2.1 Introduction

Nuclear research emulsion is generally used in the study of nuclear interactions as both the target and detector. Much of the data on hadron-nucleus and nucleus-nucleus interactions have come from pure emulsion stacks exposed to cosmic rays or to accelerator beams. The nuclear emulsion records the passage of the charged particles as tracks which can be seen under the microscope, after chemical processing, as 3-dimensional strings of silver grains. The undeveloped emulsion consists of roughly equal parts by volume of silver halide crystals and a gelatin matrix which holds the grains in place. The passage of a charged particle through the emulsion renders some silver halide crystals along its path developable. During the development process, these crystals are converted into silver grains and the undeveloped crystals are washed out of the emulsion. The developed silver grains vary in diameter roughly from 0.1 to 1.0 micron.

The nuclear emulsion consists of two groups of nuclei, viz. a light atom group of H, C, N, O, etc. which are constituents of gelatin and a heavy atom group of silver halides (mainly bromide). Normally, the emulsion also contains some water. Glycerine is used as plasticizer, to prevent it from becoming brittle. The chemical composition by weight of nuclear emulsion can be summarized as 1% hydrogen (H), 16% carbon-nitrogen-oxygen (C,N,O), and 83% silver-bromide (Ag,Br). The composition of standard emulsion as well as atomic weight $A_i$, number of atoms $N_i$ per c.c, and moles per c.c for the element of
atomic number \( Z \) are given in Table 2.1 (1).

When a particle of charge \( ze \) and mass \( M \) traverses a medium of atomic number \( Z \) and mass number \( A \), it excites and ionizes the atoms of the medium due to Coulomb interactions. This results in loss of energy of the incident particle. The rate of energy loss \( dE \) per unit length \( dX \) traversed is given by (2)

\[
\frac{dE}{dX} = \frac{4 \pi N Z z^2 e^4}{m v^2 A} \left[ \ln \left( \frac{2 m v^2}{I(1 - \beta^2)} \right) - \beta^2 \right],
\]

(2.1)

where \( v \) is the velocity of the particle, \( \beta = v/c \), \( N \) is the number of atoms per unit volume of the stopping material, \( I \) is the mean ionization potential and \( m \) is the mass of the electron. It is clear from equation (2.1) that the energy loss does not depend on the mass \( M \) of the incident particle. It is only a function of its velocity and charge. Since the logarithmic term varies only slightly with \( v \), the energy loss is proportional to \( z^2/v^2 \) and \( Z/A \) to an approximation at low velocities \( (v \ll c) \).

The nuclear emulsion is a versatile instrument for the detection of charged particles. It produces a visible track along the trajectory of a charged particle. Particles of different ionizing powers produce tracks which appear quite different. It has a unique spatial resolution and can resolve events in space separated by even a few microns. The nuclear emulsion has high density and high stopping power, about 1700 times the stopping power of standard air. Due to this, many short lived particles can be brought to rest in emulsion, before they decay. Sensitivity of an emulsion could be changed according to the requiremen
TABLE 2.1*

The chemical composition of standard emulsion

<table>
<thead>
<tr>
<th>Element</th>
<th>$Z_i$</th>
<th>$N_i$ ($\times 10^{20}$)</th>
<th>$A_i$ ($\times 10^{-3}$)</th>
<th>Mole/c.c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>47</td>
<td>101.01</td>
<td>107.88</td>
<td>16.764</td>
</tr>
<tr>
<td>Br</td>
<td>35</td>
<td>100.41</td>
<td>79.92</td>
<td>16.673</td>
</tr>
<tr>
<td>I</td>
<td>53</td>
<td>0.56</td>
<td>126.93</td>
<td>0.094</td>
</tr>
<tr>
<td>S</td>
<td>16</td>
<td>1.35</td>
<td>32.06</td>
<td>0.216</td>
</tr>
<tr>
<td>O</td>
<td>08</td>
<td>94.97</td>
<td>16.00</td>
<td>16.050</td>
</tr>
<tr>
<td>N</td>
<td>07</td>
<td>31.68</td>
<td>14.01</td>
<td>05.147</td>
</tr>
<tr>
<td>C</td>
<td>06</td>
<td>138.30</td>
<td>12.00</td>
<td>22.698</td>
</tr>
<tr>
<td>H</td>
<td>01</td>
<td>321.56</td>
<td>01.01</td>
<td>53.571</td>
</tr>
</tbody>
</table>

* Totals: $N = 7.898 \times 10^{22}$ atoms/c.c.

$$n_e = \Sigma N_iZ_i = 1.0446 \times 10^{24} \text{ electrons/c.c.}$$

$$= 1.7338 \text{ moles/c.c.}$$
of the experiment. G5 emulsions are so sensitive that singly charged particles of \( v/c \sim 1 \) and even electrons and fission products of all energies can be recorded. The nuclear emulsion being light as compared to other detectors has served very well the need of cosmic ray experiments. After the development of nuclear emulsion, if it is kept under specified condition, the photographed events can be preserved for many years.

Beside these, the nuclear emulsion has some drawbacks also. It requires special dark room processing and very careful handling before development. In the emulsion it is not possible to predict the target nucleus involved in the collision and the time of the particle's detection. The emulsion technique is also very slow.

In the following sections of this chapter, the details of emulsion stack used in the present experiment is given and the experimental techniques adopted in the present experiment including scanning, measurements of charge, etc. have been discussed.

2.2 Details of the Stack

A stack of BR-2 emulsion, consisting of 40 plates, each of size 18.7 x 9.7 x 0.06 cm\(^3\) with printed grid, exposed to 4.5 A GeV/c carbon beam at synchrophasotron of the Joint Institute of Nuclear Research (JINR), Dubna, USSR, has been used in the present investigation. The plates after development were mounted on glass. In order to obtain almost horizontal carbon tracks, the incident beam was allowed to pass through the plates parallel to one of its edges and in the plane of the
emulsion. Due to negligible dip angle, most of the carbon tracks travel the full length of the stack provided that they have not interacted in between.

2.3 Scanning

When the nuclear beam passes through an emulsion stack, the beam particles interact with the nuclei of emulsion and a number of charged and neutral particles are produced. The emulsion by virtue of its photographic action records tracks of the charged particles. A track is the signature of the charged particle responsible for its formation. All the charged particles produced in an interaction have a common vertex. When the interaction is viewed under high magnification of a microscope it looks like a 'star'. The process of locating the position of an interaction in the emulsion stack with the help of microscope is called the scanning. Two methods of scanning commonly used are area scanning and line scanning. In the following section the two methods of scanning are discussed in detail.

2.3.1 Area Scanning

Area scanning is actually the volume scanning, because in the scanning the search of events is also done in the depth of the emulsion plate using the Z-motion of the microscope. Area scanning of an emulsion plate is usually done in strips equal in width to a side of an inscribed square in the microscope field of view. The procedure is to cause the focal surface in the emulsion to sweep up and down from the surface of the emulsion to the glass by rolling fine focus control (Z-motion of the microscope) while observing the events successively
coming into and going out of the view. One such elementary motion down or up is called a scanning traverse. Before shifting the field, more than one traverse may be made to locate events. For better efficiency, the field of view must be divided into a number of separate small areas so that the whole of the area can be seen clearly before the next traverse. The field of view is then shifted along the X-axis with the help of X-motion of the microscope and then the same procedure is repeated until the whole X-strip of the stack is completed. On completing one X-strip, the field of view is shifted towards the next X-strip by giving the displacement of Y-motion of microscope equal to or less than one field of view. The volume of the emulsion scanned in this way is equal to \( nw^2T \), where \( n \) is the number of scanning traverses, \( w \) is the width of the inscribed square, and \( T \) is the thickness of the emulsion plate. This technique is very slow, even at a magnification as low as 100, only 0.2 to 0.3 of a cubic centimeter per hour could be scanned using this technique.

Area scanning is useful when the primary particles enter over a wide solid angle; when they have a large energy spread; for investigating the behaviour of neutral particles; when a large population of certain easily seen events, stars or decay is wanted. The disadvantages of area scanning are the bias against small events and against some directions of emission of secondary particles. For instance, a decay in which the single minimum ionizing secondary is steeply dipping can be easily missed and a two prong star is less noticeable than a fourteen prong one. When area scanning is done, these inefficiencies must be remembered and corrected for.
2.3.2 Line Scanning

In this method the track of beam particle is picked up near the leading edge of the stack and it is followed until it interacts or leaves the stack or reaches the point of interest. The same procedure is adopted for the next beam track and in this way the whole stack may be scanned. This method of scanning has more relative efficiency and there is no probability of missing a particular kind of interaction. This type of scanning is effective only in the following conditions of exposure:

(i) beam flux is not dense and is spread up throughout the leading edge,

(ii) beam does not dip much, i.e. it traverses a considerable length in an emulsion plate if the beam particle does not interact, and

(iii) the length available for the traversal of beam particle is large.

In the present investigation we have adopted the method of line scanning to scan the emulsion stack. For this purpose we have used a NIKON OPTIPHOT (JAPAN) microscope having 7.0 cm movable stage and the scanning was performed using 60X objective and 10X eyepieces. The emulsion plate was placed on the microscope stage in such a way that beam flux was nearly aligned with the X-motion of the microscope stage. The position of all the beam tracks entering the leading edge (entrance side) of a grid were noted. The beam tracks were picked up at 3mm from the leading edge of the stack and followed until they interacted
The tracks were also followed backward in order to be sure that they did not come from other interactions. We picked up almost all events having a difference between the charge of projectile and principal projectile fragment of $\Delta Z = Z_p - Z_F < 2$. One prong events with a deflection angle of secondary track less than $3^\circ$ and without visible tracks from excitation or disintegration of the projectile and/or the target nuclei were due to elastic scattering and were rejected. A total of 4587 inelastic interactions of carbon nuclei were picked up by following $63254.74$ cm of primary track length, leading to the mean free path of carbon nuclei in emulsion equal to $(13.79 \pm 0.25)$ cm.

### 2.3.3 Scanning Efficiency

To calculate the efficiency of scanning, normally two observers scan certain samples of the area of the emulsion stack. Suppose two observers $A$ and $B$ scan a particular sample containing $N$ number of true events. Let $N_A$ be the number of events observed by observer $A$ but not by observer $B$, $N_B$ be the number of events observed by observer $B$ but not by observer $A$ and $N_{AB}$ be the common number of events observed by both observers. If $E_A$ and $E_B$ are the efficiencies of observers $A$ and $B$ respectively, then

\[
N_A = E_A \cdot N (1 - E_B),
\]

\[
N_B = E_B \cdot N (1 - E_A),
\]

and
\[ N_{AB} = N_{A} \cdot E_{A} \cdot E_{B} \cdot \] (2.4)

From these relations, we get

\[ E_{A} = \frac{N_{AB}}{N_{AB} + N_{B}}, \] (2.5)

\[ E_{B} = \frac{N_{AB}}{N_{AB} + N_{A}}, \] (2.6)

and

\[ N = \frac{(N_{AB} + N_{A})(N_{AB} + N_{B})}{N_{AB}}. \] (2.7)

In order to calculate the scanning efficiency in the present experiment, the scanning was performed by two different observers on around one fourth of the sample. The number of events missed by either observers was negligible. Therefore, in our experiment the scanning efficiency was nearly 100%.

2.4 Classification of Secondary Particles

In a nucleus-nucleus collision in addition to shower, grey and black track producing particles, we have another kind of particles, the projectile fragments which are collimated within a narrow cone around the beam direction and have the same momentum per nucleon as the beam particles. In the following sections we present the criteria adopted for classifying different types of particles.
2.4.1 Black Tracks

The secondary tracks having ionization greater than 10 times the minimum ionization or plateau ionization, i.e. \( g > 10 g_0 \), where \( g_0 \) is the plateau ionization, or relative velocity \( \beta < 0.3 \), range in emulsion \( L < 3.0 \) mm and dip angle \( \Theta_d < 30^\circ \) are classified as black tracks. The tracks are mainly produced by fragments emitted from the excited target nucleus. The total number of black tracks in a star is denoted by \( N_b \).

2.4.2 Grey Tracks

The secondary tracks having ionization in interval \( 1.4 g_0 \leq g \leq 10 g_0 \) or relative velocity \( 0.3 \leq \beta \leq 0.7 \), range in emulsion \( L \geq 3.0 \) and having dip angle \( \Theta_d < 30^\circ \), are classified as grey tracks. These tracks are mainly due to the recoiling nucleons, mostly protons, but with an admixture of deuterons and particles of mass number 3. The total number of grey tracks in a star is represented by \( N_g \).

Conventionally, the sum of the number of black and grey tracks, produced in a collision is referred to as the heavy prongs or heavily ionizing tracks and denoted by \( N_h \) ( = \( N_b + N_g \)).

In the present experiment, each heavily ionizing particle with dip angle \( \Theta_d < 30^\circ \) was assigned a geometrical weight factor \( W \) such that

\[
W = 1, \text{ when } 150^\circ \leq \Theta \leq 30^\circ, \\
\text{otherwise}
\]
\[ W = \frac{n}{2 \sin^{-1} \left( \frac{\sin 30°}{\sin \theta} \right)} \tag{2.8} \]

where \( \theta \) is the space angle of a particular track.

2.4.3 Fast Secondary Particles

2.4.3.1 Shower Tracks

The secondary tracks having ionization less than 1.4 times the minimum or plateau ionization, i.e. \( g < 1.4 g_0 \) or relative velocity \( \beta > 0.7 \), are taken as shower tracks. These tracks are mainly due to the singly charged particles. Most of the shower particles are pions, but there is a small portion of charged K-mesons, fast protons, anti-protons and hyperons among them. The total number of shower tracks produced in a star is represented by \( N_s \).

2.4.3.2 Projectile Fragments

In a peripheral collision only a part of the projectile nucleus is directly involved in the collision. The projectile nucleus is therefore breaks up into singly charged fragments, neutral particles and also into multiply charged fragments. In a collision, the multiply charged fragments can easily be separated from the target fragments as they are collimated in a narrow cone in the forward direction and have velocity almost equal to the velocity of the projectile nucleus. The ionization of the projectile fragments varies with their charges and does not change over a wide range. The projectile fragments are classified into two groups, according to their ionization.
(i) Doubly charged fragment \((Z = 2)\) of the projectile is the particle with an ionization \(g \simeq 4 \, g_\circ\), without any change in ionization along a length of at least 2 cm from the interaction vertex and having an angle of emission \(\theta < 3^\circ\).

(ii) Multiply charged fragment \((Z \geq 3)\) of the projectile is a particle with an ionization \(g \geq 6 \, g_\circ\) without any change in ionization along a length of at least 1 cm from the interaction vertex and having an angle of emission \(\theta < 3^\circ\).

The charge of projectile fragments was estimated by their ionization measurements and by counting the number of delta-rays. The fragments having charge \(Z = 1\) were not identified individually and their number was estimated using the method given in reference (3). The details of charge estimation will be given in section (2.6).

2.5 Measurements

Measurements in emulsion consist of determining the co-ordinates of points, in a suitable co-ordinate frame, measurement of distance between points, measurement of area and volume, measurement of projected and space angles, measurement of statistical deviations of a track from a straight line, measurement of track curvature etc. with the help of high magnification of a microscope. In the present experiment, measurements have been done of those parameters which are of our interest. The measurements have been performed using M4000 series Cook's (England) microscope with 100X oil objective and 15X eyepieces. Before starting measurements on a star, its depth was
measured and stars which were found lying within 30 µm from the top or bottom surface of the emulsion were rejected and the measurements were not performed on such stars. This has been done to facilitate the measurements.

2.5.1 Shrinkage Factor

It is found that, while the unmounted stacks may suffer both lateral and vertical shrinkage, the mounted stacks commonly undergo the vertical shrinkage only. Therefore, in the present experiment the vertical shrinkage factor was determined before starting the measurements. The frequent determination of shrinkage factor was found to be necessary because its volume changes considerably with humidity, temperature etc. The shrinkage factor was calculated using the relation

\[ S = \frac{T}{T'} \]  \hspace{1cm} (2.9)

where \( T \) and \( T' \) are the thicknesses of the emulsion before and after the processing. The thicknesses before the processing of the emulsion plates were available at three different positions, i.e. middle and both side of the plate at particular positions. The thicknesses were measured at the same points from time to time and shrinkage factor was calculated using the above expression.

2.5.2 Measurement of Angle of Emission of Secondary Particles

The secondary particles' tracks are generally well separated
from each other in space, except some showers and projectile fragments, which are emitted in the forward direction. Therefore, except the projectile fragments and showers in the forward direction, the projected angle and dip of the secondary tracks were measured directly by the goniometer and by the Z-motion of the microscope. The details of this measurement are as follows.

The primary track of the star of interest was aligned parallel to the X-motion of the microscope. The vertex of the interaction was focussed at the centre of the graticule of the goniometer. The primary beam track was aligned with one of the reference line of the goniometer. Now the secondary tracks were aligned one by one by rotating the goniometer and the goniometer scale reading was taken for the projected angle with respect to forward direction of the primary beam. For each track the dip was measured by moving the Z-motion of the microscope, with respect to the dip of star vertex. Now the dip angle, \( \Theta_d \), was calculated by using the relation

\[
\Theta_d = \tan^{-1} \left( \frac{S \cdot \text{dip}}{L} \right),
\]

(2.10)

where \( S \) is the shrinkage factor and \( L \) is the projected length or length from the vertex to the point at which the dip was measured. The space angle, \( \Theta \), can now be calculated using

\[
\Theta = \cos^{-1} (\cos \Theta_p \cdot \cos \Theta_d),
\]

(2.11)

where \( \Theta_p \) is the projected angle and \( \Theta_d \) is the dip angle. In this way the space angles of all secondary particles, except the projectile
fragments and the showers in the forward direction, were measured.

2.5.3 Measurement of Angle of Emission of Projectile Fragments

The projectile fragments lie in a narrow cone in the forward direction and therefore are not well separated. The same problem arises in the case of shower particles in the forward direction. Therefore, the angle of emission of projectile fragments and shower particles lying in the forward direction was measured using the co-ordinate method which is more accurate.

To measure the angle, first the beam track of the star was aligned parallel to X-motion of the microscope with the help of graticule. The vertex of the star was then focussed and the readings of X-motion of the scale and Z-motion were taken. Now the stage was moved forward to at least ten fields of view very carefully. Again the projectile fragment was focussed and the readings of X-motion and Z-motion were taken. The difference of the two readings gave the $\Delta Z$ reading for the projected length $\Delta X$, the difference of the two X-readings. The $\Delta Y$ reading was taken from the eyepiece graticule scale for a segment $\Delta X$. Now the projected angle $\theta_p$ and dip angle $\theta_d$ were calculated using relations

$$\theta_p = \tan^{-1} \left( \frac{\Delta Y}{\Delta X} \right), \quad (2.12)$$

and

$$\theta_d = \tan^{-1} \left( S \cdot \frac{\Delta Z}{\Delta X} \right), \quad (2.13)$$

where S is the shrinkage factor. Knowing $\theta_p$ and $\theta_d$, the angles
of emission of projectile fragments and the shower in forward
direction were calculated using relation (2.11).

2.6 Estimation of Charge of Projectile Fragments

The projectile fragments emitted from the collisions consist
of various types of particles having their charges ranging from
1 to 6. For an accurate kinematical analysis of the projectile
fragments, it is essential to know the charges of these fragments.
As we have mentioned in section (2.1) that when a high energy relativistic particle traverses through the emulsion it produces ionization along its path. The density of the developed grains is a function of charge and velocity of the particle. At comparatively higher velocities the grains are well separated and can be counted easily.

In the present experiment the estimation of charge has been
done using $\delta$-ray density method and using blob and gap method. These methods are discussed in the following sections.

2.6.1 Delta Ray Density Method

Most of the electrons which are ejected from the atoms by charged particles are generally of very low energy, but some times occasional collisions lead to the ejection of electrons of a few KeV or more. The tracks of such electrons are known as $\delta$-rays. Certain conventions are adopted for counting the number of $\delta$-rays associated with the track of a charged particle. Dainton et al (4) define a track to be a $\delta$-ray which contains at least four grains,
while Tidman et al. (5) take a grain configuration to be $\delta$-ray which has a projected range of at least 1.58 $\mu$m on the plane of the emulsion from the axis of the track. We have used the convention adopted by Tidman et al. (5) for measuring the $\delta$-ray density. The number of $\delta$-rays depends on the resolution of the emulsion, its sensitivity and also on the charge and velocity of the moving particle. Information regarding the charge of a particle can be obtained by counting the number of $\delta$-rays along the trajectory of the particle.

Neglecting the smaller terms depending on the particle structure and sign of the charge, the differential cross-section for the transfer of energy in the interval $dE$ to a stationary unbound electron by the electric field of a point charge $Ze$ is given by (6)

$$\frac{d\sigma}{dE} = \frac{2\pi Z^2 r_o^2 mc^2}{\beta^2 E_{\text{max}}} \left(1 - \frac{\beta^2 E}{E_{\text{max}}}\right) \frac{dE}{E^2} \text{ cm}^2. \quad (2.14)$$

The energy, $E$, of such knock-on electrons extends up to a maximum value

$$E_{\text{max}} = \frac{2mc^2\beta^2\gamma^2}{1 + 2(m/M)\gamma + (m/M)^2}, \quad (2.15)$$

where $\beta$ is the particle velocity, $m$ is the electron mass, $c$ is the velocity of light, $\gamma = (1 - \beta^2)^{-1/2}$, $M$ is the mass of the particle, and $r_o = e^2/(mc^2)$.

It should, however, be pointed out that the lower limit of $E$ that defines a recognizable $\delta$-ray in emulsion depends on the range
energy relation for low velocity electrons, the grain size of the emulsion, the scattering of these slow electrons, the sensitivity of the emulsion, and the density of background electron tracks.

From equation (2.14), it is obvious that the density of $\delta$-rays increases with the square of the charge of the particle. While counting the number of $\delta$-rays, one should bear in mind the fact that the core of the track also broadens as the particle charge increases. At relativistic velocities, when $\beta \rightarrow 1$, $E_{\text{max}}$ becomes quite large compared to any practical minimum $\delta$-ray energy. Therefore, from equation (2.14), the number of $\delta$-rays exceeding a particular minimum energy, $E_{\text{min}}$, becomes simply

$$n_\delta \approx (2\pi r_0^2) \frac{mc^2}{E_{\text{min}}} z^2$$

$$= \text{constant} \cdot z^2. \quad (2.16)$$

The above expression suggests that if the value of the constant is determined empirically for a particle of known charge, the charge of other relativistic particles can be determined with good accuracy.

2.6.2 Blob and Gap Method

This method, first introduced by Ceallaigh (7) and later on extended by Fowler and Perkins (8) is an important advancement in the technique of ionization measurements. It is based upon the fact that the gap length distribution is exponential and may be written as

$$H(l) = B \exp (-gl), \quad (2.17)$$
where \( H(l) \) represents the density of gaps of length greater than \( l \) and \( B \) is the blob density. The constant of exponential \( g \) is more or less independent of mean grain size and is, therefore, a good parameter for measurement of the ionization.

Further, if \( H_1 \) and \( H_2 \) are numbers of gaps of length exceeding \( l_1 \) and \( l_2 \) per unit length of the track, the coefficient of exponent, \( g \), can be determined from

\[
g = \frac{l}{(l_2 - l_1)} \log \left( \exp \frac{H_1}{H_2} \right). \tag{2.18}
\]

Fowler and Perkins have also given a relation connecting the blob density \( B \) to \( g \) in the form

\[
B = g \exp (-\alpha g), \tag{2.19}
\]

where \( \alpha \) is a parameter which is dependent largely on the average grain size, optical resolution of microscope and the convention adopted by an observer. For obtaining the value of specific ionization (Normalized grain density), \( g^* = g/g_0 \), \( g_0 \) may be calculated in the following way.

The value of the parameter \( g_0 \) has been determined by measuring the grain density on a number of shower tracks. This has been done in every plate in which the measurement of specific ionization, \( g^* \), was required. It has been observed that no significant change in the value of \( g_0 \) occurs in different plates. The value of \( g_0 \) in our experiment
has been found to be \( \sim 31 \text{ grains/100 } \mu \text{m} \). To obtain the value of \( g \), the number of blobs was counted over a certain length of the track and corresponding number of gaps exceeding some optimum value was determined. The optimum value of \( l \) occurs when the condition \( gl = 2.0 \), is satisfied for all value of \( g \). The statistical error in this measurement was calculated from (8)

\[
\frac{dg}{g} = \frac{1}{(NH)^{1/2} \log \exp(B/H)}.
\]  \hspace{1cm} (2.20)

The error obtained from the above expression was sufficiently small because the number of blobs counted in a certain length of the track was greater than four times the number of gaps, i.e. \( N_B > 4 \) \( N_H \). It should be noted that \( l \) was chosen to be an integral number of smallest division of an eyepiece scale.

2.6.3 Estimation of Charge in Present Experiment

By measuring the grain densities of tracks, projectile fragments could be easily separated tentatively into two groups viz. \( Z = 2 \) fragments and \( Z \geq 3 \) fragments. For this purpose, ionization measurements were made near the interaction vertex and also at a distance of about 2 cm from the vertex. When the ionization was about four times of the minimum ionization and did not change in the second measurement, the track was identified as due to a \( Z = 2 \) fragment. To confirm this criterion further, the ionization of the track was compared with that of a distinguishable \(^4\text{He} \) track from events \( ^{12}\text{C} \rightarrow 3 ^4\text{He} \).
identification of multicharged fragments with \( Z \geq 3 \), ionization measurements were made near the interaction vertex and also at a distance of about 1 cm from the vertex. If the ionization was about six times the minimum ionization and did not change in the second measurement, the track was identified as due to a multicharged fragments \((Z \geq 3)\). The tracks were subdivided into Li, Be, B, C fragments by measuring the density of \( \delta \)-rays along the tracks.

For calibration, events in which projectile carbon nuclei breaks up into either three helium fragments \((^{12}\text{C} \rightarrow 3 \ ^4\text{He})\) or into two lithium fragments \((^{12}\text{C} \rightarrow 2 \ ^{6}\text{Li})\) and tracks of beam nuclei were used. Number of \( \delta \)-rays were counted on the distinguishable tracks of helium and lithium fragments. For helium and lithium fragments counting was done over 1 cm near the interaction vertex and also at 2 cm from the vertex. Similarly counting of \( \delta \)-rays was done on the tracks of primary beam nuclei over a distance of 1 cm at different positions. Figure 2.1 shows number of \( \delta \)-rays per cm as a function of the square of the charge of the fragments.

In order to check our charge identification, the charges of about half of the fragments were also estimated by measuring the blob density \( B \), the density of gaps \( H \), for length greater than 1.1 \( \mu m \) and the gap length coefficient \( g \) which is given by equation (2.17). Results of this method of charge identification and \( \delta \)-ray density method were in good agreement.
Fig. 2.1 Dependence of delta-ray number on the particle charge.
References


