CHAPTER I

INTRODUCTION

1.1. Importance of the Study of Nuclear Disintegration:

A detailed study of the interaction of high energy nuclear particles with complex nuclei leads to important results in understanding the structure of the target nucleus. The high energy data available at present differ markedly from anything which could have been expected on the basis of an extrapolation of the low energy experience. This is because of the fact that at higher energies the results are perhaps very sensitive to the details of interaction. Hence, an investigation of the characteristics of disintegrations of complex nuclei produced by very high energy particles may give reliable informations regarding the mechanism of disintegration as well. In addition to the informations regarding the structure of the nuclei and the mechanism of the nuclear disintegrations, we can also derive a few other important results as described below.

With the advent of high energy accelerators it has become possible to probe deeper into the structure of the nucleon in astonishingly profound manner. Several investigators[1-4] have confirmed that the nucleon consists of a dense 'core' surrounded by a virtual meson cloud. Characteristics of meson production in hadron-nucleus collisions can be investigated by analysing stars produced in high energy nuclear collisions. Various authors[5-7] have determined angular distribution of shower particles, the multiplicities and the coefficient of inelasticity by analysing stars produced in the interaction of high energy particles with complex nuclei. They have concluded that the production of mesons in high energy nucleon-nucleus collisions can satisfactorily be explained through the 'statistical' and 'Isobar' models in which the interaction is envisaged to take place between the incident particle and the individual constituents of the target nucleus. The two said mechanisms are found to contribute in the production of mesons in the energy range $\sim$(1→30) GeV. Further, from certain other studies it has been possible to establish that the interaction of energetic incident particles in the energy interval $\sim$ (1 — 25) GeV with the target nucleus takes place through the cascade mechanism instead of the 'tunnel' model.[8-9]

Recently, several investigators[10-12] have attempted to understand the mechanism of heavy fragment production in nuclear disintegration. It has been observed that the probability of emission of multiply charged particles ($Z \geqslant 3$) increases with primary energy.[13]

1.2. Importance of the Study of the Emission of Tritons and He-nuclei:

The problem of emission of fast He-nuclei and tritons is of considerable interest. This is because of the fact that the binding energies of He^3-nucleus and triton are small compared to the normal values expected in the case of other light nuclei. Therefore, it seems quite interesting to examine the mechanisms through which these particles can be emitted, particularly at very high energies. Moreover, there are other important facts at which one can arrive by considering their production at these energies. Few of them are described below.

The study of the emission of fast He-nuclei and tritons in the interaction of high energy protons with complex nuclei is an excellent tool from the point of view of elucidating the structure of the target nucleus. Indirectly it also helps to some extent in understanding the nature of pion-nucleon and nucleon-nucleon interactions inside the nucleus.

The problem of determining the abundance of He^3-nuclei in primary cosmic radiation is of considerable importance. Earlier workers while measuring the composition of cosmic rays came to the conclusion that He^3-nuclei are very scarce on the earth. Subsequently many more attempts have been made to measure the relative proportions of He^3 and He^4-nuclei. Different values for the ratios of He^3 to He^4-nuclei have been reported by them.[14-15] Recently, Rao and the Rochester group[16] undertook the study of the abundance of He^3-nuclei; they reported quite surprisingly a large yield of He^3 in cosmic radiation.

A knowledge of the abundance of He^3-nuclei in cosmic radiation is expected to throw some light on various important astrophysical questions, e.g., the nature of the cosmic-ray source, the age of the cosmic rays, their transformations in space and the possible energy dependence of their mean path lengths in space.[14]

He^3-nuclei in cosmic rays are supposed to be produced through the process of fragmentation. The fragmentation process in the case of cosmic-rays is believed to be the result of collisions of energetic heavy nuclei with the hydrogen present in the interstellar space. Any attempt to derive information about the origin of cosmic rays would, therefore, require the knowledge of the fragmentation cross-section which produces He^3-nuclei in the interaction of energetic heavy nuclei with hydrogen. This can be provided by the study of the production of He^3-nuclei in the interaction of energetic protons with the heavy nuclei of emulsion. This is because of the fact that the two "basic processes" through which He^3-nuclei are produced are essentially the same. The difference in the two cases is in the sense that the 'reference frames' in which the observations are taken are interchanged. Therefore, the informations derived from the experimental study on He^3-nuclei in proton and heavy nuclei collisions may become an extremely useful tool in interpreting the astrophysical questions mentioned earlier.

1.3. Process of Nuclear Disintegration:

Nuclear reactions induced by high energy particles in the energy region of a few hundred MeV to a few GeV have been described by Serber[17] and Goldberger.[18] The nucleus is considered as a 'Fermi gas' whose particles, the protons and neutrons, interact weakly with each other. It is assumed that the presence of other nucleons at the instant of collision of two nucleons does not influence directly the results of the collisions. According to the process of splitting of the nucleus as envisaged by Serber[17] the fast incident particle initiates a cascade of nucleon-nucleon collisions in the target nucleus. The de Broglie wave length for a particle of several hundred MeV is very much smaller than the dimensions of the nucleus. One can, therefore, visualise the incident particle trajectory inside the nucleus. Further, the nuclear collision time between the incident particle and a particle in the nucleus is short as compared to the collision time between the particles inside the nucleus. This suggests that the first step in the process can be regarded in terms of collisions between the incident particles and the individual constituents of the nucleus.

As a result of these collisions the development of intra-nuclear cascade of fast protons and neutrons takes place inside the nucleus. Finally, the target nucleus is left in a highly excited state which subsequently evaporates into nucleons and complex nucleon aggregates. Thus, if the incident energy is about a few GeV, the nuclear reactions can be described by two step model (Intranuclear cascade and succeeding evaporation cascade). This two step model predicts four categories of reaction products:[19] (1) Prompt cascade-nucleons emitted with a broad spectrum of kinetic energies ranging upto the maximum energy of the bombarding particle. It is possible that α-particles or complex aggregates of nucleons existing in the nucleus as transient substructure of clusters may be emitted from it. (2) Evaporated nucleons or nucleon aggregates emitted symmetrically in the centre of mass system with an energy spectrum characterised by the coulomb barrier and the nuclear temperature. Neutrons, α-particles and light nuclei are mostly produced in the evaporation cascade. (3) Fission products. (4) Evaporation residues.

The nucleons of the intra-nuclear cascade do not only interact with nucleons of the nucleus but also with complex structures like deuterons and α-particles. Rotenberg and Wilets[20] have indicated that the probability of production of nucleon complexes is considerable in the peripheral region of the nucleus where the density of the nuclear matter is low. The existence of clusters in the nuclear surface can be understood in terms of the nuclear density. The nucleons in the outer region of the nucleus where the nucleon density is low, are obviously less affected by the Pauli principle than those in the central part.

The decrease in the nuclear density near the nuclear surface, according to Bethe,[21] may be accompanied by the condensation of nucleons into actual groups or clusters. The idea of the existence of 2 and 4 nucleon clusters within the nucleus is also supported by various experiments.[22-29] The appearance of the light fragments among the emitted particles and their angular distribution suggest that there exist different types of complex particles or clusters inside the nucleus.

Quasi-free collisions which are accompanied by the knock-out of only one nucleon are very significant. A study of the quasi-free collision gives information about intra-nuclear nucleon momentum distribution. This process can be taken as a possible mechanism for the production of tritons and He^3-nuclei in quasi-free interactions of pions and protons with the nucleon of α-clusters. Knock-out mechanism described as a quasi-free collision between prompt cascade nucleons and α-clusters was suggested by Perfilow et al.[30] The work of Ostroumov et al.[31] on the emission of He^4-particles with energy >30 MeV in the interactions of 140, 200, 300 and 600 MeV protons with emulsion nuclei also indicates that He^4 are ejected in the collisions of the cascade nucleons with α-clusters.

Recent experiments have, however, shown that there are some phenomena which can not be described adequately by the two step model which suggests the necessity of considering the existence of an additional mechanism fundamentally different in nature.[19]

This mechanism has been referred to as 'fragmentation'. Fragmentation is believed to be a violent fast disruption of the nucleus which leads to the production of complex aggregates of nucleons with appreciable yield. Fragmentation may be fusion like process but differs from it in the angular, energy and mass distributions of the products. The process of fragmentation has been discussed in great detail by Perfilov et al.[30] The experimental studies by the authors have revealed many characteristic features of the process. Many theoretical approaches have also been made to explain the observed features of the fragmentation of nuclei at high energies.

1.4. Present Knowledge and the Scope of Work on the Emission of He-nuclei and Tritons:

From very early investigations on nuclear disintegrations in photographic emulsions, it was observed that quite a large proportion of particles emitted at low energies are α-particles. Harding et al.,[32] Page,[33] Perkins[34] and Bernardini et al.[35] have made extensive studies on the emission of α-particles from nuclear disintegration. At energies below 30 MeV, the α-particle to proton ratio has been obtained as 0.36. These α-particles have been observed to be istropically distributed and they are emitted as evaporation products from the excited nucleus. Camerini et al.[36] have observed appreciable yield of tritons emitted from the stars produced by cosmic rays. Tritons upto energies above 1 GeV have been observed by them.

Sorensen[37] has obtained the energy spectrum and angular distribution of doubly charged particles, in the study of fast particles observed in nuclear emulsion from high energy nuclear disintegration. From the experimental study of the problem he has concluded that these He-nuclei do not arise from a direct interaction between the primary particle and the target nucleus, but by secondary process in which the cascade nucleons participate in the reaction.

Yasin[38] has shown from the study of high energy nuclear disintegrations produced by cosmic-rays that the He-nuclei emitted in the energy interval of (80-500) MeV are predominantly He^3. It has been further observed by the author that the frequency of emission of He^3-nuclei and tritons, in the said energy interval, are almost equal. The differential energy spectrum of He^3-nuclei has been found to be similar to that of tritons in the same energy interval. The author has also been able to explain satisfactorily his experimental results on fast He-nuclei and tritons on the basis of the absorption of pions in nuclear alpha-clusters present in the outer region of the nucleus.

With the availability of mono-energetic beams of high enery particles, the study of the particle production in high energy collisions using different targets were made at CERN and Brookhaven.[39-42] Besides other energetic particles, He-nuclei and tritons were also observed in these high energy experiments.

Gilly et al.[40] in their experiment at 25 GeV proton energy observed tritons and He^3-nuclei of energy of a few GeV. They have also obtained equal frequencies of emission for these particles. They have not observed He^4-nuclei at these energies.

In the study of the disintegrations caused by 19.5 GeV and 9 GeV protons with emulsion nuclei, He-nuclei in the momentum range (0.2 - 4.5) GeV/c have been reported by Takibaev et al.[43] They are of the view that the emission of fast He-nuclei in the above mentioned energy interval is related with the nuclear cascade process.

Egli et al.[44] in the study of disintegrations produced by 22 GeV/c proton in freon bubble chamber have observed that majority of He-nuclei observed in the energy range $\sim$(275-600)MeV are of mass number three. They have concluded that pion-absorption in α-clusters can contribute only upto a maximum of 10% of the observed yield of He^3-nuclei. They have attempted to explain the emission of He^3-nuclei in the said energy interval through 'pick-up' process. The energy spectrum obtained by using 'pick-up' mechanism is in fair agreement with the observed one. The transverse momentum for He^3-nuclei determined theoretically using pick-up mechanism is in reasonable agreement with the experimental value.

It is worthwhile mentioning that simultaneous emission of two helium tracks from the same star has been observed by

Egli et al.[44] Takibaev et al.[43] have also reported the emission of double tracks of He-nuclei in the energy range (100-200) MeV produced in the interaction of 19.5 GeV proton with heavy emulsion nuclei. It is, however, important to note that the production of track pairs in the same star has not been found in the interaction of 9 GeV protonswith the heavy nuclei of emulsion.[43]

It has been observed by Takibaev et al.[43] that the production cross-section of He-particles, their angular and energy distributions do not depend on the energy of the incident protons. The production cross-section of He-nuclei has been observed by Egli et al.[44] to depend on the mass number of the target nucleus. It is of interest to mention that the production of He-nuclei on mass number depends as $A^{5/3}$. Furthermore, the frequency of He-nuclei increases with the increase in the number of grey and black tracks in stars in proton-bombarding energy range of (2-20) GeV. This conclusion has been found to be true even for the emission process of He-nuclei during anti-proton interactions with emulsion nuclei.

Thus, we notice that the theoretical approaches made by various workers for the interpretation of the experimental results on the emission of He-nuclei in the energy interval ~ (50-2500) MeV are different in their basic assumptions. As regards the experimental situation we notice that in the energy interval (50-500) MeV the results are based on cosmic-ray experiments in which neither the identity of the incident particle nor its energy is known. This, therefore, necessitates to investigate the characteristics of nuclear disintegration in detail pertaining to the problem of emission of fast He-nuclei and tritons in the energy interval ~(50-450) MeV. The following points of great practical importance should, therefore, be thoroughly considered in order to arrive at definite conclusions regarding the production of these particles.

Firstly, the fact that the production cross-section of He-nuclei and their energy and angular distributions do not depend on the incident proton energy seems rather strange. This problem, therefore, deserves to be examined very carefully. This can conveniently be checked by carrying out a detailed investigation of the problem at different energies with improved statistics.

Secondly, the absence of double tracks of He-nuclei in the interaction of 9 GeV protons with emulsion nuclei appears very surprising. This is because of the fact that double tracks of He-nuclei from the same nucleus have been observed in the interactions of 19.5 and 22 GeV protons with complex nuclei. Presumably the former observation may be attributed to low statistics available in the experiment. But if it actually turns out that the production of double tracks of He does not take place around 10 GeV proton energy then it would be quite interesting to examine the possible reasons for it.

Thirdly, it is significant to check the dependence of the production cross-section of He-nuclei on mass number of the target nuclei. This can conveniently be studied by investigating the production of these particles on light and heavy nuclei of emulsion.

Fourthly, the most important problem of determining the abundance of He^3-nuclei produced in high energy nuclear collision can be settled by analysing statistically the experimental data on He-nuclei.

Finally, the mechanisms proposed so far to explain the production of fast He-nuclei and tritons are in contradiction with each other. Therefore, it seems quite interesting to examine the mechanism through which these particles can be emitted.

The work described in this thesis is the result of a systematic investigation of the emission of fast He-nuclei and tritons produced in the interaction of 24 GeV/c protons with heavy nuclei of emulsion to study some of the above mentioned problems in greater detail.

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