CHAPTER V

BINARY FISSION

5.1 INTRODUCTION :

In high energy nuclear disintegration of silver and bromine nuclei in nuclear emulsion, stars are sometimes found to contain two or even more short dense prongs ($\leqslant$ 25 microns) presumably due to heavy nuclear fragment. The observed characteristics show that the production of such heavily ionising nuclear fragments might be due to a fission type process of the disintegrating nuclei. When the nucleus is highly excited, energy may be concentrated in volume and surface oscillation. As a result of such nuclear oscillations fission of the excited nucleus may occur. The cascade evaporation model remains valid for nuclear disintegrations involving such a process. The fission is supposed to compete with particle evaporation in the second slower stages of reaction. Thus the cascade process leaves the product nucleus, which, while in the process of de-excitation by evaporation may sometimes break up into two or more fragments of comparable mass. When the residual nucleus breaks up exactly into two parts, the process is termed as 'Binary fission'. If the fissioning nucleus splits precisely into three or four parts of comparable masses, they are termed as 'Ternary' and

'Quaternary' Fissions respectively. A nucleus may break up approximately into two equal parts by several processes, such as,

(1) splitting of a highly excited nucleus into two parts, followed by the evaporation of particles from the parts,

(2) splitting of a nucleus in the post cascade and preevaporation stages of the nucleus,

(3) splitting at the end of the evaporation process with no further evaporation of the particles from the fission product (except for beta activity), i.e., fission in the final stage of de-excitation.

It has already been mentioned that high energy reaction of complex nuclei, are described by the cascade evaporation model. The cascade leads to different products, each with a spectrum of excitation energies. Again in the process of de-excitation of the cascade product by evaporation the fission can compete in varying degrees throughout the process of evaporation. High energy fission phenomenon however, appears to be extremely complex and has so far defied the detailed theoretical predictions. The view is probably reasonable because of the transperancy of the nuclei to the projectile and also because of the fact that the Coupling[1] of incident particle to the collective fission mode is very small.

In the present investigations the fission characteristics of binary fission events studied are mainly due to the third process, with a possible contribution from the second one. Also a brief experimental informations regarding the possible occurance of fission in the first process is given in section 5.4.

5.2 EXPERIMENTAL PROCEEDURE AND SELECTION CRITERIA :

Two emulsion stacks one K5 (sample A) exposed to 1.8 Gev/c kaon beam and other G5 (sample B) exposed to 5 Gev/c antiproton beam have been used in the present investigation. The plates were area scanned under X10 objectives and X20 eyepiece to record all the stars having $N_h \geq 8$ and with two or more short tracks of similar characteristic in a selected volume of emulsion under high magnification ($\sim$2000), the centres of disintegration of these stars are scrutinised carefully and the stars containing two or more tracks of ranges $\leq$ 25 microns of comparable length are taken for further scrutiny. Since the tracks under study are of short range, no suitable method is available for their identification excepting by eye inspection and partly by measurement.

Attempts have also been made to avoid lighter tracks from heavier ones. In K5 and G5 emulsion identification of fission fragments becomes difficult because of the high sensitivity of the plates. However, every effort has been made to avoid contamination of lighter tracks with fission tracks, applying the following proceedure. The process involves in examining the track characteristics of a few 'hammer' track and also of tracks of some heavier nuclei, which shows clear thin down towards the end of their ranges.

It is sure that the average width of the comparatively longer fission tracks must be of greater width than that of hammer track.

It may be noted that shorter hammer tracks sometimes deviates from the straight paths but the tracks due to heavier nuclei are always straight. Hence the straight and dense short tracks are indicative of the path of heavily ionising particles.

The track produced by a particular nuclear fragment may have slightly different width at different regions because of the variation in the degree of development of different portions of the emulsion stacks. Therefore, before identifying the tracks as fission fragments, their tracks widths are compared with those of the other black prongs of the stars in the same plate. However, taking into account of all the possible errors, fission events are carefully selected from among stars with more than one short track of range $<$ 25 micron. Tracks with following characteristics were rejected. (1) Comparatively longer tracks showing no thin down length, (ii) tracks with gaps and single grain formed along the trajectory, (iii) and tracks suffering visible coulomb scattering.

5.3 EXPERIMENTAL RESULTS AND DISCUSSIONS :

From the scrutiny of 30,000 disintegrations in sample A and 3,400 in sample B we collected after applying selection criteria a total of 225 fission events in sample A and 50 in sample B, after rejecting the stars with short tracks not satisfying the criteria. The results are presented in the table below.

Table 5.1

Fraction of reactions leading to fission

Samples	No. of primary disintegration	Stars with two short tracks	Stars accepted as fission events	Fission frequency w.r.to primary disintegration
A	30,000	650	225	0.008
B	3,400	95	50	0.015

5.3a Prong Multiplicity of Fission Events :

The prong multiplicity of fission events for sample A and sample B are shown in figs. 5.1 and 5.2 respectively. The average prong multiplicities for K^- and $\bar{p}$ interactions are found to be 13 $\pm$ 0.21 and 16 $\pm$ 0.5 respectively. Corresponding excitation energies are given by 420 Mev and 500 Mev respectively. The average prong multiplicity is found to increase with the increase of the energy of the bombarding particle. It is also of interest to note that in the present studies the average prong multiplicities of fission events are found to be higher than that of non fission events but it is almost

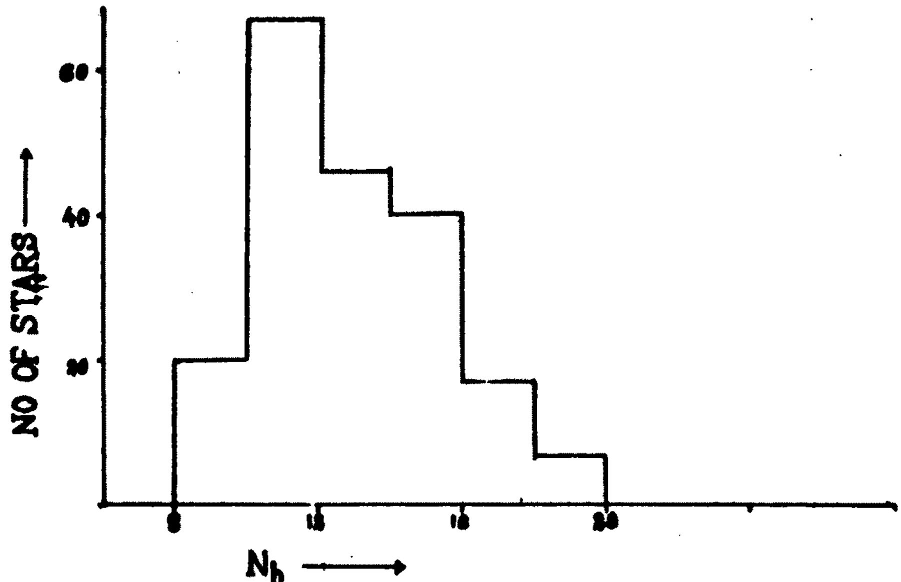

Fig 5.1

N_h DISTRIBUTION OF STARS WITH BINARY FISSION EVENTS IN K^- INTERACTIONS (225 events)

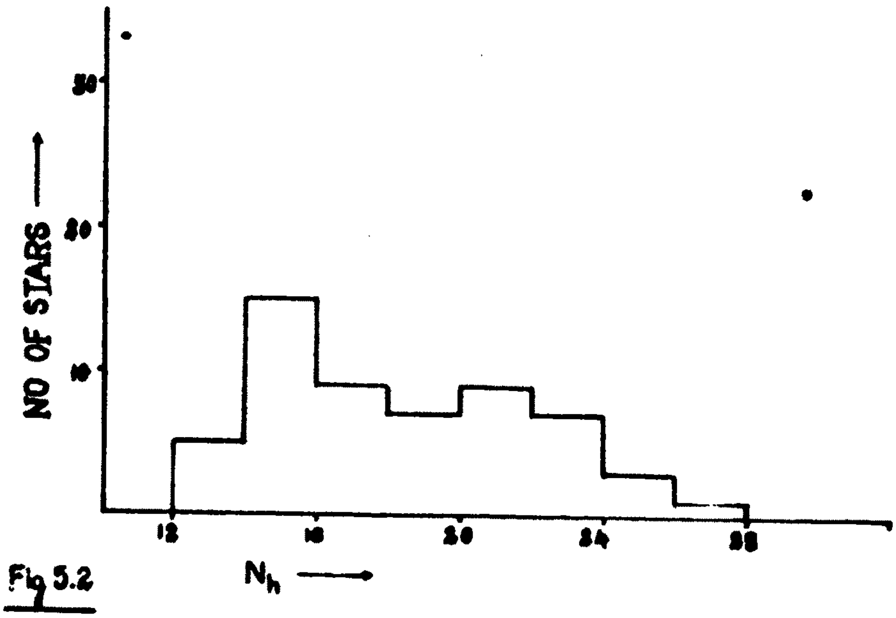

Fig 5.2

N_h DISTRIBUTION OF STARS WITH BINARY FISSION EVENTS IN $\bar{P}$ INTERACTIONS (50 events) same as that of events with recoils.

Seaberg[2] et al observed that at higher excitation energy greater number of particles will be evaporated and longer time will be required for nuclear disintegration. Longer the time greater will be the probability that the excited nucleus will be able to organise itself to a fission mode of oscillation. Therefore, high energy transfer is required for fission to occur and which might be possible in cases of central collisions only. In cases of central collision, it might be well argued that excitation energy is as such that the collective mode for fissioning nucleus breaks down thereby enhancing the emission frequency of the individual particles rather than heavy prongs. Thus it accounts for the increased multiplicity in cases of fission accompanying stars.

However, these results contradict the observations of Deka and Deka[3] for their observations of prong multiplicities for fission ($N_h = 14.3 \pm 0.4$) and non-fission ($N_h = 17.4 \pm 0.5$) stars produced in 20 Gev proton interactions. This discrepency may partly be due to the fact that in their observations for non fission stars they appear to have included stars with and without recoils. Whereas in the present observations these events have been selected in three groups, viz., (i) events without recoils, (ii) events with recoils and (iii) events associated with fission fragments.

Now, as the prong multiplicity of the events containing recoils is greater than those without recoils, therefore, one may expect to get an over all increase in prong multiplicities in their works for non-fission stars as compared to fission stars.

Besides, for the comparatively higher interaction at 20 Gev/c the fission and evaporation perhaps compete in such way, that in many cases the fission occurs during the initial process of evaporation, thus consuming a large portion of excitation energy where sufficient number of particles are yet to be evaporated from the excited nuclei. It fission occurs at this stage then the prong multiplicity will be lowered specially when the probability for emission of charged particles from fission fragment is small.

5.3b Charge Distribution of Fission Fragments :

In order to estimate the charge distribution of fission fragments, the residual charge of the fissioning nucleus can be obtained from the estimation of total charge carried away by the heavily ionising particles of the disintegrating nucleus. In doing so, the charges of cascade and evaporated particles are estimated by applying the usual method of charge determination where ever possible, otherwise it is taken to be unity. After determining the extent of total charge carried away by emitted particles, the residual charge or prefission charge $Z_{fission}$ which has been attributed[4] to the fissioning nucleus from the relation

$$Z_{fission} = Z_{Ag \text{ or } Br} - \sum z_i$$

$$= 41 \pm 6 - \sum z_i$$

where $\sum z_i$ is equal to the total charge of the emitted black and grey particles. The charge distribution so obtained are represented in the fig. 5.3 and 5.4 for both the interactions. Now from the charge distribution we find that the charge of the pre-fission nuclei (considering interactions in silver and bromine together as it is not possible to identify them separately in emulsion) extends from 20 to 34 for sample A and 15 to 27 for sample B respectively. The average charge will be 34 for interaction in silver and 22 for that in bromine. Thus the mean charge is 28 for sample A and 25 for sample B found with similar consideration. Now for region of nuclear fragments under consideration the individual mass of the fragments may be taken to be almost equal to twice the value of their charges. Hence the mass of the pre-fission nuclei is found to be 56 for sample A and 50 for sample B respectively.

Taking the fission to be symmetric the individual fission fragments will have values for charge and mass given by 14 and 28 respectively for sample A. For sample B, values are found to be about 13 and 26 respectively.

However, the estimation of the total charge carried away by each of evaporated particle can be done on the basis of Key[5] et al, taking into account the fission phenomenon to occur at the last stage of evaporation. All the cascade particles are supposed to be due to protons and then the mean charge and mass of fissioning nucleus for sample A is found to be 18 and 46 respectively for interactionsin bromine and they are found to be 30 and 74 respectively for interactions

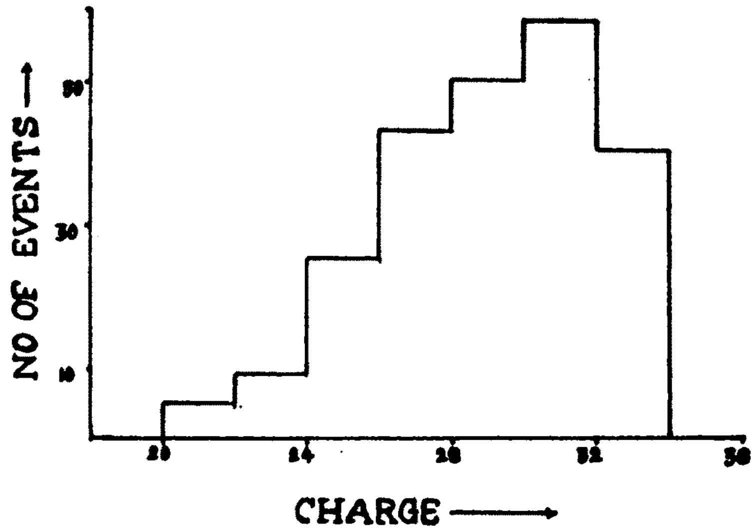

Fig 5.3 CHARGE DISTRIBUTION OF FISSIONING NUCLEI IN K^- INTERACTIONS

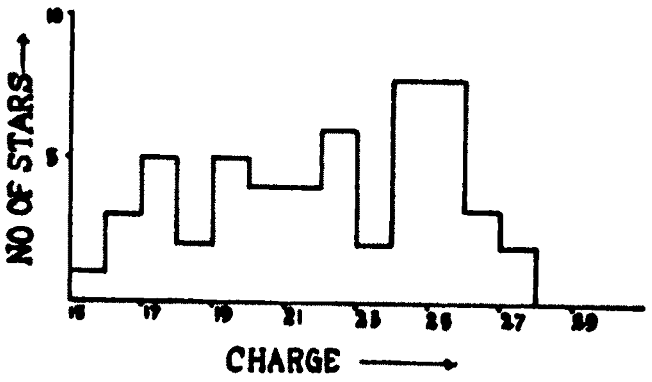

Fig 5.4 CHARGE DISTRIBUTION OF FISSIONING NUCLEI IN $\bar{P}$ INTERACTIONS.

in silver. Therefore, the average charge and mass of the fissioning nuclei are estimated to be 24 and 60 respectively. These results approximately are in agreement with the above determination. Similarly for sample B average charge and mass of the fissioning nuclei are estimated to be 20 and 47 respectively. Therefore, taking fission to be symmetric one, the average charge and mass of fission fragment in k^- interaction is estimated to be 12 and 30 respectively and the respective values for $\bar{p}$ interactions are found to be 10 and 24. However, the work of Katcoff[6] et al indicates that the charge of the individual fragments in case 3 Gev $\bar{p}$ interactions should lie between 7 and 17, consequently its mass from 15 to 35 approximately and which is in close proximity to the data obtained in the present experiment.

5.3c Cross Section of Fission Events :

The data on the fission cross-section for silver and bromine are scarce and are often in consistent with each other at high energy interactions. It is due to the fact that the high energy fission is really a complex phenomenon to account fully.

The table below gives the values of fission cross-section for silver and bromine obtained by different worker using different beam momentum with different detectors.

Table 5.2

Fission cross section obtained by different workers

Workers	Projectile	Momentum in Gev/c	Cross. section in mb	Detectors
Katcoff[6] et al	Proton	1-3	7 30 50	Photographic emulsion
Makowska[8] et al	Proton	25	23 ± 7	-
Gorichev[9] et al	Protons	9	1	-
Hudis[10] et al	Protons	2-13 29	5 6	Photographic emulsion
Brandit[11] et al	Proton	18 .59	2 0.4	Mica detector
Cabot[12] et al	N^{14} ions	126 (Br^{73})	0.4 ± 0.2	Surface barrier detectors
Present worker	kaons ANTIPROTON	1.8 k^- 5.0 $\bar{p}$	0.8 66	Photographic emulsion

However, radio chemical method[13] makes it possible to have an estimate of the upper and lower limits of fission cross-sections. Using glass detector registration efficiency of 40 p.c. is only achieved. Using mica detector, the registration efficiency is close to 100 p.c. However, it records only those fragments whose mass number exceeds about 30.

Katcoff[7] obtained an increase in the value of fission cross-section with energy of incident particles. However in our studies of fission cross-section with strange particles K^- and $\bar{p}$, the values are found to be significantly lower (as shown in the table) than that obtained by Katcoff for beam momentum comparable to that of what is used in the present experiment. For k^- interaction the fact may partly be explained by taking into account the formation of short range spallation hyper-fragments, which is nearly 10 p.c. higher in k^- interaction than that of nucleon and pion interactions. It is interesting to note that in our calculations of fission cross-section the value is almost 10 p.c. less than what is obtained by Katcoff using almost the same beam momentum as ours.
The hyper-fragments perhaps compete with the fission process and hence a lowering of fission cross-section for k^- interactions are observed. A comparative study of a few characteristics of spallation hyper-fragments and binary fission events have also been presented in the Chapter VII. The cross-section for antiproton interaction is in conformity with the increasing values for 1-3 Gev/c proton interaction as observed by Katcoff[7] et al.

Since the cross-section of fission is supposed to increase with the increase of mass number of the target nucleus, therefore, it can be assumed that the samples under study is richer in fission of silver than to bromine. But according to Cabot[12] et al fissilities are found to decrease exponentially with the ratio Z^2/A of the fissioning nucleus until $Z^2/A = 19$ (molybdenum) and then to increase again for lower Z^2/A. In the present study, Z^2/A for interaction in bromine and silver target, taking the residual nuclei to be ${}_{22}Te^{48}$ for bromine and ${}_{34}Se^{80}$ for silver, Z^2/A calculated to be 10 and 14.4 respectively. Though this contradicts the earlier observation, yet the contribution from the nuclei towards fissilities is taken to be same in the present analysis.

The table below has shown the percentage variation of fission events for beams (k^-) and ($\bar{p}$) also at a fixed interval of N_h.

Table 5.3

Percentage variation of fission events at fixed interval of 'N_h'

N_h interval Sample A	8-10	11-13	14-16	17-19	20-22	
P.C. of fission event	13.3 ± 3.2	44 ± 5.1	31.1 ± 4.2	11.1 ± 2.9	0.8 ± 0.02	
N_h interval Sample B	12-14	15-17	18-20	21-23	24-26	27-29
P.C. of fission event	14 ± 3.0	32 ± 4.1	20 ± 3.3	16 ± 3.1	14 ± 3.0	4 ± 1.1

5.3d Range Distribution of Fission Fragments :

The range distribution of binary fission fragments for both the samples A and B are shown in the figures 5.5 and 5.6. The mean value of ranges in k^- fission events is found to be ~ 9 microns and that found in $\bar{p}$ fission events is ~12 microns. The ranges of fission fragment change slightly with their prong multiplicity and that is given in the table below.

Table 5.4

Variation of fragment ranges (fission) with prong multiplicity

Stars with N_h interval	8-10	11-13	14-16	17-19	20-22
k^- (Lower and upper limit of ranges in microns)	3-12.5	3.5-23	4-24	4-17	12-16.5

Stars with N_h interval	12-14	15-17	18-20	21-23	24-26	27-29
$\bar{p}$ (Lower and upper limit of ranges in microns)	6-14	7.5-22	6-25	7.5-24	6-18	10-23

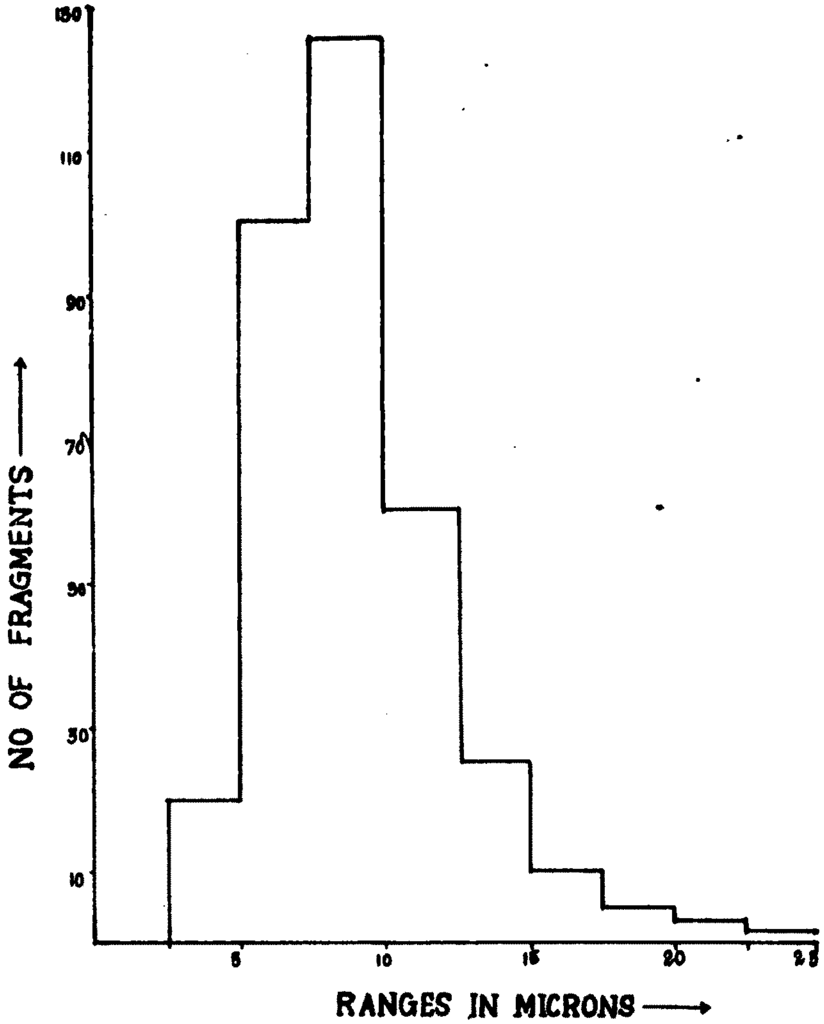

Fig 5.5 RANGE DISTRIBUTION OF FISSION FRAGMENTS IN K^- INTERACTIONS (225 EVENTS)

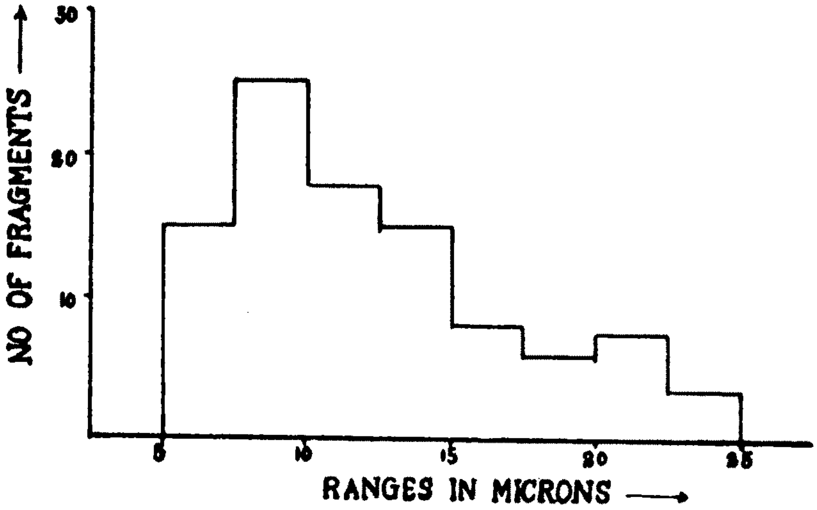

Fig 5.6 RANGE DISTRIBUTION OF FISSION FRAGMENTS IN $\bar{P}$ INTERACTIONS (50 EVENTS)

It is in conformity with the fact that the fission fragments receive their energy mainly due to coulombic repulsion between them. This repulsive force between the fragments corresponding to different 'N_h' group is such that both the heavier and lighter fragments receive energy sufficient to traverse almost equal ranges in the medium. It indicates that the ranges of fission fragments are independent of prong multiplicity. The results obtained from this consideration are found to be similar with the work of Deka and Deka with 20 Gev/c proton beam in emulsion and also with Katcoff.

5.3e The Range Velocity Curve :

With the help of range velocity curve of ${}_{15}P^{31}$ and ${}_{25}Mn^{55}$ as drawn in figure 5.7 relative to range momentum curve of Lou[14] et al, the measured range distribution of the fission fragments are converted into their respective velocity distribution as done in case of recoils. Because the velocity of a fragment of given range does not change appreciably for the variation of masses, we get a fairly accurate range velocity distribution of fission fragments for both the samples A and B as shown in figures 5.8 and 5.9. The velocity ratio of the fragments are also shown in the figures 5.10 and 5.11 for samples A and B. It is observed that about 90 p.c. of the fission pair have velocity ratio equal or less than two.

The mutual coulomb repulsion of the two fission fragments in contact is supposed to be equal to the kinetic

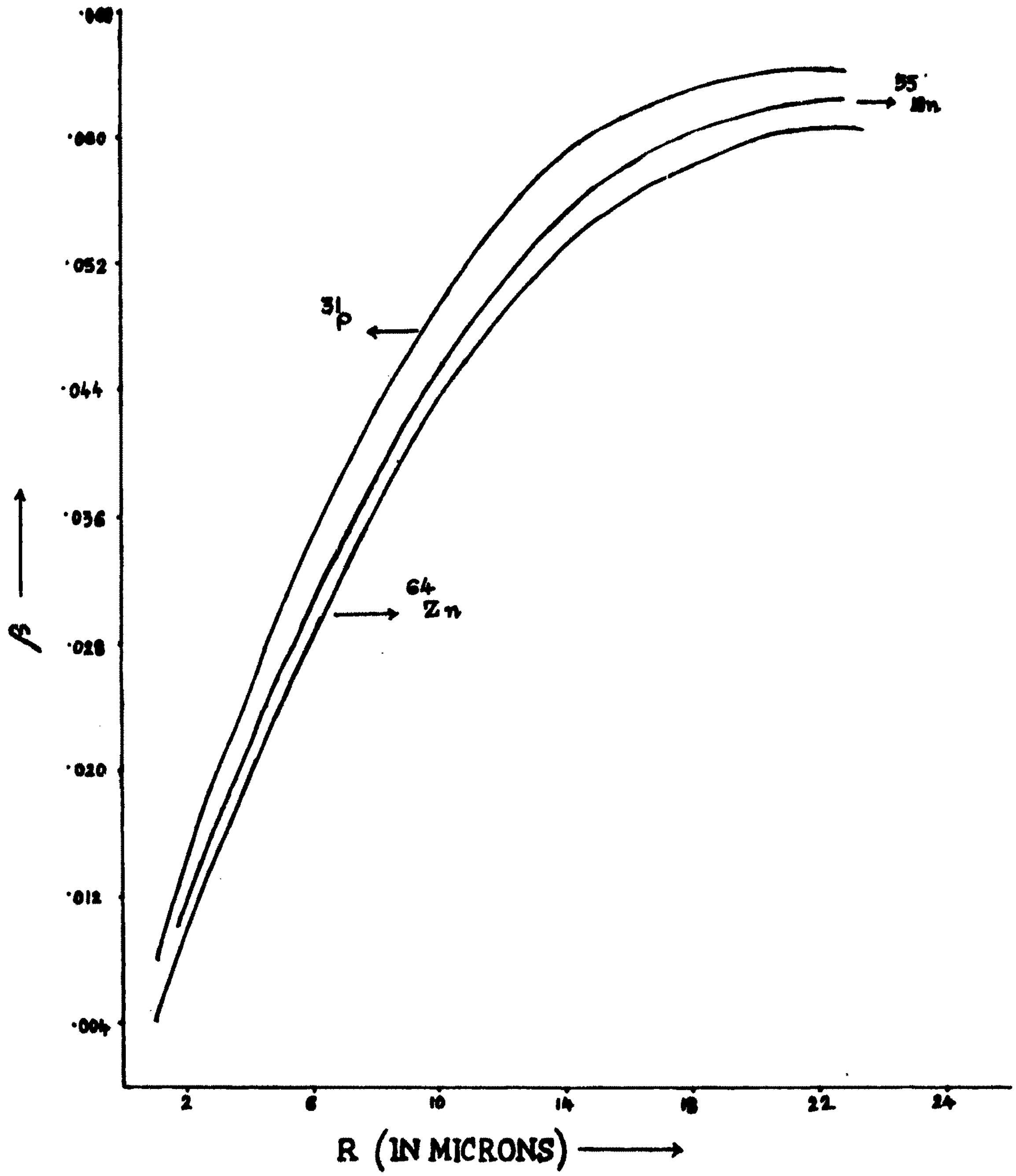

Fig. 5.7 RANGE VELOCITY CURVE FOR HEAVY IONS

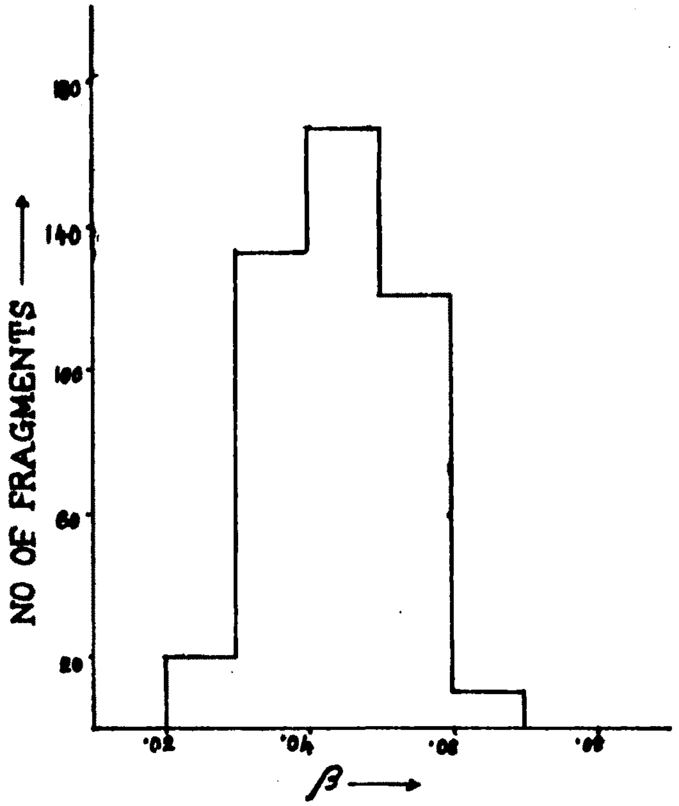

Fig 5.8 VELOCITY DISTIBUTION OF FISSION FRAGMENTS IN $\bar{K}$ INTERACTIONS

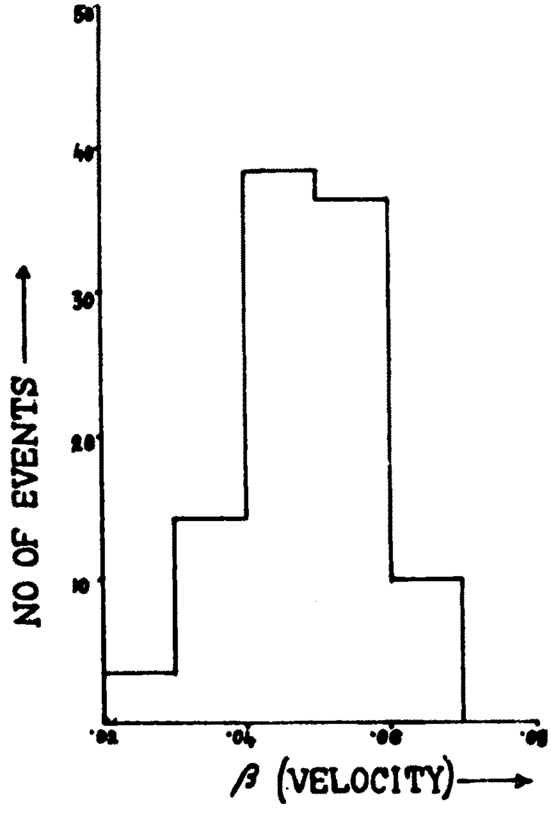

Fig 5.9 VELOCITY DISTRIBUTION OF FISSION FRAGMENTS IN $\bar{P}$ INTERACTIONS

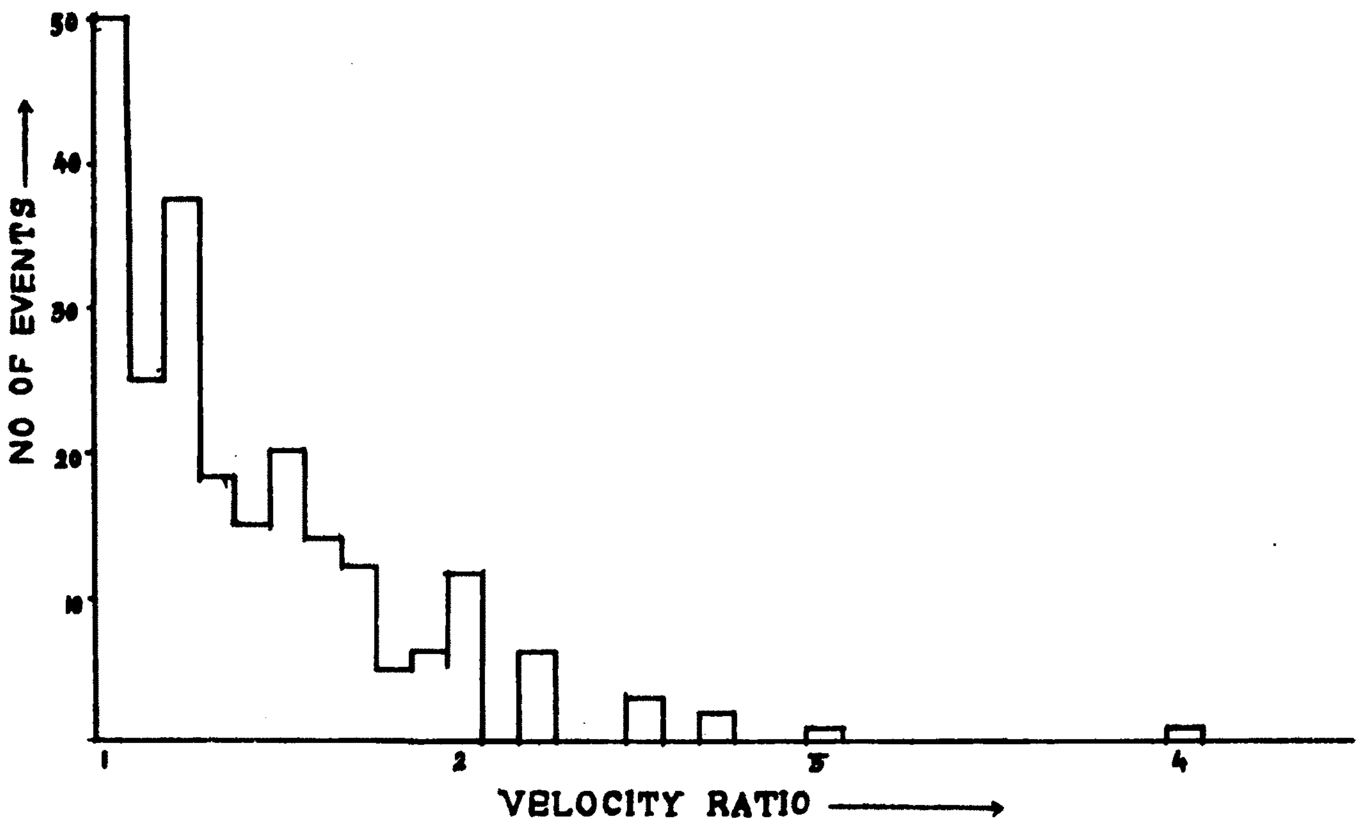

Fig. 5.10. DISTRIBUTION IN VELOCITY RATIO FOR THE TWO FISSION FRAGMENTS (K^- INTERACTIONS)

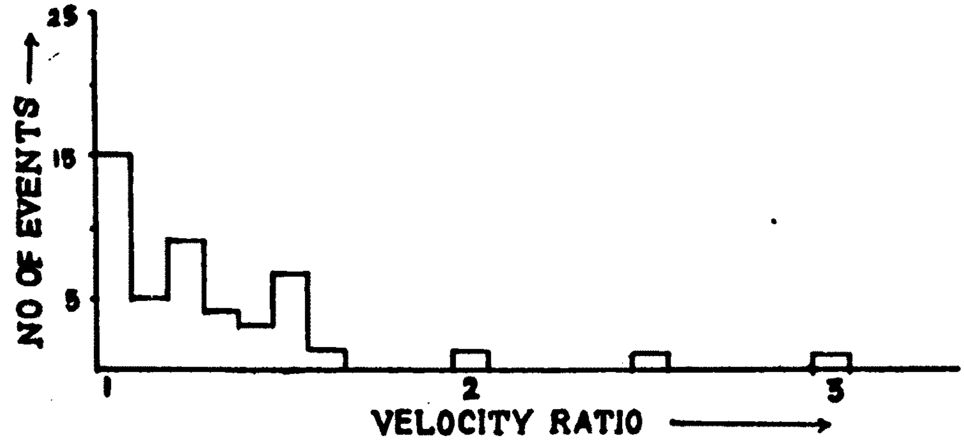

Fig 5.11. DISTRIBUTION IN VELOCITY RATIO FOR THE FISSION FRAGMENTS ($\bar{P}$ INTERACTIONS)

energies of the fission fragments. Again assuming the fragments to be spherical in shape, the coulomb energy is given by,

$$E = (ez)^2/2R \sim 30 \text{ Mev}$$

$$\text{for } z = 12$$

where (ez) is the charge of each fragment assuming it to be a symmetric division and $R = R_0 A^{1/3}$ is its radius taking the value of $R_0 \sim 1.35$ fermi for fission products of ${}_{24}Cr^{54}$. The kinetic energy of each fragment of ${}_{12}Mg^{24}$ determined using the table of Heckmann[15] et al comes out to be $\sim$ 22.5 Mev. This corresponds to a visible energy release of 45 Mev. Thus we find that observed value is some what greater than that can be accounted for mutual coulombic repulsion. This may be due to the fact that this is a case of high energy induced fission in a moving system. However, this energy corresponds approximately to a velocity of 0.040C. The measured velocity of the fragment in the laboratory system is actually the resultant of the coulomb velocity β_c and the velocity of the prefission residual nucleus β_r, since it is assumed that the fission takes place in a moving system. The angle between these two vectors β_c and β_r may vary arbitrarily between 0^o to 180^o. The observed width of the velocity distribution can be accounted for by the combined effect of the two factors. This also justifies our selection criteria for ranges (5 - 25 microns).

1. Width of the distribution in β_c:

The coulomb energy for different fission fragments will be different because they have different mass and charges. This actually broadens the coulomb velocity distribution of the products and the width of which can be obtained only after estimating the charge of the individual fragments, and may range from 0.02C to 0.07C.

2. Width of the distribution in β_r:

It can be well accounted on the basis of cascade-evaporation model that the prefission residual nucleus will have a velocity due to the resultant of the momentum transfered by the incoming projectiles and the particles evaporated from the nucleus. βr the velocity of the prefission residual nucleus, may be assumed to be equal (approximately) to the mean velocity of the residual nucleus of the ordinary non-fission stars. The value of which can be estimated from the velocity recoil curve as shown in fig. 4.5 and its range spectrum from 0.01C to 0.05C.

3. The orientations (relative) of the vectors βc and βr:

When the two vectors βc and βr are in the same direction for a fissioning nucleus the resultant velocity of one fragment will be $(\beta c + \beta r)$ whereas for other one it will be $(\beta c - \beta r)$. But when the two vectors are at right angles to each other, both fission fragment will have equal velocity and which is a case in symmetric fission. Therefore, it can be argued that the relative orientations of the vectors can broaden the velocity distribution of the fission fragments.

4. Relative mass of the product :

The coulomb energy is shared equally between the two fragments in case of symmetric binary breakup, but in case of asymmetric breakup the lighter fragments will have higher velocity than heavier one. This also contributes to the observed width of the velocity distribution of the fission fragments.

5.3f Range Ratio Distribution of the Fission :

From the pattern of the range ratio curves for both the samples as shown in the figures 5.12 and 5.13 it is observed that the range ratio is almost independent of the bombarding beam energy. In the case of purely symmetric binary fission of the rest system range ratio of the two fragments becomes equal to unity. But in cases of asymmetric fission the range ratio exceeds the value unity, because, one of the fragments will be lighter than that of the other one. However, it is of interest to note that in the moving system even for a purely binary breakup the range ratio may exceed the limiting value of one, because of the relative orientations of the two vectors β_c and β_r of the fissioning nucleus. In our study, the limiting values of range-ratio of the fragments is less than 2 (about 90 p.c.), but in few cases extends upto 3 for both the samples. It is found to be quite

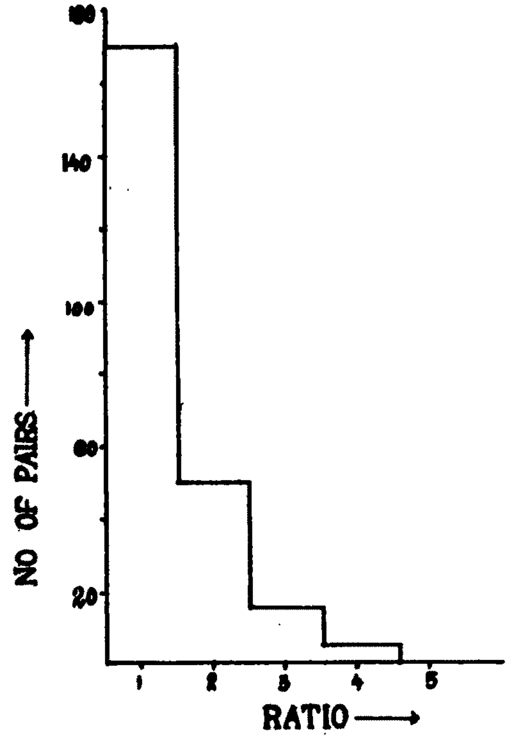

Fig 5.12 DISTRIBUTION IN RANGE RATIO OF K^- INTERACTIONS (225 EVENTS)

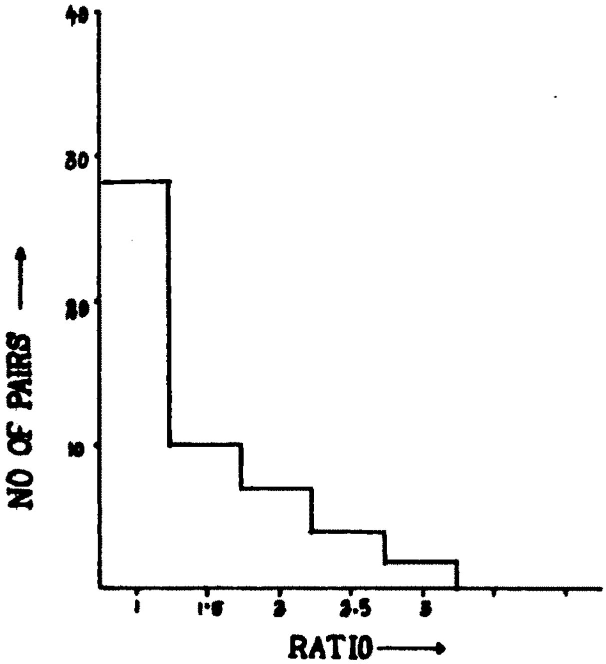

Fig 5.13 DISTRIBUTION IN RANGE RATIO OF FISSION FRAGMENT PAIRS OF $\bar{P}$ INTERACTIONS (50 EVENTS)

in conformity with the work of Beckar[7] et al. The maximum and minimum ranges of the symmetric fission fragments can be estimated taking into account the relative orientations of the two velocity vectors β_c and β_r. Taking the value of $\beta_c \sim 0.040C$ and $\beta_r \sim 0.019C$ and if they are aligned along the same direction, one of the fragments may have ranges 15.0 microns while the other have range 3.0 microns. Thus the maximum permissible range ratio value is about 5.

From the various data obtained on range ratio distribution it can be well argued that most of the fission events are symmetric. Baker[7] and Lavrukhina[16] have also reported the predominance of symmetric fission in high energy nuclear interaction of medium weight nuclei. Similar is the case with heavy element fission at high energy. Ofcourse, it is known that asymmetric binary breakup is restricted to low energy nuclear interaction whereas symmetric fission is a phenomenon of high energy nuclear interaction.

5.3g Angular Distribution Between the Fission Fragments (Binary Break up) :

The figures 5.14 and 5.15 represent the angular distribution of fission pairs for k^- and $\bar{p}$ interactions.

If the binary fission occurs in the rest system of the nucleus, the fission products will fly apart from each other to opposite directions almost in a straight path due to coulomb repulsion between them. In this case the angles, between the fragments will be more less around 180^o. In the present analysis, it is found that the mean angle between the fragments deviates from 180^{o} by an angle of 40^{o} in case of sample A and 50^{o} in case of sample B. This non-collinearity is supposed to be due to the reason that the fission occurs in a moving system. The centre of mass velocity of the fissioning system can be estimated from the knowledge of the non-collinearity of the fission products. In the present experiment, the centre of mass velocity is found to be 0.019C for sample A supposing the direction of its motion along the bisector of the mean angle between the two fission fragments each of which is moving with mean velocity of 0.046 in the laboratory system, in case of symmetric fission. The mean fragment velocity of the moving system is then calculated to be 0.042C for A. Our observed mean velocity of the fission fragments therefore agrees well with the expected value derived from the coulomb repulsion between the nuclei produced in symmetric binary breakup. Moreover, from the shape of the distribution in angles between the fragments (Figs. 5.14 and 5.15) it is found that the angular distribution is almost independent of the incident beam momentum. However, the mean angle between the fission pairs ($140^{o} \pm 5^{\circ}$ for k^{-} and $130^{o} \pm 5^{\circ}$ for $\bar{p}$) appear to decrease with increasing momentum. These results agree with those of mean angle = 138^{o} for 1-3 Gev/c proton interactions obtained by Backer[7] and mean angle 128^{o} for 20 Gev/c proton interaction obtained by Deka and Deka[3]. This may be due to the fact that with higher energy the fission pairs receive a forward momentum thus resulting in a decrease of mean angles

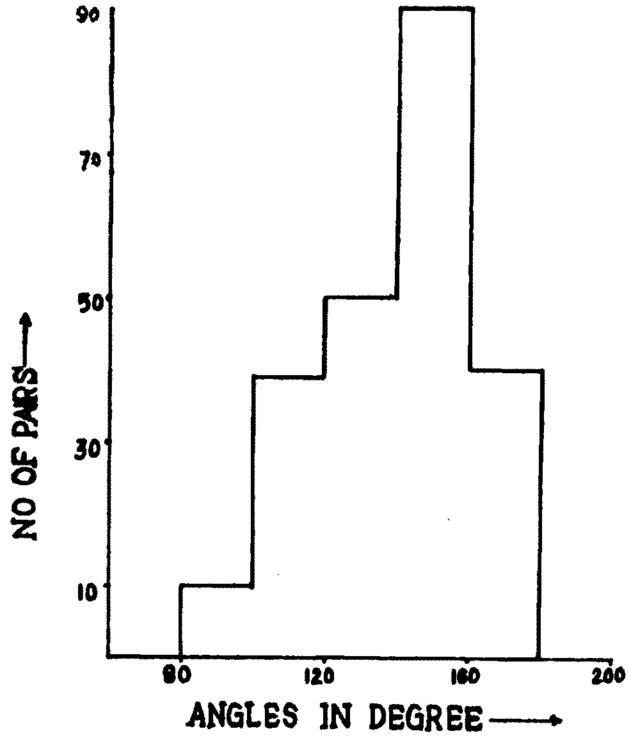

Fig 5.14 ANGULAR DISTRIBUTION BETWEEN THE FISSION FRAGMENTS IN CASE OF K^- INTERACTION

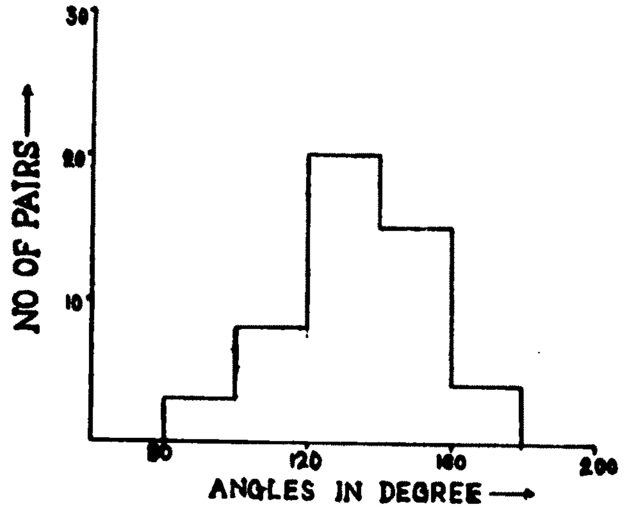

Fig 5.15 ANGULAR DISTRIBUTION BETWEEN THE FISSION FRAGMENTS IN CASE OF $\bar{P}$ INTERACTION

between the pairs.

5.3h Angular Distribution of the Fission Bisectors :

In order to study the direction of motion of the pre-fission residual nuclei in symmetric breakup, an attempt has been made to investigate the angular distribution of the 'fission bisector' that is the line bisecting the angle between the fission fragment pair, with respect to the direction of the incident primary beam. This is represented in figs. 5.16 and 5.17 for both the samples. It is interesting to note that angular distribution of fission bisector is strikingly similar to that of the angular distribution of residual recoils of ordinary non-fission stars while using the same beam momentum in k^- interactions. The direction of motion of pre-fission residual nuclei would have been isotopically distributed due to random momentum transfered by the evaporating nuclear particles, but due to the effect of the initial momentum transfered by the incoming particle to the residual nucleus an angular anisotropy is introduced in its direction of motion. This is in view of the fact that fission takes place in a moving system. The forward-backward ratio for fission bisector and of recoiling nucleus for k^- interactions are found to be 1.40 ± 0.08 and 1.38 ± 0.08 respectively. The present observation agrees well with the work of Barker[7] et al.

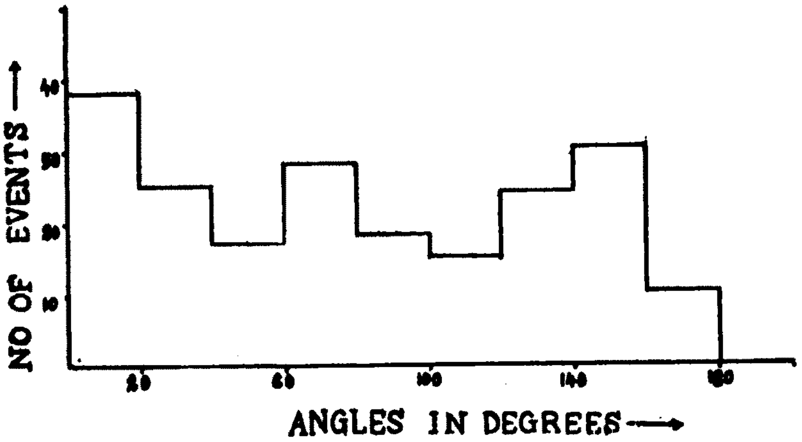

Fig 5.16 ANGULAR DISTRIBUTION OF FISSION BISECTOR IN K^- INTERACTIONS

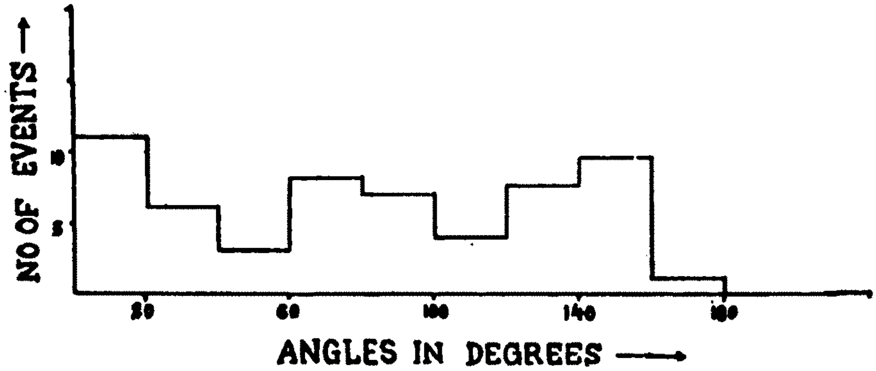

Fig 5.17 ANGULAR DISTRBUTION OF FISSION BISECTOR IN $\bar{P}$ INTERACTIONS

5.3i <u>Angular Distribution of the Individual Fission Fragments With Respect to Primary</u> :

It is seen that mean angle between the fission fragments deviates from 180° by angle of 40° in the laboratory system. Moreover, pre-fission residual nuclei also do not maintain their distribution isotropically. Therefore, the line of motion of the fission fragments observed in the laboratory system with a mean deviation of 20°, considering fission occurs in the moving system. Thus a pre-fission residual nucleus moving at an angle less than 20° with respect to the direction of the primary beam would have both the fragments in the forward hemisphere and if it moves at an angle more than 160° with respect to primary direction both the fragments would be in the backward direction. But when it lies at an angle between 20° to 160°, one of the fragments would be in the forward and other will be in the backward direction.

Here, in this experiment, the distribution of angles of the fission fragments with respect to the primary beam direction is given in the fig. 5.18 for sample A. It is observed that out of 225 fission events only 32 events have their fragment in the forward hemisphere and only 16 events in the backward hemisphere and the remaining events have equal distribution in both the hemisphere. Thus in all 241 fragments are in the forward direction and 209 fragments in the backward direction. This gives the F/B ratio to be 1.15 ± 0.07. On similar consideration the forward-backward ratio for sample B

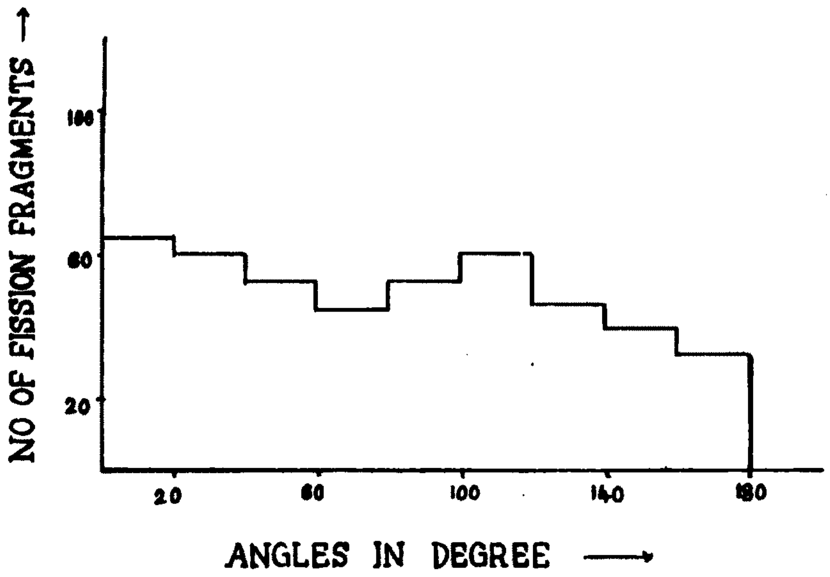

Fig 5.18 ANGULAR DISTRIBUTION OF INDIVDUAL FISSION FRAGMENTS IN K^- INTERACTIONS.

is found to be 1.12 ± 0.05. It is interesting to note that results obtained from above consideration agrees well with the experimental observation of F/B of fission bisector in the present study.

5.37 DISCUSSIONS :

In studying the fission phenomenon events with two heavily ionising short tracks emitted almost in opposite direction are taken as genuine fission events. However, a short fragment and a recoil may be emitted from the disintegrating star in such a way that may simulate a fission events and thus may contaminate the data collected. The contamination of this type may be checked from the following analysis. It appears from the velocity ratio (V_1/V_2) distribution curve for fission fragments, as shown in the figure 5.10 and 5.11 that the distribution curve falls off rapidly. Such a rapid fall is not expected for fragment recoil model of the disintegrating nucleus. Again, in our studies it is observed that the angle between the fission fragments vary from 90° to 180° with a mean angle for sample A at $140^\circ \pm 5$ and at $130^\circ \pm 5$ for sample B. Whereas in fragment recoil model angular distribution between them may vary from 0°- 180°. Thus we are justified in taking over events as genuine fission events.

Moreover, a close scrutiny of different aspects of fission events and recoils reveals some interesting results. Table below reflects some of the similarity in observations for both the events for kaon interaction in nuclear K5 emulsion. Further, a comparision of the angular distributions of the recoils and fission bisectors is also represented in the fig.5.19.

Table 5.5

Some aspects of fission compared to recoils

Observation	Excitation energy in Mev	Charge	Mass	Range	Distribution of angular bisector	F/B
Fission	420	24	60	9	anisotropic	1.40±0.08
Recoils	420	24	60	3.8	anisotropic	1.38±0.08

From the observed characteristics as compared, it can be inferred that the process of their production may be similar but are alternative to each other because fission seems to be due to the splitting of the residual excited nuclei which otherwise would have recoiled and thus would give rise to the recoils as studied in Chapter IV.

5.4 POSSIBLE EXAMPLES OF FISSIONS AT INITIAL STAGES :

Miller and Hudis[17] observed that the high energy nuclear disintegration is generally a two stage phenomenon

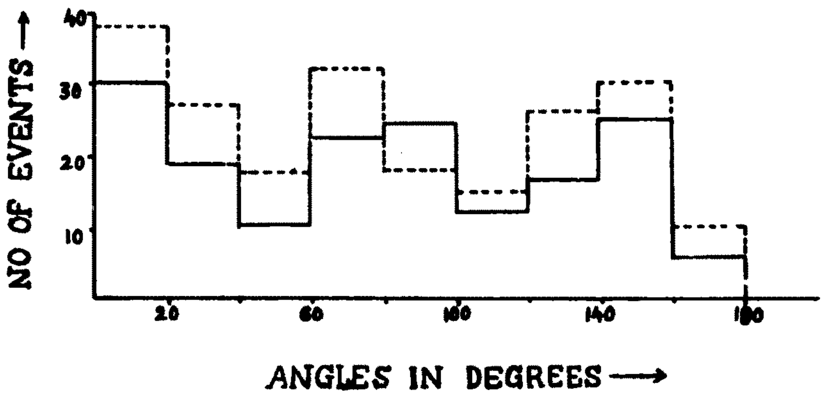

Fig 5.19 ANGULAR DISTRIBUTION OF RECOILS AS COMPARED TO THAT OF FISSION BISECTORS.
------FISSION
——RECOILS

(1) a knock on cascade in which some high energy nucleon particles are found to be ejected and (II) subsequent deexcitation of the excited nucleus by the process of nuclear evaporation along with nuclear fission as its competing process. The fission evaporation competation have been studied extensively by different workers[18-20] and they found that this is independent of the excitation energy. However, the work of Metropolis[21] et al. based on Monte-Carlo technique indicate that the competetion between evaporation and fission is independent of excitation energy upto about 100 Mev.

As there is no clear-cut model as to explain the fission phenomenon, as discussed in Chapter I, it is assumed that in high energy nuclear disintegration, evaporation from the highly excited nucleus takes place during the process of de-excitation and then in some cases the residual nucleus eventually breaks up into two equal parts of comparable masses resulting in fission. The events are generally isotropic. However, in some cases the highly excited nuclei may split, first into two parts with simulteneous evaporation of secondary particles from the separated parts. Now, these particles evaporated from the two oppositely moving parts, cease to be isotropic in the laboratory system, instead they are confined to the two divergent cones with their apex at the centre of disintegrating stars.

5.4.i Experimental Procedure :

Over and above the usual technique and selection criteria adopted for binary fission, scanners were instructed to observe the events where all the prongs (Black, grey) are distributed an-isotropically.

Events so obtained are carefully examined under high magnification to observe special characteristic if any in those events.

5.4.ii Results :

About 11 events of this type were recorded for observations. The observation made on these events lead to the following informations -

(i) The prongs are confined to two divergent cones having apex at the centre of the disintegrating stars.

(ii) The cones are oppositely directed and the angular separation between them are on the average is about 100^{0}.

(iii) In about three cases, each cone is found to contain a short recoil, in some cases only one recoil and in some cases no recoil at all.

(iv) Each cone of the stars contains nearly equal number of heavily ionising prongs ($N_h \sim 5$).

Microphotograph of this type of events are shown in the plate 2.

5.4 iii DISCUSSION :

The presence of these events with anisotropic prong distribution may be usually explained by the fact that there is always some natural statistical fluctuations in the spatial distribution of the emitted particles. This may sometimes lead to the significant deformation in their angular distribution. However, contribution to that effect is claimed to be small[22]. In the light of the above findings one may believe that these events represent the fission at the pre-evaporation stage as follows from the competetion between the fission and evaporation of de-excited nuclei under cascade evaporation model. Therefore, it may be concluded that these events are binary fissions at the initial stages of de-excitation of the disintegrating nuclei.

5.5 SUMMARY :

To summarise our observations we may note the following few points.

For general fission events -

1. The excitation energy for production of fission is high as compared to the non-fission events.
2. The average charge and mass of the pre-fission are found to 24 and 60 nuclei respectively for sample A, and for sample B it is found to be 20 and 47 respectively.
3. Fission cross-section for sample A is found to be lower whereas for sample B it is in conformity with Katcoff but not as expected by Hussain.
4. Average range of the fission fragments in k^- interaction is found to be 9 microns whereas $\bar{p}$ interaction is observed to be about 12 microns.
5. Range ratio of the fission fragments for both the

samples are mostly confined to 1 to 1.5.

6. Angular distribution between fission pairs - the mean value is found to be $140^{\circ} \pm .5$ for sample A and sample B it is found to be $130^{\circ} \pm 5$.

7. Distribution of fission bisector for both the samples are observed to be anisotropic with $F/B = 1.40 \pm 0.08$ for k^- interaction and $F/B = 1.3 \pm 0.06$ for $\bar{p}$ interaction.

8. They are similar to recoils.

9. For fission at the initial stage, the anisotropic distribution of the prongs goes to such an extent that they are confined two oppositely directed divergent cone which may be an indication of fission at initial stage of de-excitation.

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