CHAPTER II

EXPERIMENTAL ARRANGEMENT AND TECHNIQUE OF MEASUREMENT

2.1 THE NUCLEAR RESEARCH EMULSION :

The study of nuclear phenomenon using photographic emulsions is a result of the hundred years of research and industrial applications. A photographic emulsion consists of myriads of crystals of Silver halides mostly the bromides having linear dimensions between 0.1 to 1.0 micron embedded in gelatine. When light falls on the emulsion or when a charged particle moves through it, some of the halide grains are changed in such a way that on development they are turned to metallic silver. After processing, because of the transparancy of the gelatine, the path of the charged particle traversing the emulsion is visible under a microscope as trails of black silver grains. The modifications in the grains thus brought about by radiations are commonly invisible and the effect is described as the formation of a 'latent image'.

Kinoshita[1] and Reinganum[2] first used the photographic emulsion in the year 1911, when they observed that Alpha particles moving through photographic emulsion produces developable grains. This method, later on, received wide appreciation and application primarily due to constant efforts of C.F. Powell and his collaborators[3-5] - G.P.S. Occhialini

and a host of other workers. Now a days nuclear emulsion of various sensitivities are manufactured. The Illford G5 electron sensitive emulsions are in widest use. Nikfi-R emulsion has been developed successfully by Russia with their properties very similar to G5 emulsion. K5 is similar to G5 except in grain size. Besides, there are less sensitive emulsions like Ko which may be used to record the tracks of heavy ions only.

The nuclear emulsion can be used as a detector for nuclear tracks with many adventages for studying the nuclear disintigration in high energy nuclear interactions. It is continuously sensitive during the whole of the time, the plate is exposed. It is simple, less expensive, light weight and may be contained in a small volume. Because of the high stopping power of emulsion, it may be considered as a compact Bubble Chamber. Often it permits analysis from a single and direct records, while several thousands of stereoscopic cloud chamber or bubble photographs would be needed to get the same result. The trajectories are preserved in the gelatine permanently, so that the events can be restudied at any time from any aspect. In addition to the various light and heavy elements present in the emulsion, it can be loaded with other suitable target elements to study the various aspects of disintigration in different nuclei. It permits accurate determination of energy and charge of particles with low velocity, and since it has a relatively high stopping power most of the secondary fragments and hyper-fragments are brought to rest within the emulsion. The important limitations

of the method is that its composition can not be changed arbitrarily, so that interaction studies in emulsion are limited to those nuclei normally present and other with which the emulsion can be loaded. The other major imperfections of the methods are the uncertainties in the identification of very short and steep tracks. Also it is difficult to make a study with a magnetic field, which should be comparatively very high to produce its effect.

The special characteristics of emulsion technique have made it a means for cooperative conduct of high energy research. Irradiations are often made with large accelerating machines, in rocket flights and in balloons. The events may be analysed thousands of miles away and sometimes in several countries in the same time.

2.2 EMULSION STACKS AND THEIR EXPOSURE :

Two stacks one ilford K5 and another an ilford G5 have been used in the present investigation. Ilford K5 emulsion was exposed in an one stage separated beam at the Brookhaven A.G.S. machine. As a result of only one stage of separation there is a large pion back-ground in the beam with $K/\pi \sim 1$. The stack contains $4 \times 10^7 K^-$ confined to central 100 plates[6]. The total intensity is 2×10^5 K^-/sq. cm. 60 pellicles from this stack was kindly sent by Prof. A. J. Herz of C. E. R. N. as a free gift. Each plate is of size 20 cm x 10 cm with a thickness of 600 microns.

A G5 emulsion stack was exposed to a beam of 5 Gev/c

anti-proton at the C. E. R. N. synchro cyclotron. It consisted of 41 pellicles each measuring 28.8 cms x 14.0 cm x 600 microns and was exposed at a distance of 176 m from the target in order to minimise the contamination due to the pions, kayons and hyperons. The flux of $\bar{P}$ was estimated to be 28 particles/ mm^2 and the beam entered the stack along the longer side of the pellicles covering a width of 5 cm in the middle beyond which the intensity falls abruptly. The beam tracks were fairly collimated with an average dip angle of 1^o in the unprocessed emulsions. Five plates were taken as loan from Dr. G. C. Deka for the present investigation.

2.3 PROCESSING OF EMULSIONS :

The usual photographic processing, i.e., developing, stopping, fixing, washing and drying must be carried out for nuclear emulsion. But the processing of thick nuclear emulsions carried on similar lines as used for processing of ordinary photographic films or paper does not yield satisfactory results. The thick emulsions, very often, are found to have variations of developed grain density with depth, distortions and spurious scattering etc. This difference follows from the fact that photographic films are very thin (less than 100 microns) and less concentrated in composition as compared to thick emulsions which are usually 600 to 1200 microns thick and contain high concentrations of silver halides (82.73 p.c. by weight).

To achieve uniform development throughout the thick

ness of emulsions, these thick emulsion needs special attention and care in processing. It is now achieved by well known temperature cycle method by Dilworth Occhialini and Payne[7]. This method, in principle takes advantage of the fact that the rate of development varies with temperature much faster than the rate of diffusion of the processing chemicals throughout the emulsions.

To minimise the distortions of tracks in plates, careful handling of the emulsion plates are essential during processing. The small amount of distortions that may still present are mostly uniform and can be eliminated from the coulomb scattering of the track.

The origin and behaviour of the spurious scattering (S.S.) is not clearly understood and the amount of spurious scattering appears to depend on large number of parameters, such as, handling of the emulsions after manufacture and development technique utilised, etc. Careful processing thus reduces the spurious scattering.

The groups in the laboratories of Copenhagen, Bristol, Bombay, Lausane, Brussels and Cern have been engaged to overcome the special problems relating to concentrated and thick nuclear research emulsions.

The following standard proceedure is used by various group for developing pellicles by the temperature cycle method.

(i) Mounting of the pellicles on the glass plates and drying them.

(ii) Soaking the plates in distilled water (pre-soak).

(iii) Soaking the plates in developer.

(iv) Hot stage development of the plates.

(v) Stop bath.

(vi) Fixing the plates.

(vii) Washing of the plates.

(viii) Drying of the plates.

A short and brief account of the different stages of processing are given below.

1. Mounting of the pellicles on to the treated glass plates and drying them :

The glass plates are first soaked in a solution of gelatine, glycerine, and wetting agent of definite proportions in distilled water.

The pellicles are mounted on the glass plates in the solution. The assembly is removed from the solution and the emulsion is rolled on to the plates by a roller. The plates are dried for about two days after mounting.

2. Soaking the plates in distilled water :

The plates are soaked in pure distilled water with slight trace of wetting agent on it. This is to be continued for two to three hours at 5^{0}C for 600 microns thick G5 and K5 emulsion plates. The emulsion absorbes water and swells to about twice their original thickness during this state. This actually helps to have an approximately uniform distribution in depth of the developer before appreciable degree

of development has taken place.

3. Developer soak :

The plates are now soaked in the developer solution for two to three hours at 5°C (plate thickness - 600 micron). Water in the emulsion are replaced by the developer and because of low temperature little development of the emulsions takes place at this stage. The ideal developing agent should quickly penetrate the emulsion and should possess moderate to high temperature coefficient, produce negligible back ground fog and stain in the emulsion and remains stable upto 30°C. The developers, namely, Amidol are used for the purpose.

4. Hot stage :

To have approximately uniform development throughout the depth of the emulsion, the temperature of the pellicles soaked in developer is generally raised. There are, namely, two different methods, viz., 'dry hot state' and 'wet hot state'. In the dry hot state the temperature is in the range 23°C to 28°C. In the latter process the plates from the developer solution (5°C) is transformed to another developer solution (5°C) which contains only one third the amount of Amidol and twice the quantity of KBr used for the normal solution of developer. After the plates are transferred, the temperature of the whole bath is raised to 27°C. For 600 microns emulsion (thick) the time for hot stage is almost an hour or so.

5. Stop bath :

By lowering the temperature and PH value of the solution, the action of the developer is stopped. The temperature of the stop bath should be about $5^{o}C$ and it is best if the emulsion temperature can be brought gradually to $5^{o}C$ before immersion in the fixing bath. The time required for this operation is about 2.5 hours for 600 microns thick emulsion.

6. Fixing bath :

Fixation is the process of dissolving the silver halide in hypo solution (alkali thio-sulphate solution). The contents of the solutions are modified at different laboratories. The plates from the stop bath are transferred to a fixer bath and generally it takes about three to four days to complete the fixing of 600 microns thick emulsions.

7. Washing of the plates :

Concentration of the solution should be gradually reduced until no hypo can be detected in the processed emulsion, after the fixation is complete. The plates are washed in $8^{o}C$ cold water. This operation must be carried out with utmost care, because, at this stage the emulsion is soft and swells to four to five times the original thickness. Thus the temperature of cold water and rate of washing is an important factor. It takes four to five days for washing the plates.

8. Drying of the plates :

The water in the plates is gradually removed by immersing them in the baths with successively increasing concentration of alchohol. In the final stage, the plates are dipped in 100 p.c. alcohol. To avoid emulsions peeling off from their glass surface after drying, about 5 p.c. glycerine is added to each bath at this stage. The plates are removed and dried slowly under constant humidity.

After drying the excess of silver grains remaining on the pellicle surface is gently removed by ethyl alcohol on soft paper or chamois skin is used to rub it off.

2.4 SHRINKAGE FACTOR AND DISTORTION OF EMULSION :

The original volume of the emulsion is reduced during its processing because silver halide crystals are dissolved by the fixer. For glass mounted plates a simple reduction of the thickness of the emulsion layer results. The thickness of the layer of emulsion at the time of exposure divided by the thickness at the time of scanning is called the shrinkage factor (S). The shrinkage factor depends on the temperature and humidity of the rooms in which the emulsions are kept. This shrinkage factor is important particularly for steeper tracks while making any quantitative measurements of track densities, ranges and angles in the emulsion.

The thickness of the unprocessed pellicles in p^- stack and k^- stack, were known to be 600 microns $\pm$ 15 p.c.

and 600 microns $\pm$ 5 p.c. respectively. Knowing the present thickness of any pellicle, its shrinkage factor can be easily found out. As the shrinkage factor varies from plate to plate and also at different points in the same plate, therefore, for every position of the events recorded, the value of the shrinkage factor is found individually.

To measure the space range of a track from its projected range and dip, the shrinkage factor is taken into account. The apparent dip or vertical depth as recorded by the dip-screw in any track is multiplied by the shrinkage factor to give the true dip.

The processing of the emulsion plates also results in various kinds of distortion of the tracks. It is lesser in a glass backed emulsion than that in the unmounted ones. For a precise and meaningful measurements in emulsion, the behaviour of distortion should also be understood thoroughly.

2.5 STOPPING POWER :

For making any quantitative measurement the knowledge of stopping power of the emulsion material is also necessary. The stopping power depends on the composition of the emulsion material and moisture content in it at the time of exposure. It is independent of the ambiant humidity changes making it easier to determine the stopping power once and for all by making observations on some flat tracks produced by particles of unique energy.

To determine that stopping power in the present

experiment, a few flat muon tracks from pion decays in the pellicles of both the stacks are selected. The average range of muon for each stack is determined separately. The values are 605 ± 3 microns for k^- stack and 603 ± 3 microns for p^- stack. Using the UCRL range energy tables[8], the mean range of muon of energy = 4.12 MeV in the standard emulsion is found to be nearly 600.5 ± 3 microns.

The relative stopping power is given by $K = R_{st}/R_y$ where R_{st} the range of the muon in standard emulsion and R_y is the observed range of the muon.

Therefore, the relative stopping power for

k^- stack, $k_1 = 600.5/605 = 0.9913 \pm .001$

for $\bar{p}$ stack, $k_2 = 600.5/603 = 0.995 \pm .001$

The observed ranges in the two stacks are to be multiplied by k_1 and k_2 respectively in estimating energy from ranges with UCRL range - energy tables[8].

2.6 SCANNING OF EMULSION PLATES :

Suitably cut emulsion plates are at first observed with the help of an optical microscope to scan for the events of particular interest. Each event thus recorded is further scrutinised under high power microscope, such as, Leitz Ortholux, Crooks, Koris ka and Olympus microscope. There are generally two methods for scanning, viz, (1) along the line and (2) volume or area scanning. In the line scanning a

particular track is picked up at the point of entrance through the plate and followed up to the end of its range in the pellicle or through pellicles, when the particle moves through a number of them. In the area scanning method, every portion inside the emulsion pellicles is examined for the desired events. The co-ordinates of the events are generally recorded from the numbers printed on the back of the pellicles.

2.7 IDENTIFICATION OF CHARGED PARTICLES :

A particle is said to be identified uniquely if its mass (M) and charge (z) are known precisely. A charged particle while moving through an emulsion ionises the silver halide crystals on its path. The developmental centres or latent images are formed along the path of these particles. These developmental centres give rise to black grains of silver when the emulsion is properly processed and thus the path of the charged particles in the medium is registered as a track which on analysis may act as a signature for the particle. A careful study of the track characteristics enables one to identify the particle forming the track in the emulsion. Neutral particles can not be registered in emulsion as they do not have net electrical charge to cause ionisation and the ionisation caused by their magnetic moments are also not appreciable. Now, we describe briefly the important methods by which charge and mass of the particle forming the track can be determined.

1. Charge determination :

The following methods can be applied to determine the charge 'z' of a particle stopped in the emulsion.

(a) Delta-ray (δ-ray) observation.

(b) Profile measurements.

(c) Tapering length measurements.

(a) Delta-ray observation :

When a particle of mass 'm' and charge 'ze' penetrates the matter its electric field disturbes the atomic electrons. These interaction constitute collisions of varying energy transfer in which the kinetic energy of the particle is dissipated.

The energetic electrons are generally knocked out from the atoms in such an encounter and they may produce secondary ionisation. As a result of which some short electron tracks are seen to be ejected from the trajectory of the primary particle. Such short secondary electron tracks are known as delta.rays. The production of such delta-rays is a function of the charge and velocity of the particle. The measurement of delta-ray density, under suitable condition, on a track may be used to estimate the charge of the particle. The number 'dn' of delta-rays in the energy interval from w to w + dw and produced by a particle of charge 'ze' and velocity v through the emulsion is given by the theoretical expression of Mott[9] and Sorensen[10] as,

$$dn = \frac{2\,NZ^2\,e^4}{mv^2}\,\frac{dw}{w^2} \qquad \ldots \qquad 2.7a$$

where m is the mass of the electron, N is the number of electrons per c.c. of the emulsion. The total number n of delta-rays per cm, 'n' having energy greater than w, is given by integrating the equation (2.7a) between the limits from w_1 to the maximum energy $w_2 = 2mv^2$ which a heavy particle with velocity v can transfer to an electron.

Thus,

$$N(w,v) = \frac{2\,Nz^2\,e^4}{mv^2}\left(\frac{1}{w_1} - \frac{1}{2mv^2}\right) \ldots \quad 2.7b$$

Those equations 2.7a and 2.7b are only valid for non-relativistic particles.

As is seen from the equation 2.7a the number of delta-rays, n, depends on the arbitrarily choosen value of w.

For particles of charge z and velocity v one can also write

$$n\delta = z^2 f\ (\beta = v/c) \qquad \ldots \qquad 2.7c$$

where $n\delta$ the number of delta-rays. It is seen from the equation 2.7c that at $v = \sqrt{w_1 / 2m}$ where $n\delta = o$, i.e., no delta-rays will be produced, and at $v = \sqrt{w_1 / m}$, $n\delta$ will be maximum. After this maximum value, n varies approximately as $1/v^2$. For the same velocity, the maximum value of $n\delta$ for two particles of charge z_1 and z_2 are given by the relation as,

$$n\delta\ (1)\ /\ n\delta\ (2) = z_1^2\ /\ z_2^2 \qquad \ldots \qquad 2.7d.$$

This relation is used to estimate the charge of an unknown particle by δ-ray observation in terms of the similar observation on the tracks of particle of known charge. To obtain the maximum value n_2 of δ-rays, all the δ-rays longer than a cut-off values are to be counted in equal intervals of ranges along the track of the particle of unknown charge z_2. This value n_2 may then be compared with n observed in the same way on the tracks of particle of known charge z_1. Applying the relation 2.7d the charge z_2 can be calculated out.

Thus to determine the charge of unknown particle, the observation on maximum δ-ray density is essential. Daiton[11] et al observed experimentally that the maximum δ-ray density occurs at particle velocity $\beta = v/c = 0.2$. The different conventions are adopted in counting the δ-rays. Here all tracks having three or more grains (energy $\sim$ 15 Kev) are counted. It is to be noted that high energy δ-rays producing minimum grain density escape detection almost in all cases. However, in charge estimation the δ-ray method is applicable only when the track length is $\geq$ 1 mm.

(b) and (c) Profile and thin down measurement :

The ionisation i.e., the rate of loss of energy of a charged particle is proportional to the square of the charge and inversely to its velocity. Hence, with the slowing down of the particle, the ionisation and hence the width of the

the track increases.

The increase in track width with decrease in velocity is caused generally due to -

(a) An increase in size of the developed grains with the higher energy loss in the crystal.

(b) The crowding out of the grains as their number increases.

(c) Delta-ray sensitising crystals which lie slightly off the track of the particles.

When the ionisation is low for the same particles that means for high velocity particles, most of the information can be obtained by grain counting or blob and gap counting. But the grain counting is impossible for low velocity, i.e., for high ionisation and it is the thickness of the track gives the useful information. When the track is very short, i.e., 100 microns, no other measurement is possible except the average width of the track which is a function of z. In case of multiply charged particle estimation of charge can be made by observing the tappering length which is also a function of the charge of the particles. These two methods can be described as in the following paragraphs.

(b) Profile measurement :

It has been shown by Nakagawa[12] et al that $\bar{w} \propto \sqrt{z}$ where $\bar{w}$ is the average width of the track and z is the charge of the particle. Thus by measuring the average width $\bar{w}_1$ of a track of known particle of charge z_1 and that $\bar{w}_2$ of a track of unknown particle, the charge of the latter can be estimated from the following relation,

$$\bar{w}_1 / \bar{w}_2 = \sqrt{z_1 / z_2}$$

Hence the profile measurement is important for slowing particle forming the black track. The average width measurement of the last 50 - 100 microns of a stopped particle by the visual methods consists of tracing the profile in projection of the track by measuring the distance of the two edges with the help of a micrometer eye-piece. Some workers also use the photometric method to measure the total blackness of such residual ranges.

Dilworth and Occhialini[13] observed that the width of a track depends on the following factors, as such,

(1) The means employed for its measurement.

(2) Characteristics of emulsion.

(3) Condition of development of the emulsion.

(4) Particles variables of velocity and charge.

Due to diffraction effects, the observed width of a track depends on the illuminating condition, i.e., light intensity, opening of diaphragms, etc.

The width of the track also depends on its angle of inclination to the surface of emulsion. In addition, the errors in observation increase with repeated uninterupted measurement.

(c) Thin down length measurement :

The ionisation increases gradually and attains a maximum value as the velocity of the particle decreases.

After this value, the ionisation begins to decrease again. It is assumed that when the velocity becomes as low as the velocity of the orbital electrons, the fragment begins to capture such field electrons and gets neutralised its own charge, thereby decreasing the ionisation. As a result of which track width due to a heavy charged particle attains a maximum value and then begins to thin down as the fragment begins to loose its charge. Since the process starts by capturing a k-electron the velocity of which is proportional to z, the thin down length is thus a function of charge z of the fragment. These feature of capture and loss becomes more pronounced as the charge of the fragment increases.

The relation between thin down length L in microns and the charge z as obtained by different workers are given below.

$z^2 = L/0.5$ ... Freier[14]

$z^2 = L/0.7$ ... Perkins[15]

$z = L/10$ ... Hoang[16]

These relations obviously depend on development of the emulsion and the technique of measurement used by the observer and cannot therefore, be generally applied.

The particles can also be identified by using the curve of Shigeo Nakagawa[12] giving the thin down length versus the charge of the particle. It may, however, be mentioned that thin down measurement is fruitful for a particle of $z > 3$.

2.8 MASS ESTIMATION :

The mass of the particle stopping in an emulsion can be determined by the methods described below.

(1) Grain density and range measurement :

The ranges of two particles of the same charge and velocity are proportional to their masses. As ionisation is a function of charge and velocity, the mass ratio of two particles showing the same grain density will be given by the ratio of their residual ranges.

Experimental curves can be drawn for the two particles with grain density against residual ranges of the two tracks. A series of determination can be made of the ratio of the residual ranges of the particles for the same grain density from the graph. The mean value gives a measure of the ratio of their masses. Thus the mass of the other particle can be determined, knowing the mass one.

The grain density of a track can be estimated directly by counting the number of developed grains in a measured length of the track. But when the grain density is large for a track the adjacent grains forms the blob and individual grains of which can not be resolved by the microscope. In cases like this the blobs are first counted and then converted into the grain density by making use of a suitable relation. The grain density, 'g' measured in this for a track is normalised with respect to the grain density 'g_0' of a minimum ionising track.

This normalised grain density $g^* = g/g_0$ is independent of the degree of development and the type of the emulsion used.

In order to determine the value of g_0, blob counting can be made on the tracks of primary relativistic particles and then grain density g_0 is estimated from the blob density b_0 with the help of the relation,

$$b_0 = g_0 \, e^{-g_0 \alpha} \quad \ldots \text{ Fowler}^{17} \text{ et al } \ldots \quad 2.8a.$$

where α is a parameter that depends on the developed grain size, optical resolution of the microscope and the observer. The value of g of a lightly ionising track can be estimated by determining its blob density B and gap density H and by using the relation[18]

$$H = B \, e^{-gl} \quad \ldots \quad 2.8b$$

where l is the gap length between two neighbouring developed blob and its value is adjusted in such a way that its value is approximately equal to B/4.

(2) Scattering and range measurement :

The scattering of a particle which is passing through a medium is a function of its charge, velocity and mass. Thus by comparing the scattering in the tracks of two particles of same range, the ratio of their masses can be determined. The constant Sagitta scattering measurement of Biswas[19] et al and Dilworth[20] et al can be used for this purpose. By using the calculated cell size, which is available in a tabular form

for proton and pion (Gottstein[21] et al) coulomb scattering measurements are done from the stopped end of the track in emulsions and hence the scattering parameter of a unknown particle can be estimated. The mass of the unknown particle is determined from the following relation,

$$M/M_p = (\bar{d}_p / \bar{d}) \quad \ldots \quad 2.8c$$

where M_p and M are the masses of proton and that of the particle respectively, and $\bar{d}$, $\bar{d}_p$ are the mean noise corrected Sagitta (second differences) for the particle and the proton. For a fragment of charge z the following modified equation is used,

$$M/M_p = (\bar{d}_p / \bar{d})^{2.31} \; z^{-0.36} \quad \ldots \quad 2.8d$$

In actual experimental set up the track is aligned along the stage motion of the microscope. The second differences are calculated from the intercepts made on both sides of the hair line. To avoid the large deflection of the track due to coulomb scattering a cut off at four times the mean angle of scattering is applied. The values of second differences are calculated from the third or fourth differences. If $\bar{d}_2$, $\bar{d}_3$ and $\bar{d}_4$ are average values of second, third and fourth differences respectively, then,

$$\left.\begin{array}{l} \bar{d}_3 = 3/2.\ \bar{d}_2 \\ \\ \bar{d}_4 = 2\ \bar{d}_2 \end{array}\right\} \quad \ldots \quad 2.8e$$

In the case of dipping tracks the unknown mass can be calculated from the following relation (Biswas[22] et al),

$$M = M_p \left(\bar{d}_p / \bar{d} \right)^{2.276} (\text{Sec } \theta)^{2.221} z^{0.36} \quad \ldots \quad 2.8f$$

where θ is the angle of dip and lies between 0° to 60°. For highly steep track having $\theta > 60^\circ$. The method is not applied as the error is large.

A track having a length of about 1 mm or more is suitable for mass measurement by this method. For tracks shorter than this, the number of cells decreases resulting in high standard error in measurement, which is calculated by taking the statistical error on $\bar{d}$ to be $0.75/n^2$, n being the number of independent cells taken.

3. Scattering and grain density measurement :

This method is applied for the estimation of the mass of a particle when its range is not known. The ratio of the scattering parameter for the two particles of unit charge, producing tracks of the same grain density is inversely proportional to the ratio of their masses. Therefore, we can plot grain density versus scattering parameters for the two particles. From the curve so obtained we determine the ratio of the scattering parameters for the same value of the grain density. This ratio can be obtained for different values of grain density and the mean value may be taken. If the mass of one particle is known, the mass of the other can be determined from the ratio.

2.9 RANGE MEASUREMENT

The actual range of a straight track can be determined by measuring the projected range on the surface of the emulsion and the dip angles. The projected range of straight track having range not greater than the length of the graticule scale, is measured directly with the help of a graticule scale in the eye piece. For tracks of longer length the range is measured by displacing the graticle through its own length, along the direction of the track by an appropriate number of times. In case of such displacements, a grain or other distinctive feature in the field of view which coincide with one end of the graticule is used as a fiducial mark in moving the stage. For a scattered track, it is divided into different segments and can be taken approximately as straight and then projected ranges of each segments is determined separately. The dip angle can be found out from the difference in depth of two points on the track, as can be measured by the dip screw, taking into account of the projected length between the two points and the shrinkage factor of the emulsion.

Therefore, if 'p' be the projected range of a track, 's' the shrinkage factor of the emulsion, and 'd' the difference in depths between the two ends of the track, then the true range of the track is given by,

$$R = p \sec \theta \qquad \ldots \qquad 2.9a$$

where $\theta = \tan^{-1} \frac{sd}{p}$ is the angle of dip.

In measuring theactual range of a track, errors are found to creep in due to following reasons :

(a) Uncertainty in locating the point of origin of track.

(b) Distortion of emulsion during processing.

(c) Uncertainty in observed range due to staggling.

2.10 MEASUREMENT OF ANGLES :

The space angle ψ between two tracks diverging from a common centre in emulsion having angles of dip δ_1 and δ_2 respectively and the projected angles θ between them is given by

$$\cos\psi = \cos\theta \cos\delta_1 \cos\delta_2 + \sin\delta_1 \sin\delta_2 \quad \text{rr.} \quad 2.9b$$

The angle between the two tracks in a processed emulsion can differ from the angles between them in the unprocessed emulsion for the following reasons :

(a) The emulsion shrinks in a direction perpendicular to its plane during the processing.

(b) During processing, the emulsion layers may move with respect to each other thereby causing distortion. Unless the tracks are very flat distortion will change the angles between the tracks.

(c) Coulomb scattering of a slow particle introduces an uncertainly in the direction of the track, hence it produces uncertainty in the measurement of the angles between them.

(d) Random errors also can produce uncertainties in the measurement.

The space angle between the tracks can be determined by methods of stereographic projection, using a chart called 6B circle. This method is a rapid one and requires the knowledge of projected angle between two tracks and their corresponding dip angles. The angles so measured is expressed in degrees.

2.11 ENERGY FROM MULTIPLE SCATTERING METHOD USING CELL OF CONSTANT LENGTH :

The direction of motion of a charged particle passing through a material medium changes continuously due to multiple coulomb scattering by the atomic nuclei near its line of motion. The average angular deviation $\langle\theta\rangle$ of a particle of charge ze traversing a length of path 'c' gives a measure of the quantity pv, where p is the momentum of the particle and v its velocity, the average angular deviation $\langle\theta\rangle$ is related to other quantities in a way given by following equation.

$$\langle\theta\rangle = k\ z\ (c^{1/2}/\ p.v) \qquad 2.11a$$

where k is a nearly constant quantity for a given value of c and $\langle\theta\rangle$ represent the arithmatic mean. The quantity c is called the 'Cell length' and the value choosen in practice depends upon the momentum of the particle of which the track is being measured. The values of c ranging from 25 micron to 1 cm is employed in practice.

The scattering of a particle is independent of the emulsion sensitivity and its degree of development. By measuring scattering accurately, it can be used to determine the product $p\beta/2$ of the particles magnetic rigidity and its velocity.

In actual experiment it may be found to be convenient to transform the observed value of $\langle\theta\rangle$ obtained byusing an appropriate value of 'c' to the equivalent value for a standard cell size c = 100 microns. This value is referred as $\bar{\alpha}$ and it can be written as $p\beta = kz/\bar{\alpha}$ ... 2.11b.

There are two methods for the determination of the value of $\bar{\alpha}$ in both the cases the deviation in the projection of the track on the plane of the emulsion is calculated. This methods are -

(1) Angular Methods :

Here the direction of the tangent to the trajectory is estimated at a number of equally spaced point along the track, the deviation are deduced from the difference in successive readings (Goldschmidt-Clermont[23] et al, Davis[24] et al).

This method is utilised when the available track length is small for measurement. It may sometimes be used to measure the angles between the tangents, when the particle is strongly scattered. But the method of measurement has now been generally superseeded by the Co-ordinate method of Fowler[25]. Co-ordinate method is specially preferred when the mean scattering is small.

(2) Co-ordinate method of Fowler :

The track is aligned approximately with the direction of the stage motion of the microscope, which is taken to be abscissa x. The co-ordinates of a succession of points along the trajectory are determined by selection of a cell length c parallel to x. The observations allow the angular deviations between successive chords to be reduced from the second difference of the readings.

If $\bar{d}_2$ = the mean second difference

$$= y_k - 2y_{k+1} + y_{k+2} \qquad 2.11c$$

where y_k = kth deflection of the track,

y_{k+1} = (k+1) th deflection of the track,

y_{k+2} = (k+2) th deflection of the track.

Thus, β is given by,

$$\beta = (k\ z\ c^{2/3}) / 573\ \bar{d}_2 \qquad 2.11d$$

where k the scattering constant is obtained as a function of a cell size for different values from the curve based on Molier's theory and correspond to measurement without cut off.

However, in determining $\bar{d}_2$, in practice, fluctuations associated with occasional large deflections due to single scattering may be avoided by applying the same cut off procedure as discussed in connection with mass measurement by constant Sagitta method.

The error due to distortion can also be eliminated in the same way as in constant Sagitta measurement. For dipping track the dependence on θ in range $0^{\circ} < \theta < 60^{\circ}$ can be represented by emphirical formula by Biswas[26] et al.

$$\bar{d}\ (\theta) = \bar{d}\ (\text{Sec}\ \theta)^{0.975} \qquad \ldots \qquad 2.11e$$

where $\bar{d}(\theta)$ = Mean second difference calculated with the scattering scheme applied to the projection into the plane of the emulsion of a uniformly dipping track = Absolute mean second difference.

2.12 ENERGY FROM THE OBSERVED RANGE :

From the well established range energy relation, the energy of a particle from its observed range in emulsion can be determined accurately. But such energy estimation depends on the accuracy of the range energy relation used as well as the range straggling[27] in the emulsion. The range energy relation for a heavy nucleus with charge number z and mass number M is given by the relation,

$$E = 0.251\ M^{0.419}\ R^{0.581}\ Z^{2} \qquad \ldots \qquad 2.12a$$

where E is the energy in MeV and R is the range in microns. This relation, however, does not hold good at very low energy. Instead experimental range-energy curves are more reliable.

In determining the energy of a particle from its observed range, the range energy curves published by the Barkely[8] group ϕfor different elementary particles and H^{2},

He^4, nuclei are used here. The energies of the heavier energetic particles are estimated as suggested in the same report. The momentum for a slow and very heavy fragments is estimated from the curves of Heekman[28] et al. For slow and heavy particle of mass upto 30 mp, Willkins Curves[29] (for C_2 emulsion) normalised to G5 emulsion are needed. The uncertainties in those tables are expected to be less than 0.6 percent in energy. For particles heavier than 30 mp the range momentum curves given by Lou[30] et al are used here.

2.13 CORRECTION FOR LOSS OF EVENTS :

There are certain factors in emulsion technique of measurement which may cause the loss of events actually searched for. A short discussion on relevant factor is given below.

Loss of events during scanning :

In order to collect the data required for our present investigation, the method of area scanning has been adopted. Area scanning of a pellicle is generally done in strips equal in width of a side of an inscribed square in the microscope field of view. 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 pellicle by rolling the fine focus control between the fingers while looking the events one by one coming into and going out of view. The successive areas could be examined and events could also be recorded by displacing the field of view.

It is quite possible that few events may evade detection during scanning. To have the correct estimation of the frequency or probability of occurance of a particular type of events, the events that evade in scanning requires proper estimation. The usual proceedure for an observer to scan a given volume, and record a number N_1 of the events, than to scan the same volume again by same method recording a number N_2. It 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 altered to check the presence of any further events. According to Barkas[31], if N_{12} be the number of events common to the first two scannings, then the actual number, N of events is given by

$$N = \frac{(N_1 + N_2)}{4\,N_{12}} \qquad \ldots \qquad 2.13a$$

and the scanning efficiency is

$$= \frac{2\,N_{12}}{N_1 + N_2} \qquad \ldots \qquad 2.13b$$

In the present investigation, efficiency of the scanning has been found to be 97 percent and 96 percent in the 1.8 Gev/c $\bar{k}$ and 5 Gev/c $\bar{p}$ stacks respectively.

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