CHAPTER IV.

Characteristic of nuclear interactions.

4.1 Introduction

Nature of the nuclear interaction depends upon the incident momenta, type of the projectile and on the target nucleus. At high incident energy, particle production takes place which produces shower tracks and the target nucleus disintegrates. A large fraction of the incident energy is spent in the particle production\(^5,6,3,14\) which can be estimated from the number of particles produced and from their nature of angular distribution. But below the threshold energy for meson production, the nucleus may simply disintegrate without particle production and the particle emission takes place in the statistical process as predicted by the evaporation theory. Evaporation theory was first developed by Bohr\(^5\) (1938) and later modified by LeCouteur\(^16\) (1958). According to this theory, the nuclear disintegration occurs through two steps. In the first stage known as the cascade stage, the incoming particle undergoes an elastic or inelastic
collisions with an individual nucleon in the nucleus and a large amount of energy are absorbed by the target nucleus. It is also possible that the bombarding particle escapes after only a single collision carrying off most of its original energy. In the end stages, the excitation energy of the struck nucleon is dissipated by successive evaporation of several neutrons, protons, other particles and with lesser probability, the ejection of nucleons known as heavy fragments, each after an interval of \(10^{-17}\) sec.

The created particles during the cascade stage produce shower tracks which show their ionization in emulsion, \(70\%\), of the shower tracks are pions \(^67\). The particles emitted due to the collision at the end of the cascade stage and also the energetic particles emitted during the evaporation process produce grey tracks. About \(5\%\) of the grey tracks are due to \(\pi\)-mesons. The grey tracks are produced by protons, deuterons, tritons etc. The slow particles emitted during the evaporation process produce black tracks.

A general study of the distribution of these tracks, their multiplicities and angular distribution with respect to the primary direction show important features of the nuclear reactions from which general conclusion about the reaction is drawn.


Experimental procedure

The emulsion strip was area scanned using objective of 18.5 x in conjunction with the eye-piece 10x. The diameter of the field of view was 1000 μ. All the stars produced by the primaries were recorded and each was examined under higher magnification of the order of 2000 x using the oil immersion objective. In each star, primary was identified from its characteristics of minimum ionization and parallel to the emulsion plane. In the experiment, only those stars that lie in between 50 μ from the surface and 20 μ from the bottom were used for complete detection of shower tracks. The region of emulsion beyond these limits show distortions because of non-uniform development during processing process, and any measurement made here is unreliable. The flux of the particles measured across the emulsion cell is 9 x 10^4 per μ. As the particle flux was high, it was not difficult to search the primary stars. In recording 1400 stars, 1180 were found with primaries. The relations 'E' and 'E' of Chester-III were used for the measurement of the ionization.
To measure the ionization of the relativistic particle, grain density for 100 length of 50 primaries that were all parallel to the emulsion plane were counted and the average value found is 22 grains per 100 . This value was used for the determination of grain density to distinguish the different types of tracks of charge particles. However, for accurate distinction of the tracks of particular star, the value of of primary associated with that star was also used in some cases. This makes tracks distinction clear, because the grain density of primary vary by a few grains for different primaries in different regions of the emulsion.

4.3 *Experimental results*

Fig (5) shows the distribution of the stars drawn counting only black prongs which have ranges more or equal to 10 μ, the recoils being neglected in each case. The average value of is (8 ± 2) and the average excitation energy of the emulsion nuclei is (378 ± 11 ) MeV. This value is calculated from the relation $E=4E(n_b+1)$ MeV of the evaporation theory of nuclear disintegration. From the figure, it can be seen
FIG-5. Black prong distribution of general stars produced in interaction of 18 GeV/c K meson with the emulsion nuclei.
that major nuclear reactions have taken place in light emulsion nuclei (CNO). Fig (6) shows the grey track distribution which shows that the maximum number of grey track is four. Angular distribution of grey tracks in the laboratory system is shown in the fig (7). The (F/B) value of the grey track is $1.9 \pm 0.21$. This value shows that the angular distribution is somewhat isotropic. The anisotropy of angular distribution is not due to the forward velocity of the evaporating nucleus which is of the order of $0.06c$. This is caused by the particles emitted forward during the cascade stage of the nuclear disintegration. Shower tracks produce thin ionization in the emulsion which can be easily distinguished visually. When the grain density is large, it can be distinguished from the grey tracks by making actual grain counts from either of the relation (i) and (ii). In the present case, shower tracks were not found with each star though the primary was present. The shower track distribution is given in the fig (8) which shows
FIG-6: Distribution of grey tracks produced in interaction of 18 GeV/c $k^-$ meson with emulsion nuclei.
FIG-7. Angular distribution of grey tracks produced in interaction of 1.8 GeV/c \( k \) meson with the emulsion nuclei.
in the fig (8) which shows that the maximum number of shower track is only three. The angular distribution of the shower tracks in the laboratory system is given in fig (9) which shows that 56% of the tracks are emitted at angle ~ 0° with respect to the primary direction. Only a few shower tracks are emitted backward with angle greater than 90° with respect to the primary.

In fig (10), a plot of the multiplicity $n_s$ of the shower tracks against the corresponding number of heavy prongs $N_h$ (sum of black and grey prongs) is shown. A graph is drawn through the experimental points by the method of least square fit. The relation between the shower multiplicity $n_s$ and the $N_h$ is calculated as

$$n_s = -0.0045 N_h + 1.16 \quad \text{................................. (1)}$$

The above equation shows that multiplicity does not vary significantly with $N_h$. The result seems to show that particle production is independent of the $N_h$ which are produced during the cascade and evaporation stages of the nuclear disintegration.

According to the plural theory of particle production, shower
FIG-8. Distribution of shower tracks produced in interaction of 1.8 Gev/c $\bar{K}$ meson with the emulsion nuclei.
FIG-9. Angular distribution of shower tracks produced in interaction of 1.8 Gev/c k meson with the emulsion nuclei.
FIG-10. Plot of shower multiplicity $n_s$ against $N_h$, the number of heavy prongs of the general stars produced by the interaction of 1.8 GeV/c $k$ meson with the emulsion nuclei.
particles are produced due to the several collisions of the parent particle with the nucleons as well as due to the collisions of the cascade nucleons with other nucleons of the nucleus during their passage through the nucleus which occurs in about $10^{-22}$ sec. In this case, correlation between shower multiplicity and heavy prong number may be expected. The absence of such correlation in the present case indicates that shower particles are produced by another mechanism known as Multiple theory$^{59, 60}$ of particle production. According to this theory, shower particles are produced in the single collision of the primary particle with the nucleon of the nucleus. As a result, no correlation between $\bar{n}_p$ and $N_h$ will be observed.

4.4. Conclusion

Two stage cascade model of nuclear disintegration can explain the present experimental results which show $n_p$-distribution and the angular distribution of gray tracks in agreement with the prediction of the theory. The angular distribution of the
shower tracks shows that there were produced by the direct inelastic interaction of the primary with the target nucleus in which 66% of the shower tracks are emitted nearly along the direction of incident particle. This collimated nature along the primary direction is the direct evidence of the shower production with the interaction of the primary with the nucleon of the nucleus during the cascade stage. The absence of any correlation between $n_s$ and $n_h$ indicates that shower particles are produced due to the single collision of the primary with the nucleon of the nucleus, favouring the theory of multiple production of particles.