2.1 CALIBRATIONS OF THE STACKS.

For the Ilford G5 and NIKFI-R emulsions used in the present studies, the following calibrations have been made.

(a) Determination of Shrinkage Factor:— During the processing of emulsion, the silver halide crystals unaffected by the ionising particles are dissolved by the fixer. This results in a considerable decrease of the volume of the emulsion. For glass-mounted plates there occurs considerable reduction of the thickness of the emulsion layer. The ratio of the thickness of the emulsion at the time of exposure to its thickness at the time of measurements is called the shrinkage factor. For determining the actual ranges and angles of the tracks formed in emulsion, the shrinkage factor should be accurately known. Since the shrinkage factor is sensitive to the temperature and humidity of the room where the emulsion plates are stored, it is preferably determined during the period of measurements.

In order to determine the shrinkage factor, a large number of alpha tracks due to thorium stars are recorded in the plates where most of the events, required for the study, have been found. The maximum range $R$ of the alpha track is determined by measuring the ranges of the flat tracks. Also, the maximum projected range $P$ of the tracks having nearly
Some dip angle is determined from the measurements made on a large number of inclined tracks. The shrinkage factor $S$ of the emulsion sheet can be estimated from the relation,

$$R^2 = P^2 + S^2 d^2,$$

where $d$ is the dip over the whole projected range of the track. The original thickness of the emulsion sheet at time of exposure can be computed from its shrinkage factor and the final thickness. Since the final thickness of the emulsion sheets has been found to vary from region to region, the shrinkage factor has been determined by making a large number of measurements at different points all over the emulsion surface. For G5 and NIKFI-R emulsions, the shrinkage factors have been estimated to be $2.3 \pm 0.2$ and $2.27 \pm 0.2$ and the original thicknesses to be $(600 \pm 50)$ and $(400 \pm 30)$ microns respectively.

(b) **Determination of Stopping Power:** In order to determine the energy of a particle from its observed range in a medium, it is essential to know the stopping power of the medium precisely. The stopping power of emulsion depends on the density of the chemical composition and the moisture content at the time of exposure. It is determined as follows.

A number of $\pi^+ - \mu^+$ decays are recorded in the emulsion sheets where most of the events to be studied are found. The ranges of these tracks are measured. The mean range in G5 emulsion comes out to be $(595 \pm 3)$ microns. Using
the U.C.R.L. range-energy tables, the range of the muon of energy 4.12 MeV is found to be \((600.5 \pm 3)\) microns. Since the stopping power is given by the relation

\[
(2.2) \quad K = \frac{R_{at}}{R_u}
\]

where \(R_{at}\) is the mu-range in standard emulsion,

\[
(2.3) \quad K = \frac{600.5 \pm 3}{595} = 1.01 \pm 0.001
\]

Thus the range taken from the table mentioned above has to be corrected by multiplying it by this value of \(K\).

Following the same procedure, the value of \(K\) for NIKFI-R emulsion has been estimated to be \(0.995 \pm 0.001\).

Both G5 and NIKFI-R emulsions are electron sensitive although the latter is found to be slightly less sensitive as the grain-density measurements of the primary have indicated. The stopping powers are, however, found to be practically same for both types of emulsion.

2.2. MEASUREMENTS OF RANGE.

The range of a particle is the distance traversed by it before being brought to rest. The true range of a linear track can be estimated from its projected range and the dip-angle with respect to the emulsion surface. The projected range is measured by means of a graticule scale of length 80 microns. The ranges of the tracks shorter than the graticule scale are measured directly. For the longer tracks of range greater than 80 microns, the graticule scale is shifted in
steps through its own length in a direction parallel to the track so as to measure the projected range of the required number of segments into which the tracks have been subdivided. In making such displacements, a grain or any other prominent feature of the emulsion coinciding with one end of the graticule scale has been used as a fiducial mark while moving the stage of the microscope. The tracks, which are bent or scattered, are divided into the required number of segments of suitable lengths and the projected range of each segment is measured separately. The dip angle is deduced by measuring the relative depth between two points on the track by means of a dip screw and the projected distance of separation between these two points on the graticule scale. To obtain the true dip angle corresponding to the unprocessed emulsion, the shrinkage factor of the emulsion has been taken into consideration. Thus if \( P \) is the projected range, \( d \) is the difference in the depths and \( S \) is the shrinkage factor of the emulsion, then the actual range of the track, i.e., the range of the track in the unprocessed emulsion is given by the relation

\[
(2.4) \quad R = \frac{P}{S} + d,
\]

where \( \theta = \tan^{-1} \left( \frac{d}{P} \right) \) is the dip angle.

There are, however, several factors which limits the accuracy of range measurements. These are: (i) uncertainty in determining the point from which the track originates, (ii) frequent scattering of the track which often renders it difficult to place the graticule scale properly, (iii) distortion of the
emulsion during processing and (iv) uncertainty caused by straggling.

2.3. MEASUREMENTS OF ANGLE.

The primary tracks are very nearly parallel to the emulsion surface so that their dip angle can be taken as zero. The space angle $\theta$ of a track with respect to the primary beam, in terms of its projected angle $\phi$ with the primary beam and the dip angle $\delta$, is given by the relation.

\[
\cos \theta = \cos \phi \cos \delta.
\]

The space angle $\theta$ between two tracks having dip angles $\delta_1$ and $\delta_2$ and projected angle $\phi$ between them is given by the relation

\[
\cos \theta = \cos \phi \cos \delta_1 \cos \delta_2 + \sin \delta_1 \sin \delta_2.
\]

In the measurement of the projected angle also, large errors may be introduced by several factors, such as distortion of emulsion during processing and multiple coulomb scattering of the track. Further, observational errors are invariably introduced in measuring the dip angle because of the finite depth of focus of the objective of the microscope and, in measuring the angle of the short tracks, due to uncertainty in placing the eyepiece graticule along the track of finite width.

2.4. DETERMINATION OF ENERGY FROM THE OBSERVED RANGE.

In photographic emulsion, the energy of various ions can be determined from the observed range by using the range-energy-relations given by different authors. But the precise determination of energy depends on the accuracy of these
range-energy relations and on the range-straggling in emulsion. For lighter nuclei, such as protons or alpha particles, the range-straggling is prominent and necessitates corrections in the observed range. The process of capture and loss of electrons in various orbits of a moving nucleus is an important factor that determines the range-energy relation for the nucleus. The ranges of lighter nuclei are, however, not much affected by this process as it takes place only in the last few microns of the residual range. But this considerably affects the ranges of heavy nuclei. Many authors have made efforts to derive accurate range-energy relations for the heavy nuclei taking into consideration the effect of capture of electrons in different nuclear orbits.

In the present work the range-energy relations given by several authors have been used according to the requirements. For alpha particles of energy below 20 MeV, Wilkins curves and for energies above 20 MeV, the range-energy relations published by the Berkeley group have been used. For heavier fragments with charge \( Z > 3 \) and range greater than 200 microns, range-energy curves have been drawn from the range-energy relation of protons following the instruction given in the same report of the Berkeley group. For lower energies, the range-energy curves given by Papineau have been used.

2.5. IDENTIFICATION OF CHARGED PARTICLES.

The identification of a charged particle requires precise determinations of its mass \( A \) and charge \( Z \). The tracks
formed by ions in emulsion possess some distinctive features pertaining to their mass, charge and velocity. It is, therefore, possible to identify a charged particle from the study of the features of the track.

(1) **DETERMINATION OF MASS.**

The mass of a particle producing low ionisation and stopped in the emulsion can be ascertained by the methods described below.

(a) **Grain-density and Range Measurements:** The ionisation produced by a particle in a medium is proportional to its charge and velocity and also depends on the mass. Therefore, if two particles have same charge and velocity, their ionisation will be same and the ranges will be proportional to their masses.

Experimental curves may be drawn for the two particles with the grain-density against the residual ranges of the two tracks. Then, for the same grain-densities, a series of ratios of their residual ranges can be determined from the graph. The mean value gives a measure of the ratio of their masses. Knowing the mass of one particle the same for the other can be determined.

The grain-density $g$ of a track is defined as the number of grains per unit length of the track and can be measured simply by counting the number of grains over a known range. In such measurements, it is often required to estimate the number of grains in a clump comprising several grains.
This subjectiveness introduces uncertainties in the measurement of grain-density. The difficulty is partly avoided by counting the number of such clumps or blobs of any size individually over a known range without resorting to any discrimination of the size of the clumps. This gives what is known as blob-density. The blob-density is then converted to grain-density by using a suitable relation. The grain-density thus determined, is normalised with respect to the grain-density \( g_0 \) of a minimum track. The normalised grain density \( g = \frac{g}{g_0} \) is independent of the degree of development of the emulsion. In order to determine \( g_0 \), the blob-density \( b_0 \) of a primary relativistic particle is estimated, and \( g_0 \) is determined by the following relation due to Fowler et al.

\[
(2.7) \quad b_0 = g_0 e^{-\alpha g_0},
\]

where \( \alpha \) is a parameter that depends on the developed grain size, the optical resolution of the microscope and the idiosyncrasy of the observer. The value of \( g \) for a highly ionising track can be determined from the estimate of the blob-density \( b \) and gap-density \( h \) and using the relation

\[
(2.8) \quad h = be^{-\alpha l},
\]

where \( l \) is the gap-length between two adjacent developed blobs. This value is so adjusted that \( h \) is nearly 1/4th of \( b \). In order to examine the degree of ionisation produced by the grey tracks in 65 emulsion, we have measured 867 blobs and 251 gaps of a track associated with a star due to heavy emulsion nuclei, and have
estimated its $g$ value to be 39.7 grains per 50 microns. For another track with 561 blobs and 140 gaps, the value of $g$ has come out to be 55 grains per 50 microns. The value of $g_0$ in the same emulsion sheet has been found to be about 10 grains per 50 microns. Hence the values of $g$ for the two tracks have been estimated to be .40 and .56 nearly.

(b) **Scattering and Range Measurements**— The scattering of a particle in a medium is a function of its mass, charge and velocity. Therefore, the ratio of the masses of two particles can be determined from the observation of multiple scattering of their tracks. The 'constant sagitta' method introduced by Biswas, Dilworth et al. and Holtebeck et al. can be used for the measurement of mass of a light particle. In this method Coulomb scattering measurements are performed from the end of the stopping particle using the calculated cell size available in tabular forms for a proton and a pion (Gettstein et al.), and hence the scattering parameter $\bar{H}$ for the particle to be identified can be obtained. The unknown mass of the particle is estimated by the following relation:

$$\frac{m_p}{m_P} = \left(\frac{\bar{H}_P}{\bar{H}_P}ight)^{2.31} \tag{2.9}$$

where $m_p$ and $m_P$ are the masses of the particle and a proton and $\bar{H}_P$ and $\bar{H}_P$ are the mean noise corrected sagitta (second difference) for the particle and the proton respectively.

For a particle of charge $I$, the following modified
The standard error of the estimated value of the mass $m_p$, obtained by this method, is calculated by taking the statistical error $D_p$ to be $\frac{0.76}{\sqrt{n}}$ where $n$ is the number of independent cells taken.

(2) **DETERMINATION OF CHARGE.**

The methods commonly used in emulsion studies for the identification of charge of nuclear fragments are based on the fact that the degree of ionisation of a charged particle depends on its charge $Z$ and velocity $V$. From emulsion studies it was found that the physical features of the tracks of light nuclear fragments are quite different from those of heavy ones. The pronounced tapering towards the end of the range and the large values of delta-ray density observed in the tracks of nuclei with charge number $Z > 4$ are in marked contrast with the comparatively uniform structure of the tracks of protons or alpha particles. These features become more pronounced with the increase of charge of the fragment.

The important factors, which determine the features of a track are the production of delta-rays and the neutralisation of the charge towards the extreme end of the range.

When a charged particle penetrates matter, its electric field disturbs the atomic electrons with varying amount of energy-transfer. If an electron, in sensitive emul-
sion, receives kinetic energy exceeding some 2000 eV, it is likely to have a range long enough to produce an observable track by secondary ionisation. Such electron tracks are known as delta-rays, which in emulsion, appear as thin and short tracks projecting from the trajectory of the charged particle. If the energy-transfer is less than the value cited above, the range of the electron will be shorter than the mean grain-diameter, and the ionisation will be almost entirely confined to those grains which lie exactly on the trajectory of the particle. On being developed, these grains give the central core of the track which has a width equal to the mean diameter of the developed grains.

The theoretical expression given by Mott\textsuperscript{52} for the number $N$ of electrons of energy $\geq W$ projected as delta-rays per unit length by a particle of charge $Ze$ and velocity $V$ is

$$N(W,V) = \frac{2nZe^2}{W^2} \left(1 - \frac{1}{2WV^2}\right),$$

where $n$ is the mass of an electron.

Because of $E^2$ dependence, the delta-ray density of heavy fragments is far greater than that of protons or alpha particles when the velocities of the particles are in the same order of magnitude.

Lonchamp\textsuperscript{53} pointed out that the main contribution to the width of the track due to heavy ions comes from the secondary ionisation. He also proposed a simple theory in which the width of a track can be computed in terms of delta-ray flux.
Different track-width theories have been proposed by a number of authors in which the observed track-width can be computed as a function of the charge and the velocity of the particle. But these theories do not yield an explicit functional relation between the mean track-width and the charge and the velocity; and we do not have so far a generally accepted theory of track-width. Nevertheless, the works of these authors made it possible to understand qualitatively some of the complex features of the tracks of nuclear fragments with higher charge number.

At the present time, the apparent thinning down of the track of a heavy fragment, as it slows down in a sensitive emulsion, is known to be chiefly a delta-ray phenomenon. The maximum range of delta-rays increases with the particle velocity. When the particle velocity is sufficiently high, the delta-rays are so numerous and so short that they are not individually resolved but have a continuity in their appearance and add to the increase in the thickness of the core of the track. Capture of electrons in different orbits of a nucleus occurs only over a small distance, some 10 microns, of the residual range reducing the effective charge of the nucleus. This provides an explanation of the presence of the thin core in the tracks of heavy fragments over the last few micron of the range, where the track is indistinguishable from those of protons or alpha particles.

There are, however, other mechanical causes, such as
the grain size and sensitivity of the emulsion which affect the physical condition of the track. In the region of large specific ionisation, lateral displacements of the grains may occur when the space is not enough for the developed grains to lie along the trajectory of the particle. This causes the track to buckle. The buckled tracks appear broad, and more so when they have large angle of dip.

Barkas pointed out that, for a given velocity of the nuclear fragment and a particular sample of developed emulsion, the track-width increases monotonically with the charge number of the fragment and approaches an asymptotic value determined by the maximum range of the delta-rays. The maximum range of the delta-rays, which depends on the charge of the fragment, sets a limit on the observed width of the track. For particles with high values of charge, the track-width depends on the velocity rather than on the charge.

In emulsion studies the following methods are commonly adopted for the identification of charge of the nuclear fragment.

(a) Delta-ray Observation:— The relation (2.11) shows that production of delta-rays by a charged particle is a function of its charge and velocity. Therefore, if two particles have velocities in the same order of magnitude, the maximum values \( N_1 \) and \( N_p \) of the delta rays produced by them are connected with their charges \( Z_1 \) and \( Z_p \) by the relation

\[
\frac{N_1}{N_p} = \frac{Z_1^2}{Z_p^2}
\]

(2.12)
Hence, by counting the number of delta-rays of the two particles and knowing the charge of one, the charge of the other can be determined. In making observations on delta-rays, it has been a convention to confine to those delta-rays which produce four or more grains. Such tracks correspond to energies \( \gg 15 \text{keV} \). The method is, however, applicable only to long tracks which register large number of delta-rays; for the short tracks, where the delta-rays are few, this method is not useful.

(b) **Tapering Length Measurements**: For all heavy nuclei there exists a residual range at which the developed core has a maximum width. This range is known as the tapering length. It was shown by Frier et al.\(^5\)\(^7\), Perkins\(^4\) and Hoang\(^5\)\(^8\),\(^5\)\(^9\) that for an ion the tapering length \( L \) (microns) depends on the charge \( Z \). They derived the following empirical relations connecting \( L \) and \( Z \).

\[
\begin{align*}
(2.13) \quad s^2 &= \frac{L}{0.5} \quad \text{Frier et al.}^{57} \\
(2.14) \quad s^2 &= \frac{L}{0.7} \quad \text{Perkins}^{4} \\
(2.15) \quad s &= \frac{L}{10} \quad \text{Hoang}^{58},^{59}
\end{align*}
\]

It appears that the relation between \( L \) and \( Z \) depends on the details of the method of estimating the tapering length and on the degree of development of the emulsion used and must be verified by each observer in the sample of emulsion used for the study. Identification of charge by this method is applicable to nuclei of charge \( Z > 3 \).

(c) **Average Track-width Measurements**: Apart from the
statistical fluctuations in the ionisation of nuclear fragments, the observed width of a track depends in a complex way on the conventions and means employed for the measurements. Dilworth and Oschialini undertook a detailed study of track-width by means of eyepiece-micrometer and pointed out that the observed mean width $W$ of a track depends on the following conditions.

(i) Intensity of light: The light should be monochromatic and the intensity in the eyepiece should remain constant throughout the series of measurements. The measured diameter of a single blob was found to decrease with the increase of light-intensity.

(ii) Fatigue: Errors in observations are introduced due to fatigue of the observer as a result of repeated measurements for a long period of time.

(iii) Quality of development: The variation of the grain-diameter with the variation of the degree of development of the emulsion gives rise to the major difficulty in the application of the method of width measurement.

(iv) Depth and inclination of the track: The observed width of a track depends on the depth in the emulsion where the track is located. It also increases with the inclination of the track to the emulsion surface.

In order to secure the best result, it is necessary to keep the intensity of light and the observer's fatigue under close control. In the present investigation track-width
measurements are made by means of an eyepiece-micrometer of high mechanical precision. The intensity of light is kept constant throughout the series of measurement by properly adjusting the position of the condenser unit of the microscope and opening the diaphragms by the required amount. A green filter glass has been used in order to render the white light nearly monochromatic and also to lower the intensity of the light to a limit best suited to the observer's eye.

Track-width measurements are performed over the last 40-50 microns of the residual range and, for the short tracks, over the entire range. For these measurements, we have adopted the method originally proposed by Nakagawa et al. The range has been divided into a number of cells each of which being 5 microns in length. The cell-length has, however, been chosen according to the amount of inclination of the track to the emulsion surface. Each track is put along the X-axis of the stage of the microscope and its width is measured at the cells by turns. Following Nakagawa et al., the displacement of the hair line of the eyepiece located along the upper and the lower profile of a track has been taken as a measure of the width of the track. The mean track-width has been estimated as the mean of the measurements made on the different cells.

2.6 THE POWER OF RESOLUTION AND CALIBRATION OF THE METHOD.

The accuracy in identification of nuclear fragments
By track-width measurements depends on the resolution power of the method used. In order to examine the potentiality and the resolution power of the method, we have made a series of measurements on the tracks of known identity, such as the thorium alpha tracks and the hammer tracks due to Li$^6$ and Be$^6$ nuclei. From these measurements, the correction factor necessitated by the effect of inclination of the tracks to the emulsion surface has been worked out and special calibrations have been made so as to evolve a method of identification common for tracks of arbitrary inclinations and produced by any type of ion.

(a) **Width Measurements on Flat Alpha Tracks: the effect of depth** - We have measured the track-width of a large number of flat alpha tracks of thorium stars lying at different depths of the emulsion sheets used. From these measurements we have estimated the mean width of the tracks lying at the depths ranging from 10 to 20 microns from the top surface of the emulsion sheet to be $0.85 \pm 0.02$ microns. The value for the tracks lying between 20 and 40 microns from the top surface has been found to be $0.70 \pm 0.02$ microns. Further measurements performed at still greater depths have not shown any appreciable change of the mean widths of different groups of tracks located at different levels in the emulsion sheets. However, the visibility of the tracks lying very close to the glass surface of the emulsion sheet is somewhat poor. This effect appears to persist up to a distance of about 10
FIG. 1. DISTRIBUTION IN MEAN TRACK-WIDTHS OF (a) Th α TRACKS, (b) Li²⁸ HAMMER TRACKS, (c) B⁸ HAMMER TRACKS IN G5 EMULSION AND (d) Li²⁸ HAMMER TRACKS IN NIKFI-R EMULSION.
microns from the glass surface in most of the emulsion sheets. The effect of depth has been avoided by confining the measurements only to those tracks which have been located in the central region lying below 40 microns from the air surface, 20 microns above the glass surface and .5 mm from the edges of the emulsion sheets.

(b) Width-Measurements on Flat Hammer Tracks: In order to graduate the observed width-distribution of the tracks to be identified, it is necessary to determine the dispersion of the track-width distribution of fragments of known identity. Accordingly, we have carried out measurements on 50 hammer tracks in 65 emulsion and on 20 hammer tracks in NIKFI-R emulsion. These tracks have been found to be nearly flat and centrally located in the emulsion. From visual inspections it has been found that three tracks in the former group are visibly thicker and register more numerous delta-rays than the others in the group. The mean width of each of these tracks has been estimated to be much larger than that of any other track in the group. Microphotographs of a few hammer tracks due to the decay of Li$^8$ and $\beta^5$ nuclei are shown in Plate 1.

In Fig.1 we have shown the distributions in mean width of (a) 50 alpha tracks of thorium stars, (b) 47 hammer tracks due to Li$^8$ nuclei and (c) 5 hammer tracks due to $\beta^5$ nuclei collected from 65 emulsion. The average track-width of the alpha tracks and that of the hammer tracks due to Li$^8$ nuclei have been found to be .68 and .82 microns approximate-
FIG. 2. PLOT OF THE MEAN TRACK-WIDTH OF Li$^8$ HAMMER TRACKS AGAINST THE CORRESPONDING VALUES OF DIP ANGLE IN THE PROCESSED EMULSION. THE POINTS MARKED 1 AND 2 REPRESENT B$^8$ HAMMER TRACKS.
ly, the dispersion being .08 microns for each group. The mean width of the \( \text{Li}^8 \) tracks is found to be 1.04 microns. The dashed histogram in Fig. 1 shows the mean track-width distribution of the hammer tracks due to \( \text{Li}^8 \) nuclei observed in NIKFI-R emulsion. The mean width, in this case, has been estimated to be .92 microns. Thus it appears that the track-width does not vary appreciably when one goes from \( \text{Li}^8 \) to NIKFI-R emulsion; the difference in the mean widths of two groups of hammer tracks being, on the average, only .008 microns.

(e) Width Measurements on the Inclined Hammer Tracks: In order to investigate the mode of variation of the apparent thickness of tracks of the same kind of ions with the variation of the dip angle and to evolve a method of transforming the apparent width to the real width referred to zero angle of dip, more measurements have been performed on a group of 105 'hammer tracks' of various inclinations to the emulsion surface. For the tracks inclined at angles exceeding 20° in the processed emulsion, the cell length has been chosen to be 2.5 microns, and the width has been measured as before over the last 40 to 80 microns of the residual range.

The result of the measurements are shown in Fig. 2, where the mean values of the track-width of the individual tracks are plotted against the corresponding values of the dip angle. Although the points are widely scattered, they reveal a general upward trend as the dip-angle increases. The full line fitted to the points by the method of least square is
evidently a good enough approximation for the statistics in consideration. The detailed calculation is given in Appendix I. It is apparent from the figure that the mean width increases rather slowly as the dip angle increases. The intercept of the Y-axis by the curve at \( \delta = 0 \) corresponds to the mean width of the absolutely flat tracks. This comes out to be .85 microns. The two isolated points marked 1 and 2 in the figure represent the apparent width of two hammer tracks identified as \( ^{5} \) nuclei. These tracks were visibly thicker and displayed comparatively more delta-rays.

The correction factor corresponding to a particular value of the dip angle may be expressed as the ratio of the mean track-width of the absolutely flat tracks to the mean of the apparent track-widths for that value of the dip angle. For every inclined track, the corrected mean width may be obtained by multiplying the apparent width by the proper correction factor.

2.7. CORRECTIONS FOR LOSS OF EVENTS.

In the emulsion technique there are certain factors which may cause the loss of a few events looked for. A brief discussion of the factors relevant to the present investigation is given in the following.

(a) Loss of Events during Scanning: For the present investigation the method of area scanning has been adopted in order to collect all the data required for analysis. Area scanning of the emulsion pellicles is performed in small areas enclosed by the sides of the squares of the grid printed on the emulsion
surface. The procedure followed is to make the focal surface in the emulsion to sweep up and down from the upper surface to the glass surface of the emulsion pelliole by rolling the fine focus control between the fingers while observing the events one by one coming into and going out of view. By displacing the field, successive areas were examined and the events recorded.

A few events may evade detection during scanning. The loss thus incurred requires evaluation so that correct estimates of the frequency or the probability of occurrence of a particular type of event can be made. The usual procedure followed is to scan the volume and record a number \( N_1 \) of events, then to scan it again by the same method recording a number \( N_2 \). If either sample contains events not found in the other, the scanning must be repeated until no new events are observed. The scanning technique and the magnification of the microscope may be changed to check the presence of any further events. If the volume scanned actually contains \( N \) events and the number of events found in the first scanning is \( N_1 \) and that in the second is \( N_2 \), and the number common to both the scanings is \( N_{12} \) then

\[
(2.16) \quad N = \frac{N_1 + N_2}{4N_{12}}
\]

and the efficiency \( E \) of the scanner is

\[
(2.17) \quad E = \frac{2N_{12}}{N_1 + N_2}
\]
(b) Loss of Event due to the Limitation of the Dip Angle—

The correction factor for the loss of events due to limitation of the dip angle to $30^\circ$ has been worked out as follows:

In the unprocessed emulsion the number of fragments enclosed in an imaginary cone with its vertex at the centre of the star would be the same for all arbitrary inclinations of the cone provided that the axis is always perpendicular to the primary beam and that the statistical fluctuations in the direction of emission of the fragments is ignored. For a dip angle $\delta$ degrees in the processed emulsion, the dip angle in the unprocessed emulsion is given by $\tan^{-1} (S \tan \delta)$ degrees where $S$ is the shrinkage factor of the emulsion. If, therefore, the observation is limited to only those fragments whose dip angle does not exceed the value $\delta$ (degrees) in the processed emulsion, then all the tracks which lie within the two cones having their axes perpendicular to the emulsion surface and the semivertical angles

$$2.12 \frac{\pi}{2} - \tan^{-1} (S \tan \delta) \text{ degrees},$$

would be lost. The number of fragments lost must be equal to that which lie within two similar cones having their axes parallel to the emulsion surface. By calculating, for every track, the space angle with respect to the direction perpendicular to the direction of the primary, the number of fragments lying within such cones is determined. If $S_1$ is the number of fragments recorded and $S_2$ is the number of fragments lying within the cones, the actual number of fragments will be $S_1 + S_2$. Then
FIG. 3. PERCENTAGE LOSS OF TRACKS WITH PARTICLE RANGES.
the actual number of fragments can be determined approximately by multiplying the observed number by the factor \( \frac{S_1 + S_2}{S_1} \).

From a large number of measurements the correction factors have been estimated to be \((1.23 \pm .23)\), \((1.25 \pm .25)\) and \((1.20 \pm .2)\) for the energies of 24 GeV protons, 17 GeV negative pions and 3.5 GeV negative pions respectively.

(c) Loss of Tracks going out of the Emulsion Sheets:— For an accurate estimate of the frequencies of emission of fragments, the loss of tracks due to their escape from the emulsion sheet should be taken into account. An estimate of the loss of the tracks which escape from the emulsion sheet was made by Deka from geometrical considerations of each emulsion sheet. The percentage of the loss of groups of tracks of various ranges was calculated by considering their successive positions and orientations with respect to the emulsion surface, the thickness of the superimposed emulsion being taken to be 600 microns. The mean percentage loss of tracks of various ranges was plotted as shown in Fig. 3.

2.8. CONCLUSIONS.

Width measurements on the steep tracks, particularly those which have dip angles exceeding 30° in the processed emulsion are rendered difficult by the diffuse appearance of the track profile. Further, the whole length of the cell cannot be brought into focus. Due to these reasons there is un-
certainty in placing the hair-line of the eyepiece properly along the track profile. To minimise the error resulting from this, several trials have been made in placing the hair line properly before the final reading is taken. The correction factors worked out for a hammer track of a certain dip angle should be applicable to the tracks of any other ion having the same dip angle.

The measurement, however, do not lead to any definite relation connecting the mean track-width of a fragment with its charge number\(^6\). But the method is sufficiently sensitive to the variation of the track-width with the charge number and has high resolving power so as to resolve one group of tracks from another differing by one unit of charge. Therefore we expect that the method, with unaltered measurement conventions, would enable us to identify the tracks of other heavy nuclear fragments as well.

In the present investigation the efficiency of scanning has been found to be above 96 percent as has been computed from three different scannings by changing the magnification once.

As regard the corrections for the loss of tracks escaping from the emulsion sheet where the events have been located and for the limitation imposed on the dip angle, it should be mentioned that for the stable fragments the former correction is not necessary as we have followed the trajectories to the neighbouring sheets. However, the later correction has
to be made in estimating the frequency of emission and the probability of occurrence of the fragments. In selecting the alpha pairs resulting from the decay of Be⁶ nuclei, no limitation has been imposed on the dip-angle; but, since the trajectories of the alpha particles have not been followed, the corrections for the loss of tracks have been made.