# CHAPTER V

## SUMMARY AND FINAL REMARKS

As mentioned earlier, a detailed investigation of the disintegrations produced by high energy nuclear particles leads one to understand the process of disintegration, the mechanisms for the production of different particles, the structure of the target nucleus and various other phenomena of considerable interest. Keeping these objectives in view we have attempted to investigate the characteristics of the disintegration stars caused by 24 GeV/c protons in G-5 emulsion. The study of the emission of fast tritons and He-nuclei has been of major interest to us. We have also presented the characteristics of the emitted protons with energies greater than 30 MeV. The work presented in this thesis is expected to serve as a step forward in order to study the above mentioned problems.

The present investigation has been carried out using the nuclear emulsion technique. The emulsion consists mainly of two groups of nuclei: the light group consisting of C,N,O nuclei and the heavy group mostly of Ag and Br nuclei. The separation of the disintegration stars produced by the incident particle on the light and heavy nuclei have been attempted by using the heavy prong number, $N_h$, as the distinguishing feature. The stars with $N_h \geqslant 7$ have been taken to be unambiguously due to the heavy nuclei. On the other hand, the stars characterised by $N_h < 7$ have been taken to be due to the light nuclei. However, this selection criterion does not give an unbiased group of stars belonging to the light group. The stars selected according to this criterion would be contaminated by the stars produced due to the heavy nuclei. It has been found that about 50% stars with $N_h < 7$ belong to the heavy group. The emission of He-nuclei has been observed by Takibaev et al. to take place in stars with $N_h > 8$. This result is expected because the emission frequencies of energetic He-nuclei and tritons have been found to increase with the heavy prong number, $\bar{N}_h$. The sample of stars selected by us for the study of emission of energetic tritons and He-nuclei would, therefore, not be a biased one.

For carrying out the analysis of the disintegration stars secondary tracks lying within our selection criteria were chosen for various measurements. The secondary tracks so selected were separated into singly and doubly charged groups by counting integral number of delta-rays over 800 $\mu$m residual ranges. The stopping particles have been identified by carrying out mass measurement by constant sagitta method. In addition to it, wherever possible, the specific ionization on the track of the particle together with its residual range have been measured. On the other hand, the identity of a non-stopping particle has been established by measuring the multiple coulomb scattering parameter, $\bar{\alpha}$, and the specific ionization, $g^*$. It may be pointed out that the resolution in the parameters defining the identity of the particles as deduced from various types of measurements is sufficiently good.

The following important conclusions have been drawn from the study of the characteristics of the emitted protons in the energy interval (30 - 250) MeV.

From the study of the angular distribution of the secondary protons in the above said energy interval it has been observed that the distribution is an-isotropic. If these particles were to be produced through the evaporation process then the angular distribution would have been isotropic. Thus, the angular and the energy distributions of the secondary protons suggest that these protons are not produced through the evaporation process. From a qualitative study of the grey tracks we have come to the conclusion that they are produced through the cascade mechanism. It has been observed that the transverse momentum distribution of the secondary protons obeys a Boltzmann-type of law. The average transverse momenta of He-nuclei and tritons have been observed to be approximately twice the value of the average transverse momentum of the secondary protons with the same cut-off momentum. Furthermore, the mean transverse momentum of the secondary particles has been observed to increase with their masses for all other particles.

For investigating ~~the~~ mechanism of interaction between an incident proton and the target nucleus we have determined various parameters with sufficiently good statistics. There are two mechanisms through which the interaction of incident particle with the target nucleus can be explained. These are the cascade and the tube mechanisms. In the cascade mechanism the incident particle is envisaged to interact with the individual constituents of the target nucleus. In the tube model the incident particle is visualised to interact with a group of nucleons simultaneously. The assumption that the interaction of the incident proton with the target nucleus takes place through the cascade mechanism predicts the value of $\theta^{o}_{s,1/2}$ to be 20° at 25 GeV in the case of heavy nuclei. The observed value is 24°. The two values are in fair agreement with each other. Further, the calculation for 25 GeV proton interactions with Ag and Br nuclei based on the cascade mechanism gives the value of $\theta^{o}_{g,1/2}$ and $\theta^{o}_{b,1/2}$ equal to 65 and 84° respectively whereas the experimentally observed values are 60 and 81°. Thus, we see that the two results are in reasonable agreement with each other. These observations, therefore, support the cascade model. Similarly, the mean number of shower particles produced on the heavy nuclei should be considerably larger than the mean number of shower tracks produced on the light nuclei if they were to be produced through the tube mechanism. But the observed numbers in the two cases differ very little with each other. This small difference in the mean numbers of shower tracks produced on the light and the heavy nuclei is understandable in terms of the cascade model. Moreover, the tube model cannot explain the events having the number of grey and black tracks $\sim 28$. This type of events have been found to be $\sim 4\%$ of the total stars with $N_h \geqslant 7$. Finally, the mean transverse momenta of grey particles produced in the interaction of incident protons with light and heavy nuclei have been observed to be almost equal. This result also favours the cascade mechanism. Thus, based on the above findings we conclude that the interaction of the incident protons with emulsion nuclei can be explained satisfactorily through the cascade mechanism.

The observed mean $\bar{D}$ for all the tracks of He-nuclei has been determined as $(0.305 \pm 0.005)\mu m$ while the calculated $\bar{D}$-values for $He^3$ and $He^4$ are $0.307 \mu m$ and $0.27 \mu m$ respectively. Thus, we see that the observed mean $\bar{D}$-value for the secondary He-nuclei is three standard deviations away from the calculated $\bar{D}$-value for $He^4$-nuclei. These observations suggest that majority of the He-nuclei observed in the present work are of mass number three. In order to estimate the relative proportions of $He^3$ and $He^4$-nuclei, $\chi^2$- test of the $\bar{D}$-distribution under the assumption of different mixture ratios of $He^3$ and $He^4$ has been performed. When we assume 100% $He^3$-nuclei and no $He^4$ then we get the best approximation ( $\chi^2$-minimum). The probability, corresponding to the above assumption has been estimated to be ~ 80%. This probability is reduced to 45% if we assume that 25% of the sample of He-nuclei consists of $He^4$. Thus, one can also conclude from this analysis that most of the He-nuclei in the energy interval (50-450) MeV are $He^3$. This is further supported by the following considerations. If we assume that $He^4$-nuclei are produced through diffraction scattering of cascade nucleons and pions on $He^4$-clusters supposed to exist in the peripheral region of the nucleus then we find that about 10% of the investigated He-nuclei should be $He^4$. Therefore, we conclude that about 90% of the observed He-nuclei in the above mentioned energy range are $He^3$.

The star size distributions for the stars emitting He-nuclei and for all other stars have been observed to be quite different. It is interesting to note that the emission frequency of He-nuclei increases with the increase in $N_h$ value. The mean value of the heavy prong number, $\bar{N}_h$, has been found to increase by ~ 60% in case of He emitting stars with respect to the $\bar{N}_h$ value for all other stars.

The fact that He-nuclei track pairs are produced around

20 GeV is also supported from the present investigation. Six track pairs of He-nuclei in the energy range considered in the present work have been observed giving an yield which is rarer by an additional yield factor, f, where f denotes the yield per star for the single tracks. This observation leads to the understanding that the two He-nuclei from the same star are produced independent of each other. It should be noted that the track pairs of He-nuclei have been observed in stars with $N_h \geq 18$ having the mean heavy prong number $\bar{N}_h = 24$.

From the study of the angular distribution of the investigated He-nuclei the average angle of emission with respect to the primary has been found to be $62^{\circ}$. The mean angles of emission of He-fragments with energy greater than 100 MeV produced in the interactions of 9 and 19.5 GeV protons with heavy nuclei of emulsion have been reported to be $54 \pm 5$ and $54 \pm 4$ respectively. The difference in the mean values of the angle of emission in the present work and in the other experiment may be due to the fact that the energy range of the He-nuclei in the latter case is considerably higher.

The shape of the energy spectrum of the secondary He-nuclei has been observed to be similar to that obtained by other authors at widely different energies of the incident particles. The exponents of the energy spectra of He-nuclei in the present work, in the investigations at 22 GeV/c and in the cosmic-ray experiments have been found to be almost equal within the experimental errors. This together with other informations lead to the conclusion that the frequency of emission and the angular and energy distributions of He-fragments perhaps do not depend on the primary energy.

From the study of the emission of tritons in the energy range (50-450) MeV the frequency of emission of tritons has been found to be equal to that of $He^3$-nuclei even if we consider the presence of $He^4$ to the extent of 10% of the total He-nuclei identified in the present experiment. The energy and angular distributions have also been observed to be similar to that of $He^3$-nuclei in the same energy interval. The average angle of emission of tritons in the said energy interval has been observed to be $61^\circ$. This closely agrees with the value obtained for He-nuclei. The mean number of grey and black tracks, $\bar{N}_h$, in the stars emitting tritons has been observed to be 21.3, while in the case of stars emitting He-nuclei its value is 20.6. Thus, the two values are equal to each other within the experimental error. The average transverse momenta of these particles are also equal within experimental error. All these observations, therefore, suggest that the mechanisms responsible for the production of these particles are similar. We now proceed to present the results of the investigation regarding the mechanism of emission of these fragments.

As mentioned earlier the energy of the particles emitted through the evaporation process lies much below 50 MeV and the angular distributions of these particles should also be isotropic. The energy interval covered here is considerably higher than the energy of the particles produced through evaporation. Further, the angular distributions of the investigated particles are anisotropic. Thus, we see that our experimental results cannot be interpreted in terms of the evaporation process. We have, therefore, excluded the evaporation process for explaining the production of these particles.

The idea that energetic $He^3$-nuclei and tritons may be produced in the direct interaction of primary with a nucleon or a nucleon substructure like d, t and $\alpha$-particle has not met with success. This is because of the fact that the energy of the particles supposed to be produced through this process would lie in the evaporation range. Another process which one can think of for the production of fast tritons and He-nuclei is the knock-out mechanism. The knock-out mechanism is described as a quasi-free collision between the cascade nucleons and the substructures like d, t and alpha-particle.

On binding energy considerations the probability of existence of four-nucleon clusters should be larger compared to the three-nucleon clusters. Therefore, if these particles were to be produced through the knock-out mechanism then the number of $He^4$-nuclei amongst the observed ones should be quite large compared to $He^3$ which is contrary to our observations. Therefore, the emission of these particles cannat be explained through the knock-out mechanism.

Fast tritons and He-nuclei may also be envisaged to be produced in the interaction of cascade nucleons with the nucleon clusters. It has been observed that the interaction of cascade nucleons with di-nucleon clusters cannot account for the experimentally observed triton to proton ratio. Similarly, the inelastic scattering of cascade nucleons with four-nucleon clusters cannot explain the production of these particles in the energy interval considered in the present investigation.

The emission of fast $He^3$-nuclei and tritons may be explained through the pick-up process. According to which any three cascade nucleons whose relative momenta are less than a certain value $\rho$ may coalesce into a triton or a $He^3$-nucleus. This model has been found to explain fairly well various experimental results like energy spectrum and mean transverse momentum of $He^3$-nuclei. Further, the fact that the frequencies of emission of tritons and $He^3$-nuclei in the same energy interval are equal also supports the pick-up model. But at the same time in an attempt to explain the experimental yield of $He^3$-nuclei the value of the parameter $\rho$ has been observed to be in disagreement with the expected value. According to this model the value of this parameter should be small as compared to the momenta of the cascade nucleons forming these fragments. Thus, one of the basic assumptions of the model is violated. Therefore, the fine agreement in the values predicted by this theory for various parameters and those obtained experimentally should be taken with caution. It may, however, be noted that further refinement of the theory may reproduce the experimental results with a more reasonable value for $f$ .

The production of fast tritons and $He^3$-nuclei may also take place through the absorption of the cascade pions by $\alpha$-clusters supposed to exist in the periphery of the nucleus. This mechanism also explains the experimental results quite nicely. It is further supported by the observation that there occurs an additional decrease in the $\bar{N}_s$ value in the case of stars emitting $He^3$-nuclei as compared to the corresponding values for all other stars. We, therefore, conclude that the energetic $He^3$-nuclei and tritons, atleast partly if not wholly, are produced through the absorption of cascade pions by $\alpha$-clusters of the nucleus. Based on this observation it can be said that the nucleons in the nucleus mostly exist in the form of $\alpha$-clusters.

Since the statistics on $He^4$-nuclei was not sufficient, therefore, we have not tried to investigate the mechanism of production of these particles thoroughly. But the analysis of our data on He-nuclei reveals that the production of fast $He^4$-nuclei may be envisaged to take place through the diffraction scattering of the cascade nucleons and pions on $He^4$-clusters.

There seems to be quite wider scope for the investigation of the emission of energetic He-nuclei and tritons using different target nuclei of lower mass numbers and at widely different incident energies in the GeV range.