Study on high energy interactions using nuclear emulsion technique

Evolution of the techniques of nuclear radiation detection has played the most vital role in unraveling the mystery of atomic nucleus. The radiations coming out of nucleus such as α, β, or γ rays in spontaneous transformation or various types of subatomic particles (both charged and uncharged) in induced transformations are the signals of information about the properties of the nucleus. Hence their detection and measurement are of prime importance in understanding the structure of the nucleus. The sensitive instruments, which have been developed for this purpose over the years thus act as our eyes and ears to probe the mysteries of the nucleus. Nuclear emulsion track detector is one of the sophisticated devices to detect the charged particles.

Photographic emulsions initiated accidentally their role in particle physics more than 100 years ago, when H. Becquerel discovered natural radioactivity by observing the blackening of photographic plates by uranium salts. It was the beginning of a history, which led to the discovery of the "new world" of the elementary particles.

But the method was later abandoned as the emulsions then in existence were very insensitive for qualitative studies with nuclear radiations. The density of such emulsion was low and developed crystal grains were too large and widely spaced to give any well-defined particle tracks.

Soon after the Second World War an intense research and development carried out in collaboration between the C. Powell group and Ilford led to the development of the so called "nuclear emulsions". In this developed "nuclear emulsions" the proportion of AgBr to gelatin is about 4-5 times higher than the ordinary optical emulsions and AgBr grains have diameter 0.1 to 0.2μm only. Such fine grain nuclear emulsions with thickness varying from 25-2000 μm have reopened the technique as a detector of nuclear radiation with renewed vigour. Senior physicists realized very soon that research in nuclear physics with emulsion technique offered an ideal field for reemerging university groups, not only because it was cheap but also because it was particularly suited to those coming back to, or just beginning their research after the second world war. This technique was well suited for international collaboration and the small groups emerging from the catastrophe of the war found in emulsion a way to contribute easily at the forefront of physics research.

The emulsion technique led to the discovery of the pions in 1947 and to many important contributions to the development of particle physics. Many cosmic ray experiments were carried out in the ‘50’s and the ‘60’s, contributing among other observations to the discovery of the strange particles in cosmic ray.

Physical Characteristics of Nuclear Photographic Emulsion

The photographic emulsion commonly used for recording tracks of charged particles differs from those of ordinary photographic film in two respects: The ratio of silver halide to gelatin is about eight times higher in nuclear emulsion and the emulsion layer is between 10 to 100 times thicker than ordinary photographic film. Further in modern condition, the nuclear emulsion is used frequently as a stripped emulsion without glass support.

Nuclear emulsion consists of three basic components i) silver halide chiefly bromide of density 6.47g/cc, ii) gelatin and iii) a plasticiser such as glycerine and water. Mean linear dimension of grain is 0.15μ in Ilford C2 emulsion, 0.3μ in Ilford G5 emulsion. Typical grain size variation is from 0.1μ to 1μ.

The primary function of gelatin of an emulsion is to provide a 3-D network which serves to locate the small crystals of the halide and prevent them from migrating during development and fixation. Gelatin is a complex organic substance that can absorb large quantities of water. In doing so, volume may increase tenfold. In the expanded condition diffusion of water and salts can take place through interstices between the chains of atoms of the expanded molecular network of the gelatin. But the silver bromide and the silver grains which replace some of them after development remain fixed in their position. These are of fundamental importance in recording tracks of emulsions. Gelatin also contributes to the sensitivity of the silver halide grains. It is believed for e.g.: during digestion, when the emulsion is maintained at say 60ºC for a definite period – there is reducing action of gelatin on grains of silver halide which produces surface silver atoms. The aggregates of silver atom at the surface can act as development centers.

Glycerine is incorporated in the emulsion as a plasticizer. It reduces the brittleness of the emulsion and promotes plastic flow under stress. It is particularly important if the plates are to be exposed in vacuum, for this causes the emulsion without plasticizer to strip from the glass. The adhesion of the emulsion to the glass is so strong that the glass can often fracture under stress.

Nuclear emulsions are usually made in thin films, from about 20 to 1000 microns of sizes up to 50cm×50cm. They are usually mounted individually on glass plates, and placed on microscope stages for examination. At the most convenient for an examiner of the pellicle, the thickness of the pellicle should not exceed 600 microns (even then one often has to change the objective two to three times).

The elements present in the gelatin medium (along with plasticiser i.e. glycerin) are carbon, nitrogen, oxygen, hydrogen and sulphur. From Table 1 we can have a clear idea about the composition of a standard research emulsion.

If a charged particle moves through this medium it produces a latent path along its track which after development process forms a track of the charged particle, the metallic silver grains appearing along the track.

The sensitivity of the emulsion for the detection of different types of particles depends on the grain size. Smaller the grain diameter less is the sensitivity. Particles, which are highly ionizing, require less sensitive plates for recording their tracks.

Table 1: Composition of standard emulsion

Element	**Atomic Number**	**Atomic Weight**	**No. of Atoms $\times 10^{22}$**			
			Per cc of Halide	**Per gm of Halide**	**Per gm of Gelatin**	**Per gm of Water**

Ag	47	107.88	2.071	0.32		
Br	35	79.916	2.06	0.318		
I	53	126.93	0.016	0.018		
H	1	1.008			4.57	6.70
C	6	12.00			2.42	
N	7	14.008			0.55	
O	8	16.000			1.137	3.35
S	16	32.06			0.032	

Nuclear Tracks Formation

The ionising particles which passing through the nuclear emulsion alter the silver halide crystals, which are distributed uniformly throughout the volume of the gelatin matrix, by complex electro-ionic processes. As a result of it silver specks within the crystal grains are formed. They serve as a latent image, which becomes visible by the development of the emulsion. In the development process the silver specks act as catalysts for the action of weak reducing agents, which deposit additional silver atoms from the same crystal. The deposited silver, which appears as black grains under a microscope is permanently embedded into the gelatin in the fixing process. The unexposed silver halide crystals remain unaffected in the development bath and are removed in the fixing bath, usually sodium thiosulfate, which facilitates the solution of silver bromide. Thus the opaque silver grains form the permanent track structure. To get a good track resolution, the nuclear emulsions have very small grain size and a low density of background developable grains. The probability of development of a certain crystal depends on several factors like emulsion sensitivity, energy of impinging particle, where the charged particle traverse within the emulsion pellicle etc.

Characteristics of the Tracks

Various characteristics of the tracks formed within the emulsion are discussed below:-

(i) Grain Density

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 micron of track is defined as grain density (*dn/dx*). The grain density has been found to be proportional to

- the rate of loss of energy of particle producing per unit of track *dT/dx* (in *KeV* per micron)
- the square of the charge (*Z*) of the particle, a feature confirmed by experiments

(ii) Shrinkage Factors

Gelatin and glycerine, both are hygroscopic. The actual equilibrium thickness and index of refraction of both the processed and unprocessed emulsion depends on the surrounding humidity. Then the shrinkage factor (*S*) is defined as

$$S = \frac{thickness\ of\ emulsion\ layer\ during\ exposure}{thickness\ of\ emulsion\ layer\ during\ scanning} \qquad (1)$$

Thus it is essential to know the original thickness of the emulsion for any qualitative measurement of track densities, range and angles in emulsion. The shrinkage factor is generally supplied by the manufacturer of the emulsion plates.

Classification of the Emulsion Secondary Tracks

The observed tracks of the charged secondary's of the events are classified according to the following criteria of emulsion technology :

Shower tracks**:** The relativistic shower tracks have ionization *I* less than or equal to $1.4I_0$, I_0 being the minimum ionization of a singly charged particle. The value of minimum ionisation (I_0) in terms of the grain density is about 14 - 15 grains per 100 μm for this investigation. The shower tracks are mainly produced by pions (π^+, π^-) and are not generally confined within the emulsion pellicle. These shower particles have energy in *GeV* range.π^0 is a neutral particle so it does not ionize the medium and hence we do not get the tracks of neutral pions.

Grey tracks**:** They are mainly fast target recoil protons with energy up to 400 *MeV*. Ionisation power of grey particles lies between $1.4I_0$ to $10I_0$. Their ranges are greater than 3 mm. These grey particles have velocities lying between 0.3*c* to 0.7*c*. A very few number of grey particles are produced by deuterons, tritons, He^3 nuclei etc most of which result from the nucleon cascade set up in the strucked nucleus.

Black tracks: Black particles consist of both single and multiple charged fragments. They are target fragments of various elements like carbon, lithium, beryllium etc with ionization greater or equal to $10I_0$. Their ranges are less than 3 mm. They have velocities less than $0.3c$, where c is the velocity of light in free space. Their energy is less than 30 MeV.

Projectile Fragments: The projectile fragments are a different class of tracks with constant ionization, long range and small emission angle. These projectile fragments are within an emission angle of 5^0 with respect to the beam direction.

Measurement Methods

(i) Range

When a charged particle passes through a nuclear emulsion it is decelerated due to interactions with atoms along its path. Below certain threshold energy, it ceases to ionise and its visible track terminates. The track length of the particle is the distance along the trajectory starting from its point of origin to the last developed grain. This gives a measure of the true range of the particle accurate within the narrow limit.

It should be mentioned here that the range of the particle is essentially the length of its path in an unprocessed emulsion. During processing it shrinks and undergoes other distortions. The un-mounted emulsion plates may suffer both lateral and vertical shrinkage. The shrinkage factors S_x, S_y, S_z may be defined along the principle axes of the ellipsoid into which a small sphere of the emulsion is distorted in processing. Usually $S_x \approx S_y \approx 1$ and $S_z \approx S$ for mounted plates.
Knowing the position coordinate of the centre of the star and the terminating point (x_2, y_2, z_2) of any track, its length or the range could be obtained by using the formula:
Length or range $R=\sqrt{(x_2-x)^2+(y_2-y)^2+\{S(z_2-z)\}^2}$ (2)

(ii) Space-Angle

The space angle X between two tracks can be measured by the simple co-ordinate method. If the direction cosines of the tracks are (l_1, m_1, n_1) and (l_2, m_2, n_2) then

$$cos\, x = l_1 l_2 + m_1 m_2 + n_1 n_2 \qquad (3)$$

Direction cosines of a track can be easily obtained by taking space co-ordinates 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 co-ordinates, the directions cosines are given by

$$l = \frac{(x_1 - x_2)}{[(x_1 - x_2)^2 + (y_1 - y_2)^2 + (s(z_1 - z_2))^2]^{1/2}} \qquad (4)$$

$$m = \frac{(y_1 - y_2)}{[(x_1 - x_2)^2 + (y_1 - y_2)^2 + (s(z_1 - z_2))^2]^{1/2}} \qquad (5)$$

$$n = \frac{s(z_1 - z_2)}{[(x_1 - x_2)^2 + (y_1 - y_2)^2 + (s(z_1 - z_2))^2]^{1/2}} \qquad (6)$$