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Multifragmentation Study of a ^{84}Kr$_{36}$ Projectile Interacting with a Nuclear Emulsion Detector at 1 GeV per nucleon

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This article focuses on the emission characteristic of intermediate mass fragments (IMF) produced by the interactions of ^{84}Kr$_{36}$ with the NIKFI BR-2 nuclear emulsion at an incident kinetic energy of arround 1 GeV per nucleon. The multiplicity characteristics of singly charged fragments and doubly charged fragments with respect to a function of total charge confined in the fragments for $Z \geq 3$ (Z_{b3}) are studied and reported. The correlation between intermediate mass fragments and Z_{b3} are also studied and reported. The results are found to be consistent with there from other experiments.

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I. INTRODUCTION

Nuclear fragmentation is an important experimental phenomenon in nucleus-nucleus collisions at relativistic high energy [1–5]. The nuclear emulsion detector (NED) is one of the oldest detector technologies and it has been use since the birth of the experimental nuclear and astroparticle physics [1–5]. According to the participant-spectator model (PSM), the interacting system in relativistic nucleus-nucleus collisions can be divided into three regions: (i) a participant region, (ii) a projectile spectator region, and (iii) a target spectator region. The overlapping region of the two colliding nuclei is called the participant region, in which new particles created, the remaining parts of nuclei that do not participate in the collision are the projectile spectator, which found in the projectle spectator region and target spectator, which found in the target spectator region, respectively. The velocity of the participant has a wide distribution from zero to the projectile velocity. The projectile spectator has almost the same velocity as the projectile does while the velocity of target spectator in the laboratory frame of reference is close to zero [1–5]. The projectile fragments corresponding to the spectator part are observed in forward narrow cone of $\leq 10^0$ while the target fragments are observed as highly ionizing particles that are distributed isotropically around the vertex of event. The NED is widely used in the investigations of nuclear fragmentation due to its high position and angular resolutions [1–5]. In the projectile multifragmentation process, a projectile spectator breaks into several intermediate-mass fragments. The study of the decay of such excited nuclear systems provides information on nuclear collision dynamics [1–5].

The present work focuses on the emission characteristics of the multiple charge projectile fragments ($Z \geq 3$) and the dependence of those characteristics on the mass of the fragments for the interaction of a ^{84}Kr projectile with a NED (as target) at relativistic energy. We study the correlations between the average multiplicities of singly charged projectile fragments ($Z = 1$) and doubly charged projectile fragments ($Z = 2$) with the total bound charge $Z_{b3} = \Sigma_F Z_F (Z_F \geq 3)$. We also study the correlation between the average multiplicities of intermediate mass fragments and the total bound charge. The results are compared with other experimental observations and found to be consistent with those observations.

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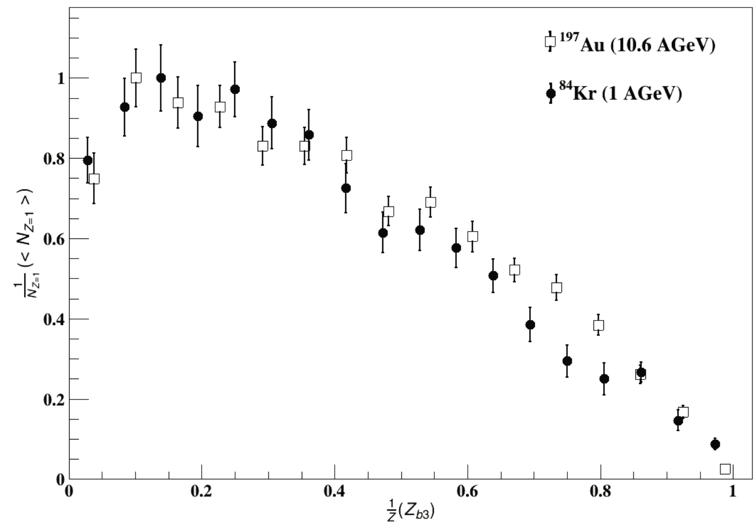

Fig. 1. Average multiplicity of singly charged fragments as a function of Z_{b3}.

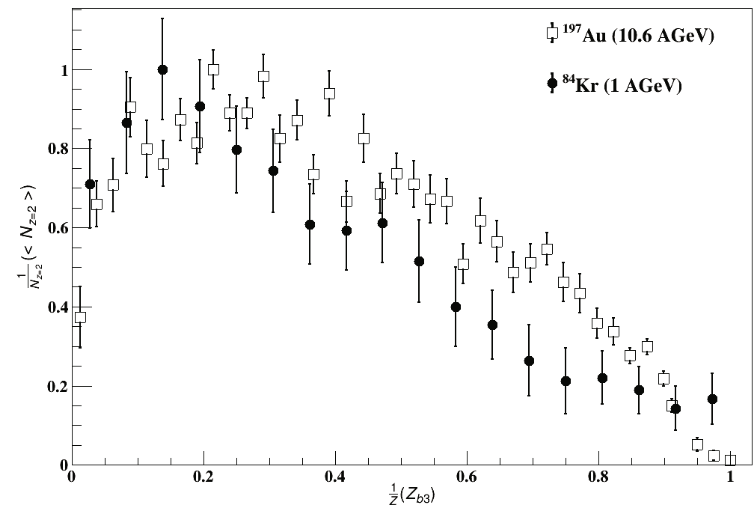

Fig. 2. Average multiplicity of doubly charged fragments as a function of Z_{b3}.

II. EXPERIMENTAL DETAILS

The NED is a composite target detector. It is a combination of several nuclei such as, H, C, N, O, Ag, and Br with small percentages of S and I. These emulsion targets are mainly classified into three major types (i) heavy target, a combination of Ag and Br nuclei, (ii) medium target, a combination of C, N, and O nuclei, and (iii) light target, a free H nucleus [1–6].

The highly sensitive NIKFI BR-2 nuclear emulsion film with dimensions of $9.8 \times 9.8 \times 0.06$ cm^3 was horizontally exposed using $^{84}Kr_{36}$ as a projectile at a kinetic energy around 1 GeV per nucleon at the entrance of the NED [1–6]. The exposure of the NIKFI BR-2 nuclear emulsion film was performed at Gesellschaft fur Schwerionenforschung (GSI) Darmstadt, Germany [1–6]. The beam tracks were picked up at a distance of 4 mm from the edge of the emulsion plate and followed carefully until they interacted with nuclei of the emulsion target or escaped from the surface or stopped in the emulsion plate. The line and the volume scanning methods were adopted for the collection of inelastic interactions by using an Olympus BH-2 transmitted light-binocular microscope [1–6].

The Olympus BH-2 transmitted-light-binocular microscope consists of a set of dry and oil immersion objectives of different magnifications for measurement purposes. The eyepiece (10× or 15×) is used to magnify the real image formed by the objective. A scale of least count of 1 μm can be fitted to the eyepieces for measurements purposes. The motions of the screws along the x, y, and z-axis can be read with an accuracy of 1 μm. The coordinates of the beginning and the terminal points of each track can be recorded by vary the microscope under a total magnification (for scanning) of 2250×. The number of events used for this analysis was 600.

The target fragments mostly come from the spectator

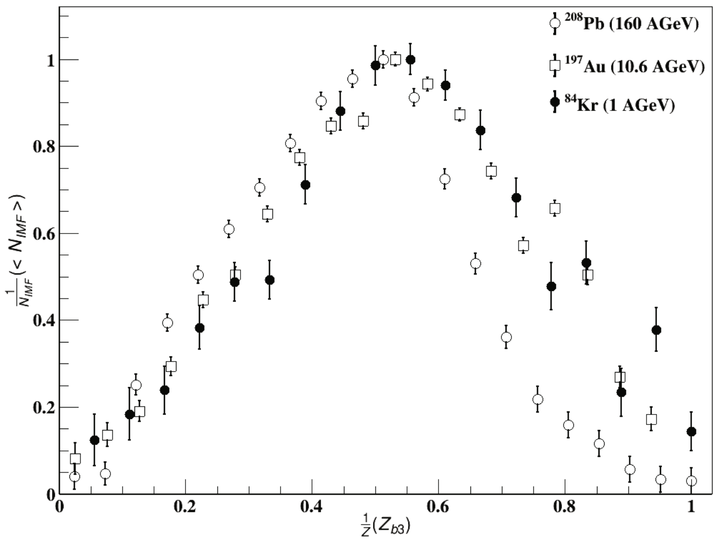

Fig. 3. Average multiplicity of intermediate mass fragments as a function of Z_{b3}.

parts of the target nucleus and can be classified based on their range (L), velocity (β) and normalized grain density (g^*) into the different categories as mentioned below [1–6]:

1. GREY PARTICLE (N_g)

These particles have L > 3 mm, $1.4 < g^* < 6.0$ and $0.3 \leq \beta < 0.7$. These are recoiled target nucleons.

2. BLACK PARTICLE (N_b)

These particles have L < 3 mm, $g^* > 6.0$ and $\beta < 0.3$. These are nucleons that evaporated from the target.

3. HEAVILY IONIZED CHARGED PARTICLES (N_h)

Black and grey particles taken together comprise heavily ionized charged fragments.

4. SHOWER PARTICLE (N_s)

These are the freshly created charged particles, which have $g^* < 1.4$ and $\beta > 0.7$. Mostly these particles are produced in the participant regions where a conversion of energy into mass may occur.

Projectile fragments come from the projectile spectator parts of the nucleus, which have charge Z ≥ 1. Their velocity is nearly that same as that of the projectile. All these projectiles fragments can be classified into three main categories: (i) singly charge projectile fragments ($N_{z=1}$) that are purely the projectile protons, (ii) doubly charge projectile fragments ($N_{z=2}$) that are generally helium nuclei, and (iii) multiply charge projectile fragments ($N_{z\geq3}$), which include intermediate and heavy charge projectile fragments [1–6]. The technique for measuring the charge of the projectile fragments are described in detail in our previous articles [1–5].

III. RESULT AND DISCUSSION

The correlations between the mean numbers of singly charged fragments and doubly charged fragments with total bound charge (Z_{b3}) are shown in Fig. 1 and Fig. 2, respectively. As we can see from Fig. 1 and Fig. 2, the multiplicity distributions of single charge ($Z = 1$) and double charge ($Z = 2$) first rise and then decreases sharply with increasing in Z_{b3} value. This indicates that a threshold exicts for nuclear multifragmentation [7–18]. The physics behind this behavior is the dominance of evaporation of nucleons and light nucleus at low excitation energy [7–10]. This study showed that the mechanism corresponding to nuclear residual fragmentation did not depend on the mass of the projectile nucleus [7–18].

Figure 1 and Fig. 2 shows that the nuclear data points of ^{84}Kr and ^{197}Au are very close to each other up to a certain value of Z_{b3}, which indicates that the nuclear residuals of the same masses that formed in interactions of different systems at relativistic high energy have approximately the same excitation energies. Thus, the distributions of $< N_{z=1} >$ and $< N_{z=2} >$ versus Z_{b3} are found to be independent of the target mass [7–18].

To understand the mechanism involving in the formation of intermediate mass fragments as well as multifragmentation, researcher have performed many experiments at different (low/intermediate/high) energies [16–18]. Figure 3 show the correlation between the average multiplicities of intermediate mass fragments and Z_{b3}. The average value of $< N_{IMF} > = 1.05 \pm 0.11$ for ^{84}Kr$_{36}$ having an incident energy 1 GeV per nucleon. After fitting the distribution with a Gaussian function we get the mean values 0.497 ± 0.002, 0.537 ± 0.003 and 0.553 ± 0.006 and the sigma values 0.203 ± 0.003, 0.237 ± 0.003, and 0.229 ± 0.007 for ^{208}Pb (160 A GeV), ^{197}Au (10.6 A GeV) and ^{84}Kr (1 A GeV), respectively. From Fig. 3, we can see that for first halves (rising parts) the distributions are almost same, which shows that the distributions are independent of the incident energy, while for second halves (falling parts) deviate from one another [16–18].

IV. CONCLUSIONS

This study showed that multifragmentation is an important parameter in heavy-ion collision, because it explains both the information equation of state of matter and the phase transition. The study of correlations between singly and doubly charged fragments with total bound charge (Z_{b3}), as shown in Fig. 1 and Fig. 2, reveals the existance of a threshold character for nuclear multifragmentation. The study of the correlation between Z_{IMF} (intermediate mass fragment charge) and Z_{b3} suggests that the distributions of Z_{b3} are independent of the incident energy, as shown in Fig. 3.

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