residue cross sections for spherical choice of nuclei by simultaneously fitting the neck length parameter. The effect of different level density parameters was also studied. Results of DCM calculations are compared with BUSCO-, GEMINI-, and DNS-based calculations. All the models use the maximum angular momentum ℓmax as the fitting parameter, which in the DCM is fixed via the neck-length parameter (ΔR) for the penetrability $P \rightarrow 1$. Also, the role of a nonzero pairing strength ($\delta > 0$) is seen, using $\delta(T)$ in VLDM as a fitting parameter, say, to Li data. The effect of different proximity potentials was also studied. Finally, some non-compound nucleus contribution is shown to be operating in the context of the reactions under study. The N/Z dependence of decay fragments is also studied for Ba isotopes with A=114–126.

Raj K. Gupta et al., (2005) The dynamical cluster-decay model (DCM) was developed for the decay of hot and rotating compound nuclei (CN) formed in light heavy-ion reactions. The model was worked out in terms of only one parameter, namely the neck-length parameter, which is related to the total kinetic energy TKE (T) or effective Q value $Q_{eff}(T)$ at temperature T of the hot CN and is defined in terms of the CN binding energy and ground-state binding energies of the emitted fragments. The emission of both the light particles (LP), with $A \leq 4$, $Z \leq 2$, as well as the complex intermediate mass fragments (IMF), with $4 < A < 20, Z > 2$, was considered as the dynamical collective mass motion of preformed clusters through the barrier. Within the same dynamical model treatment, the LPs are shown to have different characteristics compared to those of the IMFs.

The systematic variations of the LP emission cross section σ_{LP} and IMF emission cross section σ_{IMF} calculated from the present DCM match exactly the statistical fission model predictions. A nonstatistical dynamical description was developed for the first time for emission of light particles from hot and rotating CN. The model was applied to the decay of $^{56}Ni^*$formed in the ^{32}S+^{24}Mg reaction at two incident energies $E_{c.m.}$ =51.6 and 60.5 MeV. Both the IMFs and average TKE spectra are found to compare reasonably well with the experimental data, favoring asymmetric mass distributions. The LPs' emission cross section is shown to depend strongly on the type of emitted particles and their multiplicities [8].