CHAPTER IV

RECOILS ASSOCIATED WITH DISINTEGRATION STARS

4.1 INTRODUCTION :

In high energy nuclear disintegration of heavy emulsion nuclei of silver and bromine, stars are often found to contain a single short track showing very dense ionisation. They are assumed to be recoils or spallation residue. From the studies of a number of workers[1,2] it is concluded that most of them are due to the residual nuclei or recoils left when the original excited nuclei are cooled down by particle evaporation or by emission of Gamma rays[3,4]. According to cascade evaporation model of nuclear interactions, the high energy incident particles generate the cascade process in the struck nucleus and carries it to a highly excited state. The struck nucleus gathers a forward velocity due to the impact of the energetic incident particles. This stage is followed by particle evaporation and nucleus receives random impulses from the evaporated particles. The nucleus left after this evaporation process recoils producing a short and dense track. The ranges of recoils of residuals nucleus in G5 emulsion seldom exceeds 10 microns[5], but it may be more due to the number of factors, such as, (1) a residual nucleus receives a large amount of kinetic energy in the direction of its emission, (II) because of the statistical fluctuations in the direction of emission of particles or (III) because of the emission of the massive fragments in the opposite direction. The less massive recoils are likely to have larger ranges.

The studies on recoils cannot be made uniquely in emulsion because of the limitations in identifying the track with respect to their charge and mass in this detector. However, the errors can be minimised to a large extent by adopting proper selection criteria. Although the mass and charge of the recoils cannot be estimated individually an average estimate of their mass and charge could be made with sufficient accuracy by taking into account the values of the mass and charge carried away by the heavy ionising particles during the process of de-excitation of the struck nucleus.

In the present investigation effort has been made to study the characteristics of these recoils. Our aim is to see whether these characteristics have same similarity with those obtained for binary fission events. This may help us to make some conclusion on the production of fission.

Thus the study of the recoiling nuclei may in some cases be an excellent method for obtaining information about a nuclear reaction.

4.2 EXPERIMENTAL PROCEDURE AND SELECTION CRITERIA :

The K5 emulsion exposed to 1.8 Gev/c k^- has been used for this study. The pellicles have been area scanned under low magnification (X 15) to record the centres of disintegration stars containing an observable short track.

The events so collected by scanning are then examined with X100 oil immersion type of objective under a total magnification of 2000. The events lying within 20 microns from the surface are rejected and the centres of other stars are carefully scrutinised for presence of recoils. Now a short track of any mass (even a proton) ejected from the disintegrating nucleus may simulate a recoil which is nothing but the heavy spallation residue. However, we apply the following selection criteria to accept the genuine events.

(i) The tracks should be heavily ionising with a continuous black core.

(ii) They should be almost straight with visible tapering at the ends.

(iii) They should not show the characteristic coulomb scattering (as observed in the case of light fragments) along their path excluding some amount of scattering at the ends which is however, of rare occurance.

Further, as the identification becomes difficult in the case of steep tracks, the fragments with dip angle greater than 60^{o} in the unprocessed emulsion are rejected.

4.3 RESULTS .

A total of 30,000 disintegration centres have been examined to find the stars with short tracks. Applying the above mentioned selection criteria, only about 165 stars containing short tracks which appear to be heavy have been accepted for analysis.

4.3a MASS AND CHARGE DISTRIBUTION :

The N_h distributions of the disintegrations of the stars contailing a recoil is represented in the fig. 4.1.

The average prong multiplicity ($\bar{N}_h$) of a star containing a recoil is found to be 13 $\pm$ 0.3. This corresponds to an average excitation energy of 420 Mev.

The charge and mass distributions of the recoils are represented in the fig. 4.2. Their average values are estimated to be 18 to 46 respectively for interactions in bromine. For interactions in silver these values are given by 30 and 74 respectively. The way of estimation is similar to that adopted in the previous chapter.

As the interactions in bromine and silver are not known separately, one has to take the average of the two values of charge and mass of recoils for both the target nuclei. The estimated values thus obtained are about 24 for charge and 60 for mass respectively. The mass may still be smaller in the case of nucleus that has evaporated many more particles. It is estimated that the average number of evaporated particles being N_b = 9.1 momentum per emitted particles being 275 Mev/c. Chandrasekhar[6] observed that the resultant of N random vactors, each of magnitude p, has magnitude $\bar{p}_r$. The most probable value of which is given by,

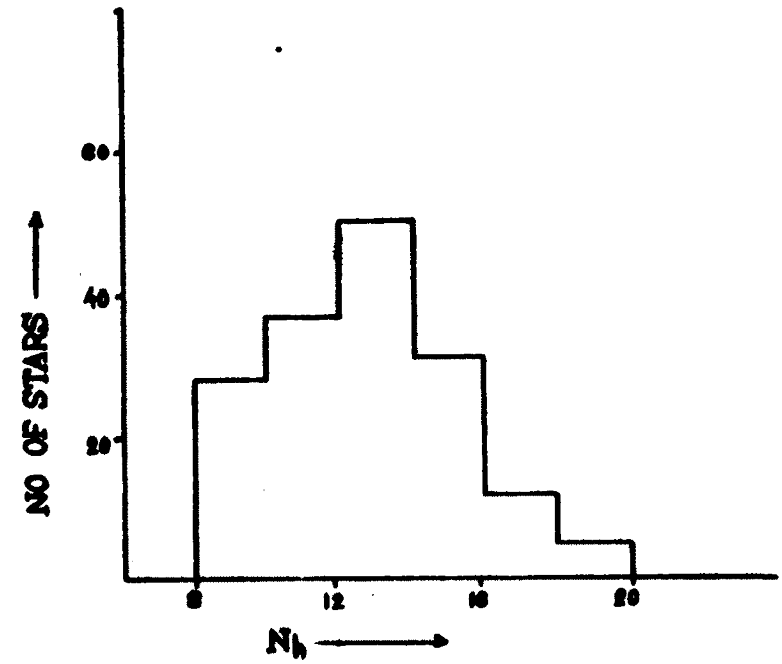

Fig 4.1 N_h DISTRIBUTION OF STARS CONTAINING RECOILS IN K^- INTERACTIONS (165 EVENTS)

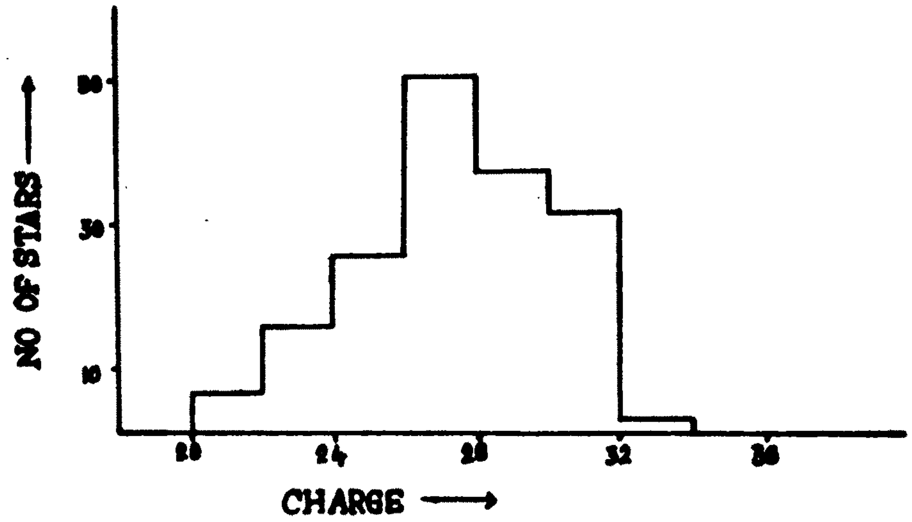

Fig 4.2 CHARGE DISTRIBUTION OF RECOILS IN K^- INTERACTIONS (165 EVENTS)

$$\bar{p}_r = p \sqrt{2/3\ N} \qquad \ldots \qquad (4.1)$$

Thus in our case momentum received by the residual nucleus is about 710 Mev/c.

Fig. 4.3 gives the distribution of the ranges of these recoils. The average values is found to be about 3.8 microns. Taking into consideration the mass of the recoiling nucleus to be 60, the corresponding velocity is found to be about 0.019 from the fig. 5.7. However, the residual nuclei sometimes receive much more energy because of the favourable statistical fluctuation in the direction of the evaporated particles. This shows that the residual nuclei may be able to produce readily recognisable tracks. Of course the emission of heavy fragments with sufficient energy sometimes helps the residual nucleus in getting appreciable energy to produce identifiable tracks[5]. However, for an evaporation residue of mass about 60, the range of track will not be more than a few microns. As a result most of the short tracks with ranges below 2 microns might have evaded detection during scanning. For this reason probably there is a fall in the number of tracks of ranges 2 - 3 microns and the absence of those of ranges below 2 microns.

4.3b ANGULAR DISTRIBUTION OF THE RESIDUAL RECOILS WITH RESPECT TO THE DIRECTION OF THE PRIMARY BEAM :

In estimating the forward and backward ratio of the ejection of recoils with respect to primary, the following

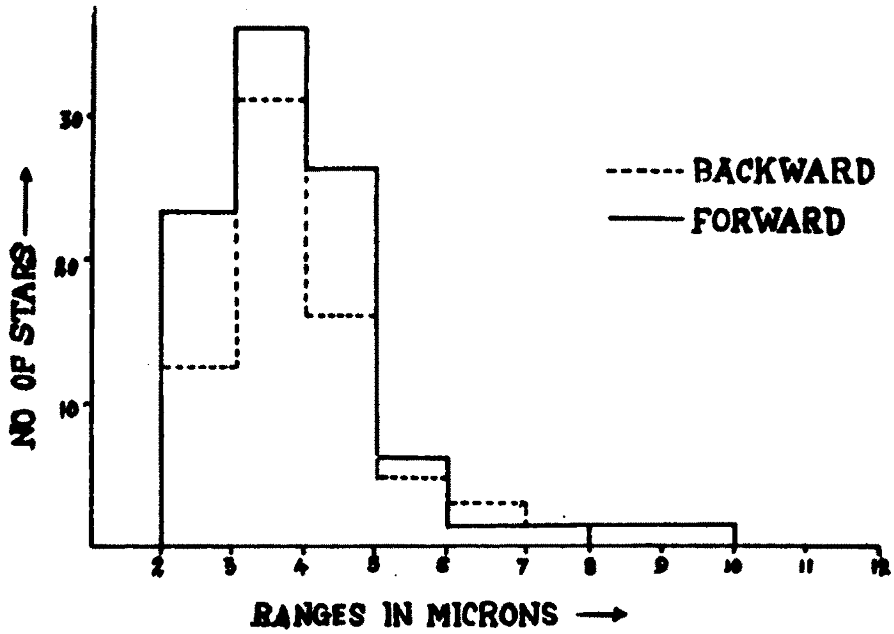

Fig 4.3 RANGE DISTRIBUTION OF RECOILS IN BACKWARD AND FORWARD HEMISPHERE IN K^- INTERACTIONS

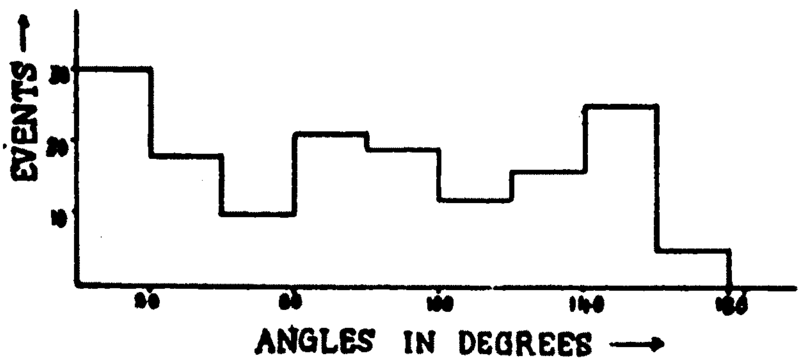

Fig 4.4 ANGULAR DISTRIBUTION OF RECOILS WITH RESPECT TO THE DIRECTION OF PRIMARY BEAM IN K^- INTERACTIONS.

criteria is taken into account. A track is classified as being emitted in the forward direction, if its space angle with respect to the primary beam direction lies in the interval of 0^{o} to 90^{o} and backward when the space angles falls between 90^{o} and 180^{o}.

Since the measurement of angle for short track involves appreciable error, we have therefore calculated F/B ignoring the tracks lying in the interval 80^{o} to 100^{o}. The results are represented in the Fig. 4.4. The departure of angular distribution from isotropy may be interpreted as due to the initial forward motion given to the target nucleus by the high energy incident particle. Due to this motion, the energy spectrum of the particles becomes broader, and slow particles emitted in the backward direction being attenuated in energy produce still shorter tracks with the possibility that a fraction of them may even be lost.

Taking into consideration the velocity of the residual nucleus due to the random momenta of the evaporating particles in the rest system to be V_1 and the velocity of the evaporating system due to the initial impact of the incident particle be V_2, the velocity of the residual nucleus observed in the laboratory system will be given by the resultant of the two vectors V_1 and V_2 and the forward and backward ratio will be of

$$F / B = (1 + V_2 / V_1) / (1 - V_2 / V_1)$$

Now, taking V_1 = 0.019C and F/B = 1.38, V_2 calculated is found to be of 0.003C.

4.3C THE VELOCITY DISTRIBUTION OF RECOILS :

As the average value of charge and mass is found to be 24 and 60 approximately, so the velocity of the residual nuclei corresponding to its observed range may be estimated from the values given by the curve for $_{24}Mn^{55}$ in Fig. 5.7. It is seen that the velocity of the heavy ions corresponding to a given range, varies only slightly with the mass of the ions in standard emulsion. Thus the curve is drawn with the help of range momentum data of Lou[7] et al. The velocity distribution of the residual nucleus is shown in fig. 4.5. Their average value is found to be 0.019 ± 0.001 C. This value is found to be slightly higher than that expected as the resultant of the velocity V_1 and V_2.

Here in our studies, it is assumed that only primary and evaporated particles contribute towards the momentum of the residual nucleus. It should also be mentioned that the production of recoils may be influenced by the emission of cascade particles also. Key[8] et al and Evans[9] suggested from the studies in emulsion that short range hyper fragments are due to the spallation of bromine and silver nuclei. Evans has reported further, the evidence of the effect of cascade particles on the production of short range hyper fragments. Since the recoils are produced by the similar mechanism they are likely to be affected by cascade stage evaporation of excited nucleus.

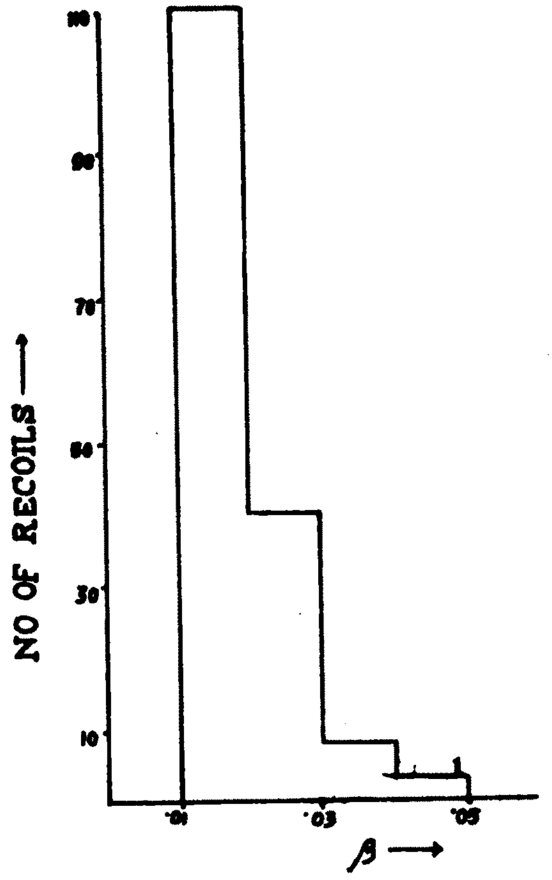

Fig 4.5 VELOCITY DISTRIBUTION OF RECOILS IN K^- INTERACTIONS.

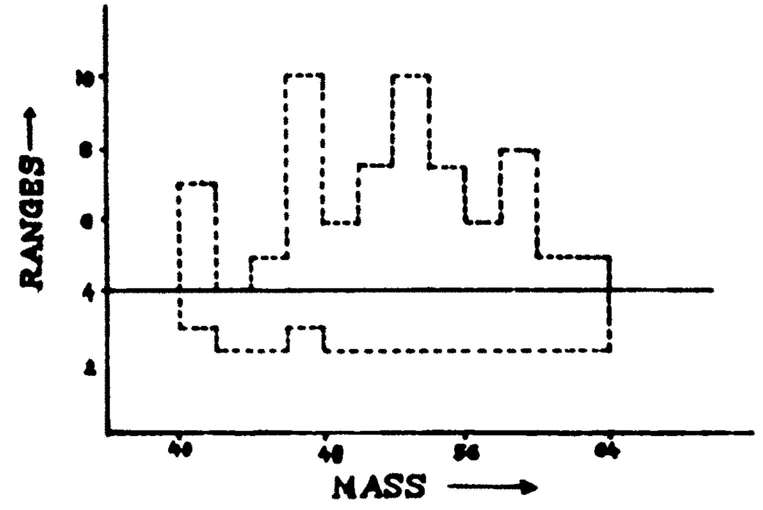

Fig 4.6 THE UPPER AND LOWER LIMITS OF RANGES OF RECOILS OF VARIOUS MASSES.

4.3d DISCUSSIONS:

From the observed characteristics as given in the previous section it may be concluded that the recoils are the spallation residue which can be explained under cascade evaporation model. The recoil energy of the residual nucleus is therefore, expected to be independent of its mass and number of evaporated particles[10]. The angular distribution of the evaporated particle is also found to be isotropic at the rest system of the evaporating nucleus. However, from the fig. 4.6 it appears that recoil ranges (and hence not the velocities) are almost independent of the number of evaporated particles.

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