NUCLEAR EMULSION EXPERIMENT

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Aim of the experiment

(i) To obtain a random sample of interaction events (stars) in nuclear emulsion

(ii) To calculate the average energy carried by heavily ionizing particles (N_h)

About Nuclear Emulsion

Nuclear emulsion is a versatile instrument to detect the charged particles. It is not only capable of counting charged particles, but also provides information regarding the mass, energies of particles and their modes of collisions. It also allows studies of angular distribution of all out coming charged particles of the individual events in space with higher accuracy and in 4π geometry, although with rather limited statistics The nuclear emulsion has high density and high stopping power. Its stopping power is approximately 1700 times the stopping power of standard air. After development, the stacks of nuclear emulsion are kept under specific conditions. Thus the photographed events can be preserved for many years.

The nuclear emulsion, basically consists of the following components

(i) Silver halides, mainly bromide with small admixture of iodine

(ii) Gelatin and glycerin

(iii) Water.

(iv) Nuclei of CNO group

The glycerin works as plasticizer for preventing nuclear emulsion stack from breaking. It may be pointed out that about 71% of interactions occur with heavy emulsion nuclei (AgBr), approximately 25% due to light emulsion nuclei, i.e. Carbon, Nitrogen and Oxygen (CNO) and only 4% with hydrogen nuclei. However, the cross-section of reactions with heavy, light and hydrogen nuclei depends on the mass and energy of the projectile. It is well known that the nuclei of nuclear emulsion having average atomic mass <A> = 73, mainly consist of CNO group with <A>= 14, the AgBr group, <A> = 94 and hydrogen <A> = 1.

Mechanism of Track Formation

When a charged particle passes through nuclear emulsion, it losses its energy by electromagnetic interactions. The energy lost by the charged particle is transferred to the electrons of the atoms. As a result of this, the later goes to an excited state. If the energy transferred to the electron is greater than the ionization potential of the atom, the electron is free to move from atom and the atom is said to be ionized. It may be mentioned that the most important mode of energy loss of a charged particle is the ionization and it depends on the charge and velocity of the particle. The ionization of the atom converts some of the silver halide grains in such a way that they when immersed in a reducing bath, known as developer, get converted into silver grains. Therefore as the charged particle passes, grains are formed, showing the path of the particle, which is termed as the track of the particle. The characteristics of the track depend on the nature and velocity of the charged particle. Higher the velocity of the charged particle, rarer will be the grain formed by it and vice versa. Sometimes it happens that the electron receives energy, which is quite enough for further ionization and thus secondary tracks are observed projecting out of the primary track of the particle. These secondary tracks are termed as δ-rays. The number of δ-rays coming out also depends upon the charge and velocity of the particle. As the particle traverses, the direction of its track also fluctuates along its length due to the statistical combination of Coulomb-scattering.

A charged particle having charge Ze and mass M when traverses through emulsion, suffers a large number of interactions with the atom of target nucleus and a large number of secondary particles, both charged and neutral come out of it. The charged particles produce their tracks and are thus recorded. The recorded event looks like a star and therefore is termed as star. The charged particle traversing through a medium, losses its energy mainly through excitation and ionization of the atoms of the medium through coulomb interactions.

Methods for the measurement of track parameters

The commonly used observable properties of a track in emulsion are

Range

Ionization

Scattering

Multiplicity

Measurements of these quantities can provide information about the mass, charge and energy of the particle forming the track.

Measurement of Range

The range of a charged particle is the average distance traversed by a particle in unprocessed emulsion before its kinetic energy reduces to zero. While computing the actual value of the range we must take the shrinkage and other distortions into account which the emulsion undergoes during its processing. These factors affect the range of the particle.

As the track of the particle is usually not straight due to the various scattering, the projected track lengths are measured in the plane of emulsion and perpendicular to it. The former is called the projected range "l" while the latter one is termed as the dip, ΔZ. Thus for measuring the range, the whole track is divided into n small straight segments. The values of l and ΔZ for each segment are measured. The measured ΔZ is then corrected for the emulsion shrinkage. It may be pointed out that in the case of unmounted pellicles both lateral and vertical shrinkage may take place.

Ionization Measurements

The ionization caused by a charged particle may be estimated by measuring grain density of the track of a particle. The track of a particle in emulsion appears as minute trail of the silver grain. The number of developed grains of silver halide per unit length of the particle is termed as the grain density which is a function of ionization loss of the particle and thus depends upon the charge and velocity of the particle. For higher velocities of the particles, the developed grains are well separated from each other and can be easily counted. However grain density g in a track, corresponding to a particular value of the ionization depends on the degree of development of the emulsion. It is therefore necessary to determine the normalized grain density g^* ($=g/g_0$), defined as the ratio of the number of grains in a track per unit length g, to the number of grains per unit length of a relativistic particle, g_0. This is taken as a suitable parameter for estimating ionization.

Angle Measurement

Space Angle

For measuring the space angle of a track with respect to the primary, its projected angle in X-Y plane with respect to the X-direction is measured. The projected angle can directly be measured by a goniometer having a least count of 0.25° under a high magnification. To measure the projected angle by goniometer, the vertex of the collisions is focused at the centre of the goniometer and the track of the primary beam is aligned with one of the reference lines of the goniometer. Now the tracks of secondary charged particles are aligned one by one with the other reference line of the goniometer and goniometer scale reading is noted for the projected angle with respect to the forward direction of the beam of the projectile. The dip angle of a track may be estimated by measuring the Z-coordinate of two points on the track separated by a known distance.

If the angular separation between the tracks in the forward cone is very small then it is very difficult to measure the projected and dip angles because of the fact that the tracks are overlapping to each other. In such cases, the X, Y, Z coordinates have to be measured. For measuring the angle, first the track of the primary beam of the event is aligned parallel to X-motion of the microscope. The vertex of the star is focused and the reading of the Z-coordinate is noted. Now the stage is moved forward to at least five fields of view. Again a point on the track of the primary beam is focused and the reading of the Z-coordinate is further taken. These two readings give the dZ reading for the projected length dx. The number of fields of view shifted will provide the dx reading for measured dZ reading. Moreover, the dy reading is taken from the graticule scale of the eyepiece of the microscope for a segment dx. Similarly, the readings of dy and dz for each track of the star are noted. While taking the Y and Z reading we must be very careful regarding the direction of the tracks.

Multiplicity Measurements

The basic information from nuclear emulsion experiments is mostly based on the multiplicity and angular distributions of secondary particles produced in the interactions of the projectiles in nuclear emulsion. The multiplicity of secondary charged particles can provide some additional information regarding the geometrical aspects of relativistic heavy ion interactions.

Details of the Stack

The plate used for the present experiment is part of an emulsion stack of NIKFI-BR-2 nuclear emulsion. The stack is exposed to a beam of ^{12}C-ions with a momentum of 4.5 GeV/c per nucleon at the synchrophasotron of the Joint Institute of Nuclear Research, Dubna, Russia. The size of each pellicle is 18.7 cm x 9.7 cm x 0.06 cm. Each pellicle is mounted on a glass plate, and is then ready for analysis.

Scanning

The process of searching the position of the events caused by the collisions of the projectile and emulsion nuclei in nuclear emulsion is known as the scanning of events.

There are two types of scanning: (i) Area scanning and (ii) Line scanning
Area scanning is used in the present experiment. In case of area scanning, the full depth of the pellicle is examined by rolling the fine focus of the control Z of the microscope. While observing the layers of the nuclear emulsion one continuously goes on looking for the disintegrations present in the field of view and before shifting the field more than one traverse must be made along the Z-motion. The field of view is shifted along the X-motion of the microscope only when the whole X-strip of the pellicle is computed. On computing the X-strip on should switch on to the next X-strip by giving the displacement in y-direction equal to or less than one field of view. Similarly, the whole area of the pellicle is scanned out.

Classification of tracks

All the charged secondary particles produced in a primary interaction may be classified into the following categories

(i) Shower tracks

The tracks with ionization, $g < 1.4g_0$, where g_0 is the plateau ionization, are termed as shower tracks. These tracks are formed by particles having relative velocity, $\beta \geq 0.7$. The number of gery tracks in an event is represented by N_s. These are tracks are mainly of pions and mixture of fast protons.

(ii) Grey Tracks

The tracks with ionization in the range $1.4g_0 \leq g \leq 10\ g_0$ are called grey tracks. These tracks are formed by particles with relative velocity in the range $0.3 \leq \beta \leq 0.7$. The number of grey tracks in a star is designated by N_g. The grey tracks are generally protons, deuterons, tritons and slow pions.

(iii) Black Tracks

The tracks with ionization, $g \geq 10\ g_0$, are termed as black tracks. These tracks formed with particles having $\beta < 0.3$. The number of black tracks in an interaction is denoted by N_b. Black tracks are formed, basically by slow charged particles and evaporated nuclear fragments.

(iv) Heavily Ionizing Tracks

The grey and black tracks taken together are referred to as heavily ionizing tracks ($\beta < 0.7$) and their number in an interaction is given by N_h
($= N_b + N_g$)

1.

2. Observations and Calculation

Energy carried by heavily ionizing particles may be calculated by the following empirical relation.

$$E(\langle N_h \rangle) = 124*(\langle N_h \rangle) + 30 \text{ MeV} \qquad (1)$$

Here $\langle N_h \rangle$ is the average number of heavily ionizing particles in a random sample.

1. A Sample Calculation

A sample calculation method for $\langle N_h \rangle$ is described below. Let us assume that 20 interaction events are selected in a random sample. A typical tabulation of the observations is shown in the following Table.

S. No.	Coordinates X Y	Total no. of prongs	No. of shower tracks, N_s	No. of Heavy tracks, N_h
1	40 54	14	2	12
2	45 48	22	4	18
3	21 58	20	3	17
4	25 14	12	2	10
5	35 86	18	4	14
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20	21 63	12	3	9

To calculate the average number of heavy tracks per event, total events may be divided into following N_h bins.

N_h interval	Mean Value, A	No. of events, N	N_h =A*N
1-3	2	2	4
3-5	4	4	16
5-7	6	1	6
7-9	8	3	24
9-11	10	2	20
11-13	12	4	48
13-15	14	1	14
15-17	16	2	32
17-19	18	1	18
	Total →	20	182

Now

$$\langle N_h\rangle = \langle N_h\rangle / N = 182/20 = 9.1$$

By substituting the value of in eq.(1), we get

$$E(\langle N_h\rangle) = 124*(9.1) + 30 \text{ MeV}$$

$$E(\langle N_h\rangle) = 1128.4 + 30$$

$$= 1158.4 \text{ MeV or}$$

$$E(\langle N_h\rangle) = 1.158 \text{ GeV}$$

3. Result

The average energy carried by heavily ionizing particles in this sample is found to be 1.158 GeV.

4. Precautions

Emulsion plate should be carefully cleaned with a dry cotton ball for dust and moisture.

Emulsion plate should be placed on the microscope keeping the mounted surface upside.

The glass surface of the microscope should also be cleaned before mounting the emulsion plate.

- Care should be taken that the objective lens of the microscope does not touch the plate surface as it might damage the mounted pellicle.
- Each event must be scanned for its entire depth, by using the fine Z controller.
- There may be tracks originating very near from the event, but still may not be the decay product of that event. These tracks should not be counted.
- You may see a thick black track, originating from the event, along the positive x-axis. This track is formed by the primary particle and is not a product of this event, so this track should also be ignored.
- There may be scratches on the plate which might appear as a track. To eliminate these scratches, slightly move the fine Z-controller. The scratches are formed only on the surface of the plate, and will disappear even with a slight Z movement, while a track, which is formed along the depth of the plate will be visible in more than one field of view.