CHAPTER II

EXPERIMENTAL TECHNIQUES AND GENERAL CHARACTERISTICS
2.1 Introduction

Detector plays a very important role in the studies of high energy nucleus-nucleus collisions and hence this field of experimental nuclear physics has made considerable progress since the time of Rutherford's alpha particle scattering experiment with gold. With the availability of more energetic beams the complexity of nuclear reaction has been increased manifold with more number of ejectiles and hence need for better and better detector system has been felt over the period of time. Nuclear emulsion is one such detector. Developed by CF Powel [1], the emulsion has been a standard tool to study high energy h-A and A+A collisions since 1950s.

Nuclear emulsions are photographic emulsions of very high silver concentration that are thickly coated on glass backings. Ionizing particles which happen to pass through such emulsions leave behind a number of silver bromide crystals that have been so altered that, upon development, they appear as rows of black grains of colloidal silver and identify the trajectories of the particles. The more strongly ionizing the particles, the more numerous are these grains; and the greater their initial energies, the longer the resulting track. Nuclear emulsion was connected to many major discoveries in the early days of nuclear and particle physics. It was in an emulsion stack brought to high altitude that the pion[2] was discovered. Stacks of 0.5 mm thick emulsions were also lifted with balloons to very high altitudes to study the cosmic radiation. It still remains the detection technique with the best known three-dimensional spatial resolution, and zero intrinsic dead time. However its uses have gradually been decreased after the development of electronic detectors. Contrary to emulsion, electronic detectors offer immediate time correlated readout, and digitized output storable to computer accessible media. They serve therefore better the needs of most present experiments, which require large statistics of accumulated data for prompt and accurate physics result. Recent developments in automatic emulsion scanning, have given a renaissance to emulsion as a particle detector. Automatic scanning allows for fast extraction of digital information from emulsion sheets, after they have been exposed to particle radiation. Not only does it
make handling of large data sets possible, it also ensures that physics results can be produced shortly after the running of the experiment.

2.2 Some features and composition of nuclear emulsion

The nuclear emulsion technique of studying high energy h-A and A+A collisions rely mostly on the studies of various parameters of tracks produced along the trajectory of charged secondaries. The various information that can be gathered from the analysis of such tracks are enlisted herewith:

1. Curvature of a track to measure mass and charge of the charged particle.

2. Counting of the individual tracks is a measure of the number of charged nuclear particles produced in a collision.

3. The study of scattering interaction and production cross-section.

4. An extensive study on the structure of the tracks can lead to the determination of the momentum and hence the energy of the particles.

5. The investigation of lifetime and decay gives the characteristics of unstable particles.

6. A detailed study of charge and angular distribution of particles leads to the identification of some exotic phenomena namely criticality and liquid-gas phase transition.

The composition of a standard nuclear research emulsion is presented in the table 2.1.
Table 2.1 Composition of standard nuclear emulsion

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
<th>Atomic Weight</th>
<th>No. of atoms x 10^22</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per cc of halide</td>
</tr>
<tr>
<td>Ag</td>
<td>47</td>
<td>107.88</td>
<td>2.071</td>
</tr>
<tr>
<td>Br</td>
<td>35</td>
<td>79.916</td>
<td>2.06</td>
</tr>
<tr>
<td>I</td>
<td>53</td>
<td>126.93</td>
<td>4.57</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>1.008</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>12.00</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>7</td>
<td>14.008</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>8</td>
<td>16.000</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>16</td>
<td>32.06</td>
<td></td>
</tr>
</tbody>
</table>

2.2.1 Advantages of using nuclear emulsion as a detector

The distinctive advantages of nuclear emulsion are:

i) Versatile activity

Nuclear emulsion has the ability to serve the purpose of both detector and target in high energy interactions. This advantage of nuclear emulsion increases its acceptability over many other detectors. In high energy collision studies, it is often instructive to use target nuclei differing immensely in their mass number. Nuclear emulsions provide such targets since they contain a light group (H, C, O, N) and a heavy group (Ag, Br) of nuclei. Although the separation of events into these two group are not, by any means, exact, but still one can get information regarding the dependence of the production mechanism on the mass of the target nucleus.

ii) 4π Detectibility

Emulsion covers 4π geometry. It can recognize all the charged particles emitted in space in the final state of the high energy nuclear interactions. This
advantage of emulsion has made it very much useful in studying charged secondaries mainly produced particles and projectile fragments which are emitted mostly in the extreme forward angle.

iii) The stopping power

Because of the differences in the densities of the media, the stopping power in nuclear emulsion is several times higher than that of the cloud-chamber or bubble-chamber medium. The times of elapse of the charged particles are higher in emulsion compared to that of the other detectors and hence found to be suitable to study the decay of various elementary particles.

iv) Sensitivity

The emulsion detector has the sensitivity of registering all the charged particles having energies very low upto the relativistic regime. Further the sensitivity of the emulsion lasts for more than a week, which helps to record all the charged particles within this time span. Hence it is the only tool to study the cosmic ray events where the incident beam can be hardly found.

v) Mechanical features

It is most easy to handle because of its size and weight. One of the greatest advantages of using this type of detector is that it can record permanently the trajectories of the charged particles until and unless it is destroyed completely.

vi) Operating range

Nuclear emulsion has the large operation range with regard to temperature. It may be used successively in the temperature ranging from the temperature of the liquid helium upto the boiling point of the water [3].

2.2.2 Disadvantages of nuclear emulsion

Though nuclear research emulsions have great advantages of detecting various charged particles, yet it has few drawbacks:

1) The sensitivity and thickness are affected by factors like temperature, humidity, age of the emulsion, the conditions under which they are developed etc.
2) The tracks are relatively short, at best few mm in length and they must have to be studied only under a high power microscope.

4) The manual analysis at the microscope is painstaking and time-consuming. Further there is no way to identify the exact target atom in an event; one can at best conclude that the target could be a H or C, N, O or Ag, Br nucleus.

5) Another disadvantage is that they remain always sensitive to ionizing particles and there is no method to trigger them by the particles one wishes to study, unlike the cloud chambers.

2.3 The characteristics of the photographic process

2.3.1 Formation of latent image

A photographic emulsion is essentially a dispersion of silver halide crystals in a gelatin matrix [1,3-4]. The elements present in the gelatine medium (along with plasticizer i.e. glycerine) are carbon, nitrogen, oxygen, hydrogen and sulphur. The nuclear emulsions are fundamentally the same as general purpose photographic emulsions, but have several distinguishing features:

- The silver halide crystals are very uniform in size and sensitivity.
- There are very few crystals that may be developed without exposure to a charged particle (very low chemical fog).
- The silver to gelatin ratio is much higher than in a conventional emulsion.

When such an emulsion is exposed to relativistic hadron or heavy ion beam the incident particle while passing through emulsion may collide one of the nucleus of the atom it consisted of. As a result of such collision, a number of charged secondaries and radiation will come out of the interaction centre. These ionizing charged particles (radiation) on passing through the emulsion modify the silver ion of AgBr crystals along its trajectory. These are known as latent image centres, as they are not visible until the emulsion is developed. On development all the crystals
containing a latent image centre are reduced to metallic silver which are easily distinguishable because of their black colour. Thus, as a charged particle advances through emulsion, it leaves behind a trail of black grains called track. By investigating the characteristics of these tracks, ionization produced may be determined and information about their charges and velocities can be obtained. The tracks in an interaction appear to come out from a single vertex. The recorded interaction in emulsion is thus called a star due to its characteristic appearance.

2.3.2 Processing of nuclear emulsion

2.3.2.1 Development

Photographic development is the process by which the latent image contained in an emulsion is made visible by the reduction of silver ions in the silver halide crystal to metallic silver. When developing nuclear emulsions, a developer is usually chosen which reduces those crystals containing a latent image centre completely and leaves those unchanged, not containing a centre. The development time used for processing material should be sufficient for those crystals with a latent image centre be reduced completely, but not so long that unexposed crystals are developed. In practice, a certain number of crystals will be developed even though they do not contain a latent image centre. These grains, when developed, constitute what is known as fog or background. Developing agents may be divided into two main groups, depending on the source of silver ions for reduction. In practice, most developers give a combination of the two sorts of development. The first group is known as physical developing agents. In physical development, silver ions are provided from the solution in the form of a soluble complex. These are deposited on the latent image centre and are reduced to metallic silver. This produces spherical particles, the precise shape of which is affected by pH. Chemical developing agents make up the second group and are more usually chosen when processing nuclear emulsions. However, the choice between a physical developer and a chemical developer will largely depend on the grain structure required in the processed image. In chemical development, silver ions are provided from the silver halide crystal containing the latent image centre. The action of a chemical developer produces a mass of filaments bearing little resemblance to the original crystal. If silver halide
solvents such as sulphite are present in a chemical developer, an opportunity exists for some physical development to occur. In this case, the filaments in the processed plate will be shorter and thicker. Chemical development, like many other chemical reactions, is dependent on temperature. In general, development occurs more rapidly at higher temperatures - below 10°C development virtually stops. For this reason it is important to keep the processing temperature constant during the development, otherwise it will not be possible to assess the correct development time. Chemical developers are also dependent on pH and will only maintain a given activity within a narrow pH range. In general, the less alkaline the environment, the less active the developer will be. For this reason, the use of an acid stop bath is often recommended at the end of the development. This stops development immediately so that the development time can be controlled precisely.

2.3.2.2 Stop bath

After development, the material is transferred to an acid stop bath. This may be made up with 0.2-2% acetic acid solution. Like development, stop bath times vary with layer thickness. A time of 1 minute will suffice for thinner layers, rising to around 10 minutes for a 100 micron layer.

2.3.2.3 Fixation

The purpose of fixation is to remove all the residual silver halide, leaving the metallic silver to form the image. If the silver halide is left in the emulsion, it will slowly go brown and degrade the image. The fixing agents most widely used are sodium or ammonium thiosulphate, which form thiosulphate complexes with the silver halide. Silver thiosulphate is soluble in water and so may be removed from the emulsion by washing. It is important to use a fixer which has not been exhausted when processing nuclear emulsions; otherwise some silver halide will remain in the emulsion. To ensure that it is all removed a fixing time should be used which is twice the time it takes for the emulsion to clear [1].

2.3.2.4 Washing and Drying

After fixation, the emulsion must be washed very thoroughly. This is to remove all the silver thiosulphate complexes in the emulsion. If any do remain, they
will eventually break down, forming silver sulphide which is brown and will obscure the image.

After washing, the plates are soaked in a solution of glycerine of strength 2 to 5% and dried. The glycerine solution is used to prevent the stripping of dried emulsion from the glass. The final drying of processed plates may be carried out by placing them with the emulsion surface horizontal in a gentle current of air [1].

2.3.3 Calibration of stack

When the emulsion is processed, there occurs a reduction in its volume as the silver halide crystals are dissolved by fixer. The ratio of the thickness of the emulsion before and after processing is called the shrinkage factor (S) [1]. This factor determines the relationship between the geometrical conditions during exposure and during observations.

2.3.4 Shrinkage factors

Gelatine and glycerine, both being hygroscopic, the actual equilibrium thickness and index of refraction of both the processed and unprocessed emulsion depends on the surrounding humidity. Consequently, we defined the shrinkage factor [1], S as:

\[
S = \frac{\text{Thickness of emulsion layer during exposure}}{\text{Thickness of emulsion layer during scanning}} \quad (2.1)
\]

Thus for any quantitative measurement of track densities, range and angles in emulsion, the original thickness of the emulsion is to be known. The shrinkage factor is generally supplied by the manufacturer of the emulsion plates [5-6].

2.3.5 Emulsion stack and their exposure

Nuclear emulsion pellicles of the type NIKFI-BR-2 and dimensions 20×10×0.06 cm\(^3\) were irradiated parallel to their lengths by a 4.5 A GeV \(^{24}\)Mg beam from the JINR synchrophasotron at Dubna.
2.4 Microscope

In this work, a high magnifying power optical trinocular research microscope (Olympus BH-2) was used to magnify and study the particle tracks in nuclear emulsion. In general, these microscopes consist of a set of objectives (including an oil-immersion one) of different magnifications. A pair of eyepiece (15 ×) was used to magnify the real image formed by the objective. Disintegration centre’s were scrutinized and different parameters of various tracks were recorded under higher magnification (1500 × oil immersion) using the same microscope.

2.4.1 Scanning Procedure

The scanning of the emulsion plates are carried out as a part of a planned programme in which minimum biased events are identified in a systematic way. The two different methods of scanning are generally employed:

i) Area Scanning

In area scanning, the focal surface in the emulsion is swept up and down, from the surface of the emulsion to the supporting glass. This is done by rolling the fine focus control while observing the events successfully coming into and going out of view. Each field of view is scanned through out its depth, from one surface of the emulsion to the other. Thus, a definite area (in fact the volume) of the plate is covered.

Area scanning is employed if the following situations arise:

a) When all the events of certain type in a given volume of emulsion are to be found.

b) When a sample of a particular kind of event is required.

c) If the situation demands a representative sample of events.

d) When the number and an unbiased spectrum of events in a given volume are to be found.
But the area scanning will not be a favorable process, for single diffractive
dissociation events or interactions with H-nuclei.

ii) Along the Track Scanning

If a stack of emulsion is exposed to a beam of particles entering one face in a
perpendicular direction, and if one intends to study the density and distribution of
the beam entering the stack, then the procedure for finding tracking of a specified
type is to traverse each plate parallel to the leading edge and perpendicular to the
incoming tracks. This type of scanning is known as along the track scanning.

In the present investigation along the track scanning method has been
employed for identifying the Mg-Em interaction.

2.5 Principle of identification of charged particles using emulsion

A charged particle passing through a photographic emulsion slows down as a
result of interactions with the atoms of the emulsion along its path. These
interactions result in a loss of energy of the incident charged particle. The forces
responsible for this energy loss are electromagnetic involving the electrons of the
atoms of the emulsion medium. The energy transfer to the medium takes place as a
result of interactions, which may be elastic (the atom is displaced but its internal
state remains unchanged) or inelastic (the atom is both displaced as well as excited
internally). The total rate of loss of energy of a particle of charge Ze moving with a
velocity $\beta$ due to interactions while it travels through a medium is given by [4,7-8]:

$$\frac{-dE}{dx} = \frac{2\pi nZ}{\beta^2} \frac{2r_o^2}{\beta^2} \ln \left( \frac{2m_e c^2 \beta^2 \gamma^2 W_{\max}}{I_0} - 2\beta^2 - 2C \right)$$  \hspace{1cm} (2.2)

Here, $r_o = \frac{e^2}{m_e c^2}$, the classical radius of electron

$m_e =$ mass of electron

$I_0 =$ mean ionization potential

$\beta =$ relative particle velocity
\[ \gamma = \frac{1}{\sqrt{1 - \beta^2}} \]

\( W_{\text{max}} \) = maximum energy imparted to the electron.

\( C \) = correction term to be applied at high velocity of the projectile.

The development of grains in the emulsion takes place by the loss of energy of a charged particle through the process of ionization while passing through nuclear emulsion. The number of grains deposited per unit length of track is defined as grain density \( (dn/dx) \). The grain density has been found to be proportional to to \( \frac{dE}{dx} \), which in turn is related to \( Z \) and \( E \) (or \( \beta \)) of the charged particle. Experiments have shown that as the velocity of a charged particle approaches \( \gamma \), the grain or blob-density in its track reaches a minimum value for \( \beta = 0.95 \) and then rises again to a nearly constant value for \( \beta > 0.995 \) [9-12]. The rise of grain density \( (g^*) \) above the minimum value \( (g_o) \) as the energy of particle increases due to the longitudinal contraction and lateral extension of the field of the moving particle [1]. This leads to the excitation and ionization of atoms at increasing distances from the trajectory of the particles. In association with the above, the rate of loss of energy \( (E) \) increases with \( \sim \log E \). This increased rate of loss is not reflected in a corresponding increase in the grain density, because much of it is dissipated at points outside the core of the track. Some of the additional energy loss leads however, to the formation of relatively low energy, \( \delta \) rays which contributes to the observed limited increase in the grain density.

This minimum grain density \( (g_o) \) plays an important role in the identification of different charged secondaries emitted from the target nucleus.

Another important parameter for the measurement of charge of particles traversing the emulsion medium is the delta rays, which are electrons knocked free from atoms by the primary ionizing particle. Delta rays of energy \(< 5 \text{ keV} \) have their tracks so contracted that the mean distance between the origin of \( \delta \)-rays and its point of arrest is covered in such a manner that the \( \delta \)-ray tracks are tied into knots by
scattering and are closely confined to a region near the trajectory of the charged particle. When the energy of $\delta$-rays increases slightly, their effective range increases and the $\delta$-ray electrons escape from the trajectory of parent particle. They make the neighboring grains develop in the form of spurs to the particle track and give a clearly distinguishable $\delta$-ray track. Thus, the $\delta$-rays having energy $< 5$ KeV are retained in the grains and have a contribution towards ionization but those having a greater energy are excluded. For a constant velocity, the $\delta$-ray density is directly proportional to the square of the charge of the particle whose track is formed [5].

2.6 Classification of secondaries

2.6.1 The classification of charged secondaries

All the charged secondaries emitted or produced in an interaction are classified into the following categories in accordance with their normalized grain density $g^*$, defined as $g^* = g / g_0$, where $g$ is the observed grain density and $g_0$ is the minimum number of grains per unit length developed due to a singly charged particle, ionization etc.

(i) Black track producing particles ($N_b$)

These are mainly the evaporation products (protons) of the remnant of the target nucleus and the fragments emitted at the final stage of the nuclear collision from the excited target nuclei. They have range $L < 3$mm from interaction vertex from which they originates and $g^* > 6.0$. This ionization range corresponds to protons with kinetic energy $< 30$ MeV and velocity less than 0.3c. Their multiplicity is denoted by $N_b$.

(ii) Grey track producing particles ($N_g$)

These are the particles having grain density $1.4 < g^* \leq 6.8$ and a range $L > 3$ mm in emulsion. These tracks are mostly due to recoil target protons with kinetic energies in the range 30–400 MeV and in the velocity range $0.3 \leq \beta \leq 0.7$ with a small admixture of slow pions, deuterons, tritons and helium nuclei. Their multiplicity is denoted by $N_g$. 
The black and/or grey tracks together are called the heavily ionizing particles ($N_h$), their multiplicity of which is denoted by $N_h = N_b + N_g$.

(iii) **Shower track producing particles ($N_s$)**

These are the singly charged relativistic particles with grain density $g^* < 1.4$, corresponding to pion energies above 70 MeV and proton energies above 400 MeV. Most of these tracks belong to pions contaminated with small proportions of fast protons and $k$-mesons and having $\beta > 0.7$.

2.6.2 **The classification of projectile fragments**

The noninteracting (spectator) fragments of the projectile nucleus having charge $Z_{PF} \geq 1$ and having velocity close to the beam velocity, are the tracks which lie within the narrow forward narrow cone around the beam direction and their ionization remains constant for at least 20 mm from the interaction point.

The forward angle is the angle whose tangent is the ratio between the average transverse momentum of the projectile fragments to the longitudinal momentum ($P_l$) of the beam. Taking $P_l$ as the beam momentum in AGeV itself, i.e.

$$\theta_f = \tan^{-1}(P_t / P_{beam})$$

for the present study, $\theta_f$ is found to be equal to $0.2/P_{beam} = 3^o$

The PFs are further classified into three categories

a) Heavy projectile fragments ($N_f$): PFs with charge $Z \geq 3$

b) Alpha projectile fragments ($N_\alpha$): PFs with charge $Z=2$

c) Singly charged ($N_z = 1$) relativistic projectile fragments

Since these projectile fragments have velocities nearly equal to the initial beam velocity, their specific ionization may be used directly to estimate their charge.
The total multiplicity of the secondary charged particles \( N_{ch} \) [13-14] for an emulsion event is the sum of all the charged particles that are emitted or produced in an interaction.

\[
N_{ch} = N_s + N_g + N_b + N_{pf}
\]  

(2.4)

2.6.3 Selection criteria for electromagnetic dissociation events

Each event was very carefully examined and qualitatively classified into four principal categories [14-15]: (i) central events, (ii) semi-central events, (iii) peripheral events and (iv) electromagnetic events. The electromagnetic dissociation (ED) events, as described in ref.[14,16], were picked up among the peripheral ones with no visible excitation of the target nucleus \( N_h = 0 \) and with an additional constraint that the sum of charges of all the PFs with \( Z_{PF} \geq 1 \) inside the fragmentation cone are always 12 for the \(^{24}\text{Mg}\) beam. The contribution of the nuclear peripheral events in these samples of the electromagnetic events is effectively minimized subject to the requirement that the number of produced shower particles \( N_s \) in ED events \( \leq 1 \). According to these stringent selection criteria, the numbers of ED events corresponding to the incident beams \(^{24}\text{Mg}\) at 4.5 AGeV are estimated to be 77 out of the entire sample of data.

The accuracy of the \( Z \) determination was always better than 1 unit. This was verified by summing up the charge of fragments in events of electromagnetic dissociation type [17].

2.6.4 Selection criteria for the type of events

For the present study, we have used the following selection criteria for determining the type of events [18-21].

a) \( N_h \leq 1 \): \(^{24}\text{Mg} - \text{H interaction}\)

b) \( 2 \leq N_h \leq 5 \): \(^{24}\text{Mg} - \text{CNO interaction (having no short track)}\)

\(^{24}\text{Mg} - \text{AgBr interaction (at least one short track)}\)

c) \( N_h > 8 \): \(^{24}\text{Mg} - \text{AgBr interaction}\)
d) $6 \leq N_h \leq 8$: Mg-CNO/AgBr interaction (CNO for no heavy short track and AgBr for heavy short track)

2.6.5 Charge estimation of Projectile Fragments

The charges of the projectile fragments were estimated by adopting the method of ionization measurement. Although different methods are employed to estimate the charge of PF’s [1], the fundamental principle is related to ionization in some way or the other. For emulsion technique this ionization is related with the grain density, i.e., the number of developed grains per unit length. With low ionization there is no significant error in the estimation of the grain density. But with the increase in grain density, it is not possible to resolve the adjacent grains even under a high magnification microscope. In the tracks of heavily charged fragments, the grains get clogged to each other to form blobs and thus the counting of individual grains become impossible. One then counts the number of developed blobs and the gaps between them per unit length as the measure of PF charge.

The charge of various PF’s can be measured by adopting a number of methods of measurement which are listed below:

a) Grain density.
b) Blob and hole density.
c) lacunarity and opacity [22]
d) $\delta$-ray density and
e) Relative track width measurement.

Since each method has its own limitations, therefore a single method cannot be applied to estimate the charge of the PF’s over the entire range. Also, to estimate the charge of PF’s with better accuracy, one should not measure a single parameter related to the ionization of the track. For the present study therefore, in most of the cases, more than one parameter of a particular projectile fragment’s track has been measured and made a cross examination of their values before finally assigning the charge to that particular PF. Suitable track parameters are being measured for different charge range of the PF’s.
2.7 Measurement Methods

2.7.1 Measurement of grain density

Grain density depends on the particle velocity. So the grain density provides means for the estimation of particle velocity.

To measure the developed grains in a track of a charged particle, the most obvious method is to count the developed grains in the measured length of the track. At low grain densities, the error in such measurements may not be great. But as the grain density increases, adjacent grains become irresolvable under the microscope, the error in this case is certainly high. Another counting procedure is merely to determine the mean linear density $B$, of resolvable clumps, known as blobs consisting of one or more grains. The estimation of the number of blobs in a track is equivalent to measuring the number of gaps. So that gap counting and blob counting are equivalent terms.

2.7.2 Measurement of dip angle

The dip angle of a particular track $\delta$ can be calculated using the relation:

$$\tan \delta = \frac{\Delta Z}{L}$$

(2.5)

where, $\Delta Z$ = the true difference of depth between any two points in the track.

$L$ = length of the projection of the track between these two points.

Since the index of refraction of the emulsion may not be same as the oil used for an immersion objective (and certainly will not be same as air when an air objective is used), the depth measurement, even using a microscope with linear, accurately calibrated focusing motion, may not be correct. If dry objectives are used, the apparent depth $d_a$ will be less than the true depth $d_t$:

$$d_t = \mu_e \cdot d_a$$

(2.6)

with oil-immersion objectives, however, the $d_a$ and $d_t$ are more or less equal because of the close approach of equality of the refractive indices of the immersion
oils commonly employed \( (\mu_o = 1.52) \) and the emulsion

\[
d_i = \mu^\prime d_a \quad ; \quad \mu^\prime = 1
\]  

(2.7)

The true angle of dip, \( \Delta \), at the time of the parent particle is given by:

\[
\tan \Delta = S \tan \delta = S \Delta z / L = S \mu . \Delta z / L
\]  

(2.8)

S being the shrinkage factor.

### 2.7.3 Measurement of Space angle

The space angle \( \theta \) between two tracks can be estimated by the simple coordinate method. If the direction cosines of the tracks are \((l_1, m_1, n_1)\) and \((l_2, m_2, n_2)\) then:

\[
\cos \theta = l_1 l_2 + m_1 m_2 + n_1 n_2
\]  

(2.9)

Direction cosines of a track can be easily obtained by taking space coordinates \((x, y, z)\) of any two points on the track. If \((x_1, y_1, z_1)\) and \((x_2, y_2, z_2)\) are the readings of the space coordinates, the direction cosines are given by:

\[
l = \frac{(x_i - x_j)}{\left[ (x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2 \right]^{1/2}}
\]  

(2.10)

\[
m = \frac{(y_i - y_j)}{\left[ (x_i - x_j)^2 + (y_i - y_j)^2 + (z_i + z_j)^2 \right]^{1/2}}
\]  

(2.11)

\[
n = \frac{(z_i - z_j)}{\left[ (x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2 \right]^{1/2}}
\]  

(2.12)
References


