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A Study of Excitation Functions in the Interaction of 4He + 59Co System at 4-9MeV/Nucleon

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Abstract

The excitation functions for six reactions produced in the interactions of 4He +59Co have been measured in the energy range up to 41MeV using the activation technique. The measured excitation functions are compared with theoretical calculations done using the computer program COMPLET. The effect of the variation of various program parameters on calculated excitation functions have been studied. The study signified that an admixture of equilibrium and pre-equilibrium emissions is required to reproduce the presently calculated excitation functions.An attempt was made to deduce the contribution coming from pre-equilibrium emission. It was found that the pre-equilibrium contribution increases with projectile energy. Further, the threshold of pre-equilibrium emission for different reaction channels is found to be different, depending on the associated Q-value. Furthermore, the present result revealed a strong correlation between pre-equilibrium contribution and particle multiplicity.

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INTRODUCTION

The technological advances have often pushed new scientific discoveries. This is most true in nuclear reactions, where the development of new accelerator and detections technologies has allowed the investigation of nuclear reaction dynamics in the most extreme conditions. A nuclear reaction is one in which an atomic nucleus interacts with some nuclear projectile resulting in the emission of nuclear particles, heavy ions and/or radiations leaving behind the residual nucleus. Most of the known nuclear reactions are produced by exposing different materials to a beam of accelerated nuclear particles. Macroscopically, in a nuclear reaction, one may have the information of the reaction process before and after the reaction has taken place. However, what exactly happens during the reaction itself is not well known. In order to understand the interaction mechanism between the projectile and target nuclei, the behavior of the emitted particles and the residual nucleus nuclear reaction models have been proposed.

The study of nuclear reactions induced by light projectiles in general and alpha particle in particular has again attracted the attention of nuclear physicists. One of the main reasons for this is the requirement of precise nuclear data needed for the development of recently proposed Accelerator Driven Sub-critical (ADS) reactors. Further, the data also have verity of applications including the field of medical sciences, environmental sciences, transmutation of nuclear waste etc.

One of the important aims of the study of such reactions is to enhance the basic understanding of the reaction mechanism. The evaluation of the cross section is one of the main tasks in the field of low energy nuclear reactions. These reactions are described by different models which depend on the energy of the projectiles. Depending upon the time at which they occur, the nuclear reactions are classified under two categories namely compound nucleus reaction and direct reaction. Between these extreme processes there are the pre-equilibrium reactions.

To calculate the cross sections in the model of compound nucleus and in pre-equilibrium models, one of the most important ingredients is the level density. There are indications that compound and pre-compound reaction processes play an important role at moderate excitation energies. The nuclear data for the accelerator driven technologies are required for a large number of the target elements covering almost entire periodic table over a wide range of energies. As such, more detailed and accurate measurements are needed to fulfill this requirement of data. The nuclear data required for these applications are obtained mainly from the nuclear scattering (nuclear reaction) and from the reaction model calculations, which depend on the optical models, whose parameters are determined by elastic scattering andthe total cross-section data.

Efforts have been made to obtain the estimates of basic nuclear reaction cross-sections both experimentally as well as theoretically. Though, considerable data is available in literatureon α-induced reactions but the cross-section values measured by different groups of workers for the reaction, generally, do not agree. It may not be out of place to mention that theoretically it may be possible to explain the measured excitation function (EFs) for a given reaction channel individually using a certain theoretical code. However, a consistent analysis requires reproduction of excitation function for all open channels simultaneous using the same code.

Fitting of excitation function for an individual channel may improve the description of the data for the partial channel at the cost of other open channels. However, it is unacceptable from the point of view of physics. At moderate excitation energies, reactions induced by nucleons and light-heavy ions are found to proceed through CN as well as PE emission.

As such, precise measurement of EFs for such cases and their analysis may be used to find out the relative contribution of equilibrium and PE processes.Several phenomenological as well as quantum-mechanical models have been made to explain the pre-equilibrium (PE) reaction mechanism. To explain this mechanism many models have been proposed, including the pioneer work of Griffin , Intra – nuclear cascade (INC) model, Harp – Miller – Berne (HMB) model, exciton model, and hybrid or geometry dependent hybrid (GDH) models. Descriptions of these models are given in chapter two. Apart from the semi-classical models of the nuclear reactions for the successful reproduction of the excitation function data, efforts are in progress to give full quantum mechanical picture in the frame work multi-step theories proposed by Feshbach, Kerman, and Kooninand others.All these models describe the method in which projectile energy gradually gets redistributed among the constituent nucleons of the composite system through a series of residual two-body interactions.

In the present thesis, efforts were made to investigate the reaction mechanisms involved in the interaction of α-projectile with ^{59}Co target at ~11-41MeV. The statistical model code COMPLET was used in the predictions analyses.

Computer Code and Formalism

The nucleus is a tightly bound system of protons and neutrons which is held together by strong forces that are not normally detectable in nature because of their extremely short range. The small size, strong forces, and many particles in nucleus result in a highly complex and unique quantal system. The nucleus is highly complex, with various degrees of freedom being excited at small excitation energy and often strongly mixed. The density of quantum mechanical states increases rapidly with excitation energy and soon becomes very large and complex. Even at lower beam energies where nuclear reactions can be initiated with charge particles, many states are available for the compound nucleus. This compound nucleus in excited energy states subsequently can decay through many different ways since separate study of each state is very complex. The models based on statistical approaches are not only appropriate, they are essential for understanding and predictions of various nuclear phenomena.

In studying nuclear reactions and other collisions processes we are always interested in a quantitative measure of the probability with which the collision process occur. This quantitative measure is always expressed through a parameter called cross-section.

Studies of nuclear reactions deal with the analysis of cross-section data in terms of statistical model for the formation and decay of the CN. Models developed by Bethe, Weisskopf and Ewing were based on Bohr's independent hypothesis for the formation and decay of compound nucleus. However, these models neglect a direct influence of angular momentum imparted by the projectile to the composite system and party. As such, these models are convenient for the study of nuclear reactions mechanism with light ion induced, where the angular momentum affects are small due to low mass of the projectile.

Several models have been proposed to understand nuclear reactions dynamics and nuclear structure and various computer codes were developed for the predictions and analysis of various products of CN decay. These computer codes can now be used to verify the reaction mechanisms formation and decay, to determine angular momentum and to search for non-statistical aspects of nuclear structure at higher excitation energies and high angular momentum.

There are two broad classifications in calculation and computer code as single-steps (SS) and multi-step (MS) calculations.

In SS calculations the excited nucleus has energy sufficient for a single decay or it is only the emission of the first particle that is of interest. However, in case of MS calculations the spectra of gamma rays and light particles contains contributions from successive decays and the distribution of heavy residues is arrived at through several or many successive decays. This problem can be treated in two ways namely Multi Step Gridded Method (MSGR) and Multi Step Monte Carlo (MSMC) method. In MSGR a grid is constructed in Z and A, for each nucleus, a population distribution over a two dimensional grid in excitation energy and angular momentum. The size of the grid in Z and A continues to expand for successive daughter nuclei until further decay is energetically forbidden. However, MSMC method follows the decay of individual compound nuclei in an initial ensemble by Monte Carlo techniques until the residual nucleus can no longer decay. The great advantage of the Monte Carlo method is that it can predict energy spectra, angular distributions and multi particle correlations in laboratory system.

In the present work we have used the statistical model codes COMPLET (modified ALICE-91) for excitation functions predictions. This code is based on MS grid method.

ALICE-91

ALICE-91 calculates particle and γ-ray emission spectra induced with neutrons, protons, and deuterons, alpha particles and heavy-ions in the energy range till several hundred MeV. The ALICE-91 code performs PE decay calculation, followed by CN decay including fission competition. The equilibrium decay channels are calculated using a deterministic method.

The code ALICE-91 employs the Weisskopf- Ewing model for statistical component and hybrid and geometry dependent hybrid (GDH) model of Blann for pre-equilibrium emission. In the equilibrium calculations, the evaporation of proton, neutron, deuteron and alpha particles has been allowed for.

The *Q* values for the formation of compound nucleus and the neutron, proton, deuteron, binding energies for all nuclides of the interest in the evaporation chain have been calculated using Myers – Swiatecki/ Lysekil mass formula.

In this code we have the facility of varying mesh size and therefore the cross-sections up to *300 MeV* $x\,\Delta E(\Delta E$ be the mesh size) can be calculated. The residual nuclei of a grid 11 mass units wide by 9 atomic members deep may be calculated. Particle spectra may be selected in the output, in addition to individual product yields and fission cross-sections.The evaporation calculations include fission competition according to the Bohr–Wheeler approach, using angular momentum dependent state and saddle point energies. These energies are taken from Cohen et al., Rotating Liquid Drop Model (RLDM) calculations.

The inverse reaction cross sections are calculated from the optical model subroutine which uses the Bechetti and Greenless optical parameter; however, there is an option of classical sharp cut off model also. The level density parameter influences the shape as well as the height of calculated excitation functions. In this the level densities of the nuclide involved in the evaporation chain can be calculated from the Fermi gas model as

$$\rho(U) = (U-\delta)^{\frac{-5}{4}} e^{\left(2\sqrt{a(U-\delta)}\right)}$$

Where *U* is the excitation energy of the nucleus and δ is the pairing term. In general for the level density parameter a value of a$=\frac{A}{K}$ is applied, where *A* denotes the nucleon number of the compound nucleus and not the residual nucleus and *K,* a constant for which values spread over a wide region have been given in literature.

In pre-equilibrium emission calculations the initial exciton configuration(n_o) and level density parameter "*a*' are very crucial quantity.

Whereas the mean free path multiplier (MFP) affects the equilibrium component.The mean free path multiplier for intra nuclear transition rates may be calculated either from the optical potential parameters of Becchetti and Greenless or from Pauli corrected nucleon – nucleon cross-sections.

In case of heavy ion, the transmission coefficients are calculated using parabolic model of Thomas. The upper limit of the enhancement of γ- ray de-excitation due to angular momentum effect can be obtained by selecting s– wave approximation.

In this, the cross section for emitting a particle at channel energy ∈ is evaluated for every partial wave in the entrance channel. Higher angular momentum of the nucleus inhabits particle emission more than γ - ray emission in the last stage of nuclear de- excitation. Therefore the peak of the excitation functions corresponding to particle emission mode willbe shifted to higher energy.A similar shift may also be obtained if the mean energy of the evaporated particles increases with increasing nuclear spin. From the nuclear rotational energy one can estimate the overall energy shift. For a rigid body moment of inertia rotational energy can be given as;

$$E_{rot} \approx \frac{m}{M} E_{lab}$$

Where*m, M* are the mass of projectile and target nuclei and E_{lab} the incident projectile energy. It is desirable to shift the calculated excitation function by the amount approximately equal to E_{rot} to account for large angular momentum imparted and it is assumed that the rotational energy for each partial wave is irrevocably committed to rotational motion and therefore no energy is available for particle emission. In case of heavy ions it does not take into account the angular momentum involved, as heavy ion projectiles impart large angular momentum to the composite system having a finite moment of inertia and consequently greater rotational energy. Because of nuclear rotation, a nucleus with a given angular momentum cannot have energy below a minimum value ${E_J}^{min}$

$${E_I}^{min} \approx J(J+1)^{\frac{\hbar}{2I}}$$

Where,*J* = angular momentum
I = moment of inertia of the composite system

The Weisskopf-Ewing Formulation

At low projectile energies the CN states are excited individually and each produces a resonance in the cross-section that may be described by the Breit-Wigner theory.As the incident energy increases the compound nucleus states become close together and become impossible to identify individual resonances. As a result of reaction amplitudes interferences the cross-section fluctuates. These fluctuating features vanish in the energy average of the cross-section since these amplitudes are complex functions with random modulus and phase. The energy average of the cross sections shows weak energy dependence and itis predictable by the theory. To do this a reaction that proceeds from the initial channel α through the compound nucleus to the final channel β. Neglecting for the time being the formation of compound nucleus in different angular momentum J, the independence of formation and decay of the CN then gives for the cross-section.

$$\sigma_{\alpha\beta} \approx \sigma_{CN}(\alpha)\frac{\Gamma_\alpha}{\Gamma} \quad (3.12)$$

Where $\sigma_{CN}(\alpha)$ is the cross-section for formation of the CN and Γ_β and Γ are, respectively, the energy average width for the decay of the CN in channel β and the energy averaged total width. From reciprocity theorem we can have

$$g_\alpha {K_\alpha}^2 \sigma_{\alpha\beta} = g_\beta {K_\beta}^2 \sigma_{\beta\alpha} \quad (3.13)$$

where $g_\alpha = 2i_\alpha + 1$ and $g_\beta = 2i_\beta + 1$ are the statistical weights of the initial and final channels, i_α and i_β the spin of the projectile and the ejectile, and k_α and k_β their wave numbers. This gives

$$g_\alpha {K_\alpha}^2 \sigma_{CN}(\alpha)\Gamma_\alpha = g_\beta {K_\beta}^2 \sigma_{CN}(\beta)\Gamma_\beta \quad (3.14)$$

or, equivalently

$$\frac{\Gamma_\alpha}{g_\alpha {K_\alpha}^2 \sigma_{CN}(\alpha)} = \frac{\Gamma_\beta}{g_\beta {K_\beta}^2 \sigma_{CN}(\beta)} \quad (3.15)$$

Since the channels α and β are chosen arbitrarily, this relation holds for all possible channels so

$$\Gamma_\alpha \approx g_\alpha {K_\alpha}^2 \sigma_{CN}(\alpha) \quad (3.16)$$

Since the total width is obtained by summing the ${\Gamma_\alpha}'s$ overall open channels

$$\Gamma = \sum_\alpha \Gamma_\alpha \quad (3.17)$$

The cross-section becomes

$$\sigma_{\alpha\beta} = \sigma_{CN}(\alpha)\frac{g_\beta {K_\beta}^2 \sigma_{CN}(\beta)}{\sum_\alpha g_\alpha {K_\alpha}^2 \sigma_{CN}(\alpha)} \quad (3.18)$$

Ejectiles with energy in the range ε_β to $\varepsilon_\beta + d\varepsilon_\beta$, leave residual nucleus with energies in the range U_β to $U_\beta + dU_\beta$, where

$$U_\beta = E_{CN} - B_\beta - \varepsilon_\beta \quad (3.19)$$

And E_{CN} and B_β are respectively the CN energy and the binding of the ejectile in the CN. Introducing the density of levels of the residual nucleus $\rho(U_\beta)$, equation (4.18) becomes

$$\sigma_{\alpha\beta} d\varepsilon_\beta = \sigma_{CN}(\alpha)\frac{g_\beta {K_\beta}^2 \sigma_{CN}(\beta)\rho(U_\beta)dU_\beta}{\sum_\alpha^{E_\alpha{}^{max}} g_\alpha {K_\alpha}^2 \sigma_{CN}(\alpha)\rho(U_\alpha)dU_\alpha} \quad (3.20)$$

or, since $k^2 = 2m\varepsilon$

$$\sigma_{\alpha\beta} d\varepsilon_\beta = \sigma_{CN}(\alpha)\frac{(2i_\beta+1)\mu_\beta \varepsilon_\beta \sigma_{CN}(\beta)\rho(U_\beta)dU_\beta}{\sum_\alpha^{E_\alpha{}^{max}} \int_0^{E_\alpha{}^{max}} (2i_\alpha+1)\mu_\alpha \varepsilon_\alpha \sigma_{CN}(\alpha)\rho(U_\alpha)dU_\alpha} \quad (3.21)$$

Where μ_α is the reduced mass of the projectile α.This is the Weisskopf-Ewing formula for the angle integrated cross-sections. The corresponding general expression for the particle emission width is

$$\Gamma_\beta = \frac{1}{\rho_{CN}(E_{CN})}\frac{(2i_\beta+1)\mu_\beta \varepsilon_\beta}{\pi \hbar^2}\sigma_\beta(\varepsilon_\beta)\rho(U_\beta)d\varepsilon_\beta \quad (3.22)$$

ALICE-91 code used the above equations in the predictions of reaction cross sections following the formation of compound nucleus at some excitation energy and with some cross-section. The Weisskopf calculation is then used with a 1-MeV grid size to perform nucleus population into the appropriate bin.

The control then moves over to the A–1 bin following neutrons emission, from the compound nucleus. This bin can also be resulted with the emission of proton, deuteron, and alpha particle. The residual nuclei obtained from the emission of aforesaid particles are stored in the respective bins. The code uses the number of millibarns in the highest energy bin (A–1) and redistributes that cross-section in the same manner. After this the control comes down to the next residual excitation bin and the process continues up to the moment all the cross-section redistributed and summed it in the appropriate bins of the residual nuclides. This logic is repeated going across the A as far as requested by an input parameter. After this the control comes down in Z to the nucleus A–1, Z–1 and repeats the process till all calculations are not completed for each input parameter.

Results and Discussions

The present thesis investigatesthe excitation functions of ^{59}Co(α, n)^{62}Cu, ^{59}Co(α,2n)^{61}Cu, ^{59}Co(α,3n)^{60}Cu, ^{59}Co(α,2p)^{61}Co, ^{59}Co(α, 3n2p)^{58}Co^{m} and ^{59}Co(α,4n2p)^{57}Co reaction channels populated in the interaction of ^{4}He projectile with ^{59}Co target at ≈11-41 MeV projectile energy. The measured excitation functions available in the literature were compared with the theoretical predictions obtained from COMPLET code (modified ALICE-91). The COMPLET code gives the results of both equilibrium (CN) reaction and pre-equilibrium (PEQ) reaction. Level densities of residual nuclei play an important role in deciding the shapes and absolute value of the excitation functions. In COMPLET code the level density parameter a, which largely affects the equilibrium components of cross section is calculated from the expression $a = A/K$ MeV^{-1}, where A is the nucleon number of a compound system and K is an adjustable constant, which may be varied to match the experimental data. Also in this code, the pre-equilibrium components of cross section is sensitive to initial exciton configuration, n_o, and mean free path multiplier, *MFM*. The sensitivity of the initial exciton number on PE cross section was done by varying the initial exciton configuration, n_o (n+p+h) which is described by the number of neutrons (n) and by the number of proton (p) in excited states, and the number of holes (h) following the first interaction of a projectile with a target. The total exciton,n_o is equal to the sum of n, p, and h.

Production of Cupper Residues

The measured excitation functions were compared with complete code predictions for different level density parameter values for representative^{62}Cu evaporation residue produced in the interaction of ^{4}He+^{59}Co system. For the representative ^{62}Cu evaporation residues, the value of K was varied to match the experimental data (K values of 8, 10 and 12 were used) and the results are displayed in figure 4.1(a). To see the effects of mean free path multiplier (MFM), which is used to adjust the nucleon-nucleon mean free path inside the composite excited nucleus was varied from 1 to 2.5. It may be observed from figure 4.1(b) that a value of mean free path multiplie (MFM=1.0) reproduced satisfactorily the measured excitation functions. Similarly the values of initial exciton number, n_o was varied from 3 to 5. As can be seen from figure 4.1(c) the measured excitation function for the same representative channel is well reproduced by COMPLET for a value initial exciton number (n_o=4).

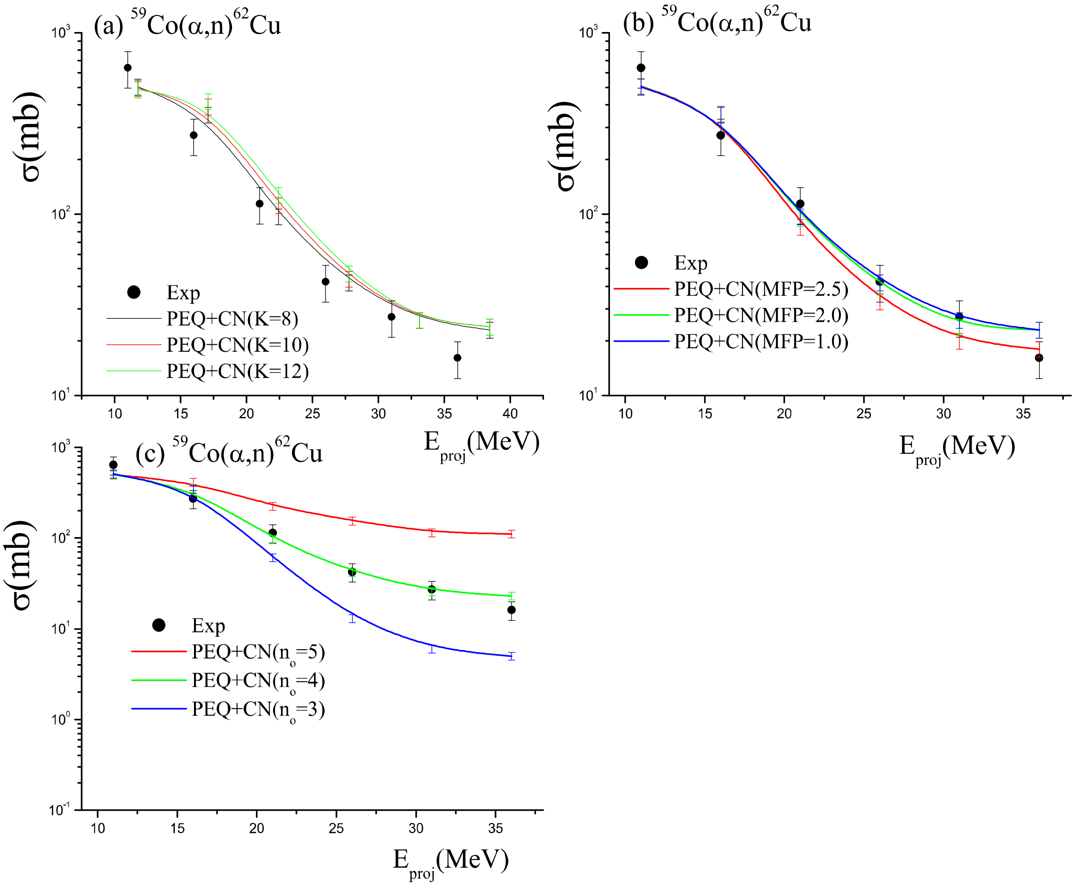

Fig. 4.1: Experimentally measured data obtained from EXFOR data source and theoretically calculated excitation functions for evaporation residues produced in ^{4}He+ ^{59}Co reaction using the code COMPLET.

Figure 4.2(b)-(c) displayed the measured excitation functions along with the COMPLET code predictions of 61Cu and 60Cu residues populated via (α,2n) and (α,3n) channels respectively at the set values of input parameters (K=8,no=4, and MFM=1.0).

In the present work all calculations and analysis were performed consistently using level density(K=8), initial exciton number (n_o=4), and mean free path multiplier(MFM=1.0).

Production of Copper Residues

The measured excitation functions along with the COMPLET predictions for ^{61}Co, ^{58}Co, and^{57}Co residues populated via(α, 2p),(α, 3n2p)and(α, 4n2p)channels are shown infigure 4.2(d)-(f). It may be observed from figure 4.2 that at higher energy points the theoretically calculated excitation functions corresponding to the level density K=8, the mean free path multiplier MFM=1.0 and the initial exciton number n_o=4 in general reproduced satisfactorily the experimentally measured excitation functions for the residues ^{61}Co, ^{58}Co, and ^{57}Co produced in the interaction of α- projectile with ^{59}Co target. Further it is clear from figure 4.2 that at lower energy points the predictions do not satisfactorily reproduced the measured data.

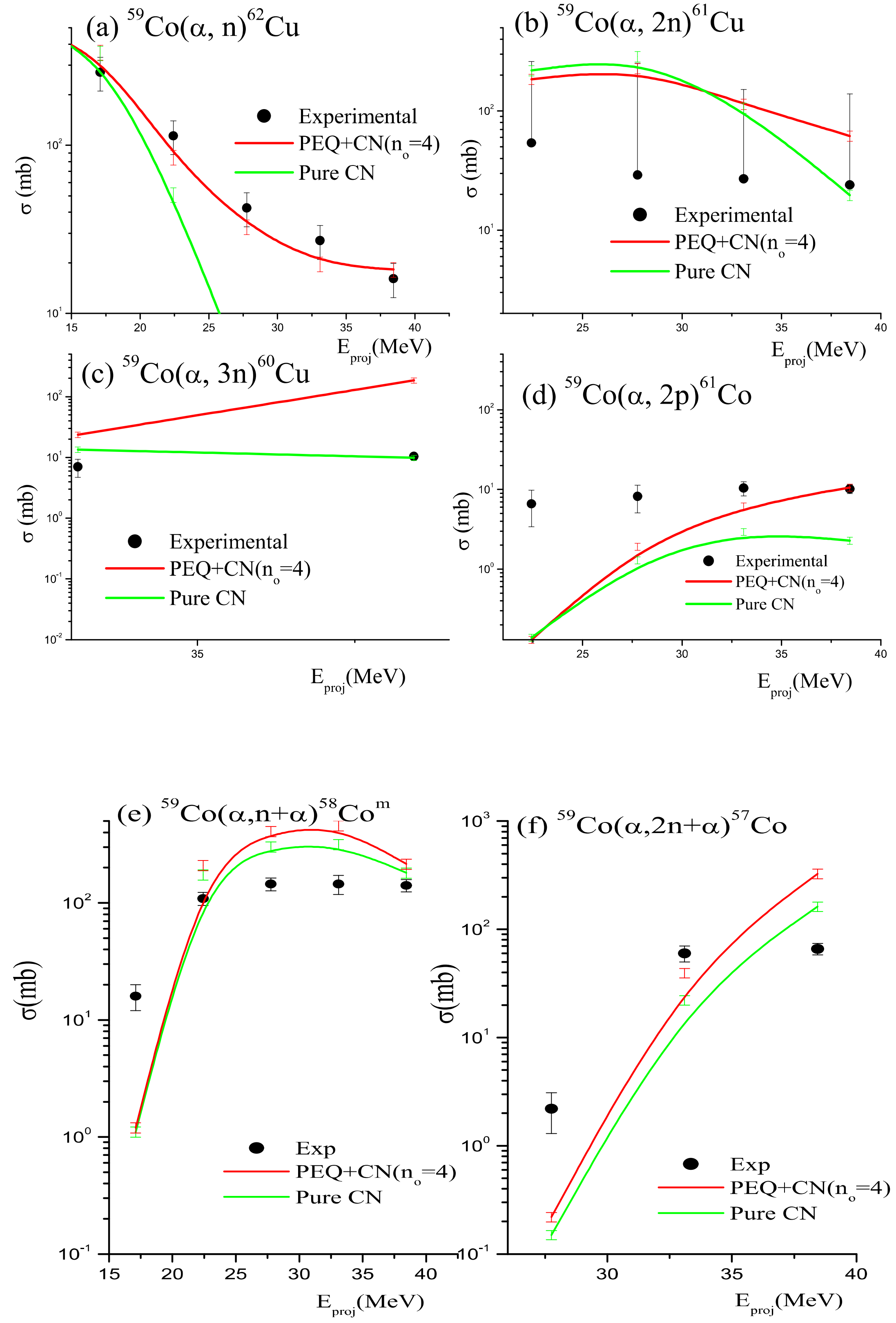

Fig.4.2: Experimentally measured data obtained from EXFOR data source IAEA and theoretically calculated excitation functions for different evaporation residues produced in the ^{4}He + ^{59}Co reaction using the code COMPLET.

For a better analysis of the experimental data the code COMPLET (modifiedALICE-91) is frequently used. This may be attributed to the fact that the input parameters of the code are few and well defined. It may further point out that the measured data set is well fitted with the prediction of the code COMPLET. In general, it is clear from Fig. 4.2 that the PEQ emission is significantly observed in most channels of the present study. Thus, a symmetric attempt has been made to estimate the PEQ contribution at a given energy for a particular reaction channel and these could be well explained in section 4.3 below.

Pre-equilibrium Contributions

To study the dependence of PEQ contribution on projectile energy, the percentage PEQ contribution, which is a measure of relative strength of PEQ component needed to reproduce the measured cross-section, defined as the ratio of the PEQ cross-section,$\sigma_{PEQ}(\sigma_{PEQ=}\ \sigma_{exp} - \sigma_{CN})$ to the experimental cross section, σ_{exp}.

The percentage PEQ contribution as a function of normalized projectile energy (E_{poj}/V_{CB}) for α + ^{59}Co system through the six channels discussed above is plotted in figure 4.3. In general, it is clearly seen from figure 4.3 that the percentage of the PEQ contribution is found to increase smoothly with normalized projectile energy.

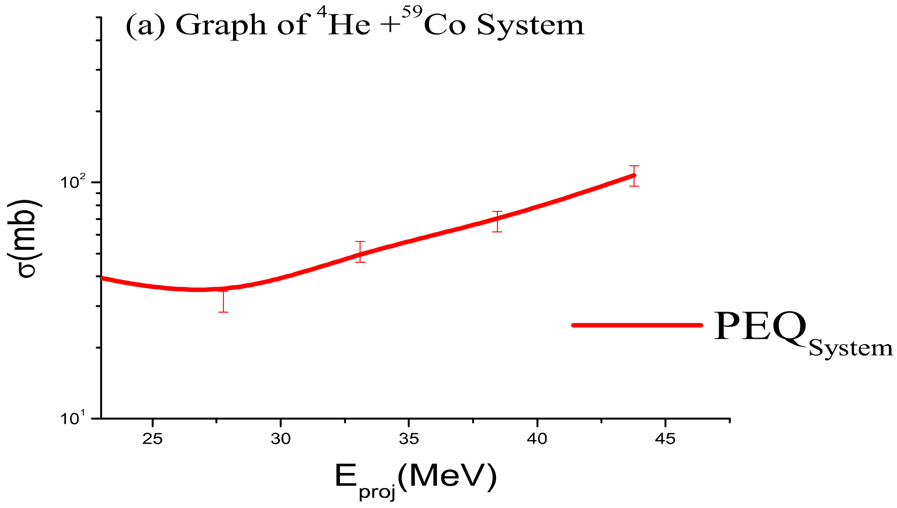

Fig.4.3: Contribution of pre-equilibrium emission for ^{4}He + ^{59}Co (total) system as a function of projectile energy.

Figure 4.4 (a)-(b) display the PEQ contributions of (α, n), (α, 2n) and (α, 2p) channels as a function of projectile energy. It may be observed from figure 4.4 the channel based contribution of PEQ emission, in general is found to increase with projectile energy. Furthermore, the threshold of PEQ emission for (α, n), (α, 2n) and (α, 2p) channels is found to be different, depending on the corresponding Q-value.

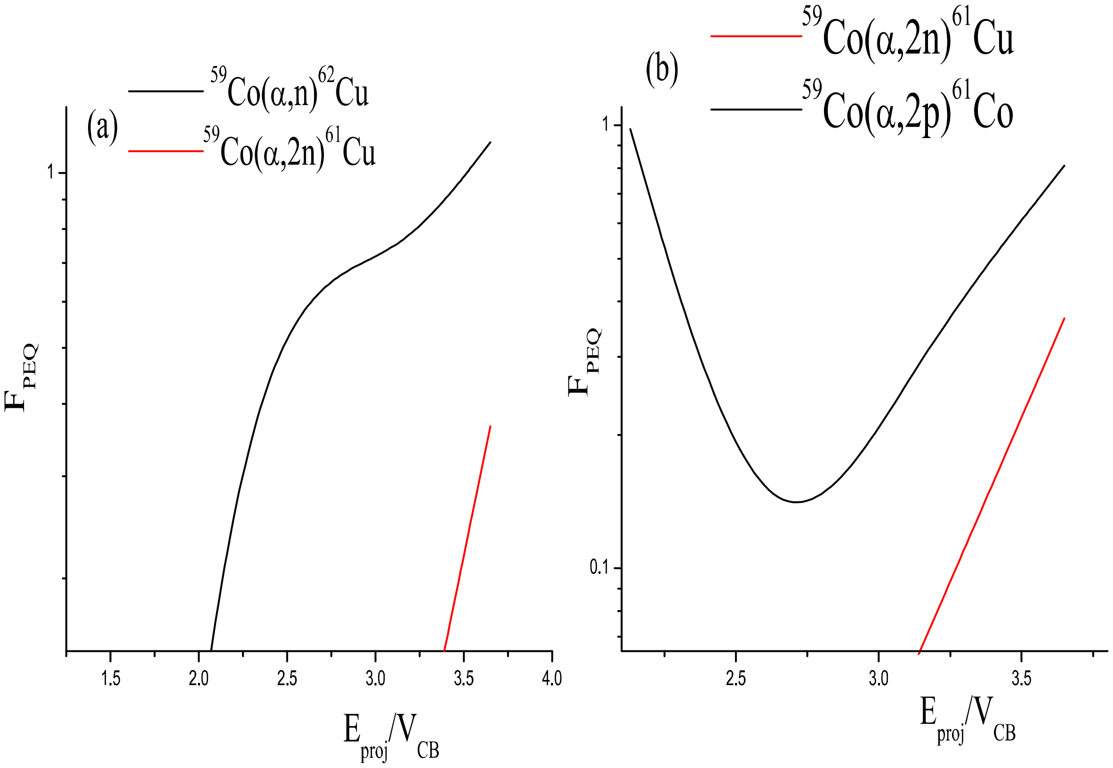

Fig.4.4: Calculation of pre-equilibrium fraction for different channels as a function of normalized projectile energy in ^4He + ^{59}Co system.

The Cuolomb barrier tends to cut off the low-energy portion of proton spectra thus reducing the number of equilibrium protons.

However, it may be pointed out that the PEQ contribution is found to be greater for the channels that consists of fewer PEQ particle(s). This may be attributable to the probability of single-particle emission is greater in PEQ emission process.

Conclusion

In this work the excitation function of ^{62}Cu, ^{61}Cu, ^{60}Cu, ^{61}Co, $^{58}Co^m$ and ^{57}Co residues populated in the interaction of ^4He + ^{59}Co system were investigated at beam energies ~ 11-41 MeV in order to study the mechanisms of pre-equilibrium emission. The experimentally measured excitation function available in the literature, were compared with the theoretical calculations done using the statistical model code COMPLET. It should be further pointed out that a set of level density(K=8), exciton number (n_o=4) with mean free path(MFM=1.0) is found to give a satisfactory reproduction of the theoretical calculation. The percentage PEQ contribution for individual reaction products is found to be sensitive to the Q-value of the reaction channels and the PEQ the particle multiplicity. As such, we conclude that the PEQ emission is an important mode of reaction in light ion induced reactions at the studied energies. In general, it is quite obvious from the present investigation at higher energy points the pure compound nucleus prediction in general failed to reproduce the measured data at projectile energies ~ 11-41MeV and disclosed significant contributions from pre-equilibrium emission.

Further, the threshold of pre-equilibrium emission for different reaction channels is found to be different, depending on the associated Q-value.

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References

[1] K.Heyde, Basic idea and Concepts in Nuclear physics second edition (1999).
[2] Satheesh B., PhD. Thesis, Department of physics University of CalcutKerale 673 635 India (2012).
[3]C.Rubbiaet.al.,ConceptualDesignofaFast Neutron operated highpowerenergyamplifier,Report CERN/AT/95-

94(ET)
[4] M.M. Musthafa, Manoj Kumar Sharma, B.P. Singh, R.Prasad, Applied Radiation and Isotopes 62(2005) 419.
[5] KraneKenneth S. IntroductoryNuclearPhysics,UnitedStateofAmerica,(1988)
[6] Hem Chandra Panday,PhD. Thesis, G.B.Plant University of Agriculture and Technology, India(2015)
[7] J. Wilczynski, K. Siwek – Wilczynska, J. VanDriel, S., Gonggrijp, D. C. J. M. Hageman, R.V.F. Janssens, J. Lukasiak, R. H. Siemssen, S. Y. Van der Werf, Nucl. Phys.**A373**, 109 (1982).
[8] N.L.Singh,D.J.Shah, S.Mukherjee(*) and S.N.ChintaLapudi(**) physics Department, Faculty of Science M.S. University of Baroda.Vadodara 390002,India(1997).
[9] Anika and Saxcna, Advances in applied Science research, 6(2015):199-203
[10] EXFOR data source IAEA, Vienna (2004)
[11] DesalegnKetema, Msc.Thesis, A.A.U,Ethiopia(2013).
[12] MarituDagnaw, MSc.Thesis, HU, Ethiopia (2017).
[13] WubishetGezahegn, MSc.Thesis, A.A.U,Ethiopia(2011).
[14]P.E.Hadgson,E.GadioliandE.GadioliErba,Introductory Nuclear Physics, Oxford Press,2003.
[15] EjiguKebede, Msc Thesis, A.A.U,Ethiopia(2014).
[16] M. Cavinato, E. Fabrici, E. Gadioli, E. GadioliErba, P. Vergani, M. Crippa, G. Colombo, I. Redaelli, and M. Ripamonti, Phys. Rev. C **52**, 2577 (1995).
[17] E. Gadioli, C. Brattari, M. Cavinato, E. Fabrici, E. GadioliErba, V. Allori, A. Di. Fillippo, S. Vailati, T. G. Stevens, S. H. Connell, J. P. F. Sellschop, F. M. Nortier, G. F. Steyn, and C. Marchetta, Nucl. Phys. **A641**, 271 (1998).
[18] D. J. Parker, J. J. Hogan and J. Asher, Phys. Rev. C **39**, 2256 (1989).
[19] P. E. Hodgson, E. Gadioli, and E. GadioliErba, *Introductory Nuclear Physics* (Oxford University Press, London, 1997), Chap. 18.
[20] I. Tserruya, V. Steiner, Z. Fraenkel, P. Jacobs, D. G. Kovar, W. Henning, M. F. Vineyard, and B. G. Glagola., Phys. Rev. Lett. **60**, 14 (1988).
[21] M. Blann, NEA Data Bank, Gif-sur-Yvette, France, Report PSR-146, (1991).
[22] V. F. Weisskopf and D. H. Ewing, Phys. Rev. **57,** 472 (1940).
[23] N. Bohr, Naturwiss, **24**, 241 (1936).
[24] K. Chen, G. Friedlander and J. M. Miller, Phys. Rev. **176**, 1208 (1968)
[25] H. Feshbach, A. K. Kerman and S. Koonin, Ann. Phys. (N. Y.) **125,** 429 (1980).
[26] J. J. Griffin, Phys. Rev. Lett. **17**, 478 (1966).
[27] K. Chen, G. Friedlander, G. D. Harp and J. M. Miller, Phys. Rev. **166**, 949 (1968).
[28] G. D. Harp and J. M Miller, Phys. Rev. **C3,** 1847 (1971).
[29] E. Gadioli, E. Gadioli -Erba and P.G. Sona, Nucl. Phys. **A217**, 589 (1973).
[30] M. Blann, Phys. Rev. Lett. **27,** 337 (1971); **27**, 700(E) (1971); **27**, 1550(E) (1971).
[31] M. Blann, Phys. Rev. Lett. **28,** 757 (1972).
[32] H. W. Bertini, G. D. Harp and F. E. Bertrand, Phys. Rev. **C10,** 2472 (1974).
[33] L. Avaladi, R. Bonetti and L. Colli-milazzo, Phys. Rev. Lett. **94B**, 463 (1980).
[34] G. M Field, R. Bonetti and P.E. Hodgson: J. Phys. G. **12,** 93 (1986).
[35] P.E.Hodgson: Workshop on Applied Nuclear Theory and Nuclear Model Calculations for Nuclear Technology Applications. Report ICTP, SMR/, 284 (1988).
[36] R. Serber: Phys. Rev. **72**, 1114 (1974).
[37] M. Blann, Phys. Rev. Lett. **21,** 1357 (1986).
[38] C. Kalbach –Cline and M. Blann, Nucl. Phys.**A 172,** 225 (1971).
[39] M. Blann, Ann. Rev. Nucl. Sci. **25**, 123 (1975).
[40] C. Kalbach – Cline, Nucl. Phys. **A210,** 590 (1973)
[41] F. C. Williams Jr., Nucl. Phys. **A166,** 237 (1971).
[42] C. Kalbach-Cline and M. Blann, Nucl. Phys. **A172**, 225 (1971).
[43] M. Blann, Phys. Rev. Lett. **27**, 6 (1971).
[44] M. Blann and H. K. Vonach, Phys. Rev. **C28**, 1475 (1983).
[45] M. Blann: Lecture given in " Workshop on Calculations for Nuclear Technology Applications" 15 February – 18 March (1988). ICTP, Trieste (ITALY).
[46] K. Kickuchi, and M. Kawai: "*Nuclear Matter and Nuclear Interactions*"(North– Holland, Amsterdam, 1968).
[47] G. D. Harp, J. M. Miller and B. J. Berne, Phys. Rev. **165**, 1166 (1968).
[48] R. D. Myers: Droplet Model of Atomic Nuclei (Plenum, New York, 1977).
[49] A. Avinash: PhD Thesis, Aligarh Muslim University, Aligarh (2004).
[50]. A. Chevarier, N. Chevarier, A. Demeyer, G. Hollinger, P. Pertossa, and T. M. Due, Phys. Rev. **C8**, 2155 (1973).

[51].J. Wilczynski, K. Siwek-Wilczynska, J. Van Driel, S. Gonggrijp, D.C. J. M. Hageman,R. V. F. Janssens, J. Lukasiak, and R.H. Siemssen, Phys. Rev. Lett. **45** (8), 606 (1980).
[52].*Introduction to Experimental Nuclear physics* (Wiley Eastern Private Limited, Delhi, 1974).
[53] .H. A. Bethe, Phys. Rev. **50**, 332 (1936).
[54] .W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).
[55] .N. Bohr and J. W. Wheeler, Phys. Rev. **56**, 426 (1939).
[56] .S. Cohen, F. Plasil and J. Swiatecki: Ann. of Phys. (N.Y.) **82**, 557 (1974).
[57]. F. D. Becchetti and G. W. Greenless, Phys. Rev. **182**, 190 (1969).
[58]. S. Fukushima et. al., Nucl.Phys.**41**, 275 (1963).
[59]. D. G. Sarantites, Nucl. Phys. **A93**, 576 (1976).
[60]. M. Blann, Nucl. Phys. **A213**, 570 (1973).
[61]. T. D. Thomas, Phys. Rev. **116**, 703 (1959).
[62]. T. Ericson: Adv. Phys. **9,** 425 (1960).
[63]. M. Blann and G. Merkel, Phys. Rev. **B137**, 367 (1965).
[64]. D. Bodansky, Annu. Rev. Nucl. Sci. **12**, 79 (1962).
[65] E. Gadioli and E. GadioliErba: Nuclear Theory for Applications 1980, IAEA-SMR- 68/1, Vienna [1981] p. 3