Arab J. Nucl. Sci. Appl., Vol. 57, 3, 1-10 (2024)

ISSN 1110-0451

Arab Journal of Nuclear Sciences and Applications

Web site: ajnsa.journals.ekb.eg

(E S N S A)

Some Characteristics of Relativistic Secondary Charged Particles Produced in ^{7}Li Interaction with Nuclear Emulsion

M. Mohery[1,2]*, A. Mindil[1], M. H. Farghaly[2] and A. E. Elmeshneb[2,3]

[1]*Department of Physical Sciences, College of Science, University of Jeddah, Jeddah, Saudi Arabia*

[2]*Physics Department, Faculty of Science, Sohag University, Sohag, Egypt*

[3]*Physics Department, Faculty of Science, Yanbu Branch, Taibah University, Saudi Arabia*

ARTICLE INFO

Article history:

Received: 29th Feb. 2024

Accepted: 31st Mar. 2024

Available online: 2nd June 2024

Keywords:

Nucleus-nucleus collisions,

High energy heavy ions interactions,

Nuclear emulsion,

Multiplicity characteristics,

Compound Multiplicity.

ABSTRACT

In the present work, the general characteristics of the interactions of ^{7}Li nuclei with nuclear emulsion at 3A GeV/c have been studied. The multiplicity of the charged secondary particles and the correlations among them are discussed. The average multiplicity, compound multiplicity, variation of the dispersion, and the variation of the average compound multiplicity with the different projectile and target mass numbers have been investigated. The outcomes demonstrate certain regularities in the interactions between ^{7}Li nuclei and emulsion nuclei, which were previously seen in tests involving lighter nuclei. The values of the average multiplicity of the secondary charged particles have been estimated, and the dependence of this average multiplicity on the mass number of the projectile has been analyzed. The impact parameter determines the average multiplicities of the secondary charged particles, which rise as the impact parameter decreases. The variation in average multiplicities of shower particles as a function of heavy ionizing particles has been discussed. The compound multiplicity has been shown to be a good kinematical parameter for studying the interaction between nuclei. The compound multiplicity's average value mostly rises as the projectile mass number does and with the target mass. The study of multiplicity correlations has shown that shower and grey particles are strongly correlated. The ^{7}Li interaction's experimental data have been methodically compared to other interactions at various energies; the new results are consistent with the corresponding results at almost the same energy. The results obtained in the current studies have been compared with those from hadron-nucleus collisions.

1. INTRODUCTION

The study of heavy ion accelerators opened a new era in nuclear accelerator studies at high energies [1, 2]. There have been many research centers that study N-N interactions, such as: The Joint Institute for Nuclear Research (JINR), Dubna, Russia. JINR operates seven laboratories one of which conducts nucleus interactions with emulsion at Dubna energy 3–4.5A GeV/c per nucleon [3].

The collisions at high energy are an important research field in modern physics. The incident projectile nucleus collides with the fixed target nucleus in the high energy heavy-ion accelerator experiment. Subsequently, the collisions produce a large number of final-state relativistic particles and nuclear fragments. It is undoubting that the collider experiment benefits studying relativistic particle production, which is expected to relate to the creation of quark-gluon plasma (QGP).

The study of relativistic Nucleus-Nucleus (N-N) collisions has engendered significant interests during the recent years [4-7]. The main goal about investigating the N-N collision at high energies is to search for new phenomena may not be obtained from a nucleon-nucleon or nucleon-nucleus interactions, such as the complex states of nuclear matter that scientists believe occurred during the early universe. These states require high pressure with high temperature, and a great massive pion density that cannot be reached in a single hadron-hadron collision [6]. One way to reproduce these states in the

Corresponding author: mmohery@uj.edu.sa

DOI: 10.21608/AJNSA.2024.273671.1807

laboratory is the collision of the heavy ion beam, perhaps as little of GeV / nucleon.

Also, the study of high-energy heavy ion reactions relates to the desire to produce and examine nuclear matter at high excitation energy and density. So, information about the nature of the heavy ion interaction mechanism may be provided by this work, which could be significant. Furthermore, it may be useful to study the multiplicity properties and disclose the mechanism of high-energy nucleus-nucleus interactions.

Many investigators [7–13] have endeavored to examine nuclear reactions, which arise from collisions between nuclei at varying energies. For example, over the past few years, numerous experimental results of these interactions between relativistic nuclei and the properties of the interactions of nuclei with emulsion at 3-4.5A GeV/c have been studied [4-14]. The characteristics of ^{6}Li and ^{7}Li interactions with emulsion [15], and the properties of compound multiplicity in the interactions between the nuclei of ^{22}Ne and ^{28}Si with emulsion at Dubna energy have been studied [4].

Understanding and appreciating the mechanism of nucleus-nucleus collisions at the energies under consideration may require a study into the correlation between the various types of secondary charged particles. As a result, many authors have examined various aspects of correlation and multiplicity [9,16,17]. Also, the results on the correlations between different particle multiplicities of the ^{22}Ne and ^{28}Si interactions with emulsion nuclei at (4.1–4.5)A GeV/c have been analyzed [9].

Despite earlier research on nucleus-nucleus interactions, additional experimental investigations are required to clarify these novel occurrences. The purpose of this work is to characterize charged particle characteristics and to investigate both regular and peculiar occurrences, as well as an in-depth investigation of these phenomena in high-energy nucleus-nucleus collisions. Therefore, this work is to detect new aspects of the interactions between the ^{7}Li nucleus and nuclear emulsions.

In this paper, we get various multiplicity distributions, as described in this study for ^{7}Li-Em collisions at 3A GeV/C, the multiplicity distributions of secondary charged particles, shower, grey, black, highly ionization fragments, and compound multiplicity are examined. In the meantime, experimental results on the correlations between various multiplicities are reported. The obtained results from the current studies have been compared with corresponding ones from collisions between hadrons and nucleus.

2. EXPERIMENTAL DETAILS

Nuclear research emulsions were first in the1940s developed to meet the needs of physicists engaged in research on cosmic radiation. Nuclear emulsion is a versatile instrument to detect the charged particle it is not only capable of counting charged particle but also provides information regarding the mass energies of particles and their modes of a collisions it also allows studies of angular distribution of all produced in nuclear interactions with higher accuracy the nuclear emulsion has high density and high stopping power. Nuclear emulsions are kept in specific conditions, so photographic events can be preserved for many years.

The investigated emulsion stack was exposed to a $3\ A\ GeV/c\ \ ^{7}Li$ beam at Dubna Synchrophasotron (Joint Institute of Nuclear Research), Russia. The stack consists of layers of type NIKFI BR-2 with dimensions of $10\ cm \times 20\ cm\ \times 600\ \mu m$. The intensity of the beam irradiation was $10^{4}\ particles/cm^{2}$, and its diameter was $1\ cm$ [18].

The along-the-track method was used in scanning of the emulsion stack. The secondary charged particles were classified as follows:

(i) Shower tracks: “$s-particles$” denoted by n_s, which is the number of shower particles, with $I^* \leq 1.4$ (where I^* is the specific ionization, I/I_0; I is the secondary particle ionization track, and I_0 is the relativistic shower track ionization in a narrow forward cone with angle $\theta \leq\ 3°$ and a velocity $\beta \geq\ 0.7$).

(ii) Grey tracks: "g-particles" denoted by n_g, which is the number of gray particles, with $1.4\ < I^*\ < 10$, range $L \geq 3\ mm$, and velocity $0.3\ < \beta\ <\ 0.7$.

(iii) Black tracks: "b-particles" denoted by n_b, which is the number of black particles. They have a specific ionization $I^*\ >\ 10$ with range $L <\ 3\ mm$, and velocity $\beta \leq\ 0.3$.

The number of shower and gray secondary charged particle tracks were taken together and termed to as new component of compound multiplicity $\mathrm{n_c}$, where $\mathrm{n_c = n_s + n_g}$. Also, the number of gray and black secondary charged particle tracks are called heavy ionizing tracks, and their multiplicities are denoted by $\mathrm{n_h}$, where $\mathrm{n_h = n_g + n_b}$ [4].

In nuclear emulsion experiments, it is difficult to determine the targets as the medium contains a variety of nuclei, such as H, C, N, O, Ag, and Br nuclei, in addition to having a complex composition. Moreover, events with $\mathrm{n_h} \leq 1$ are mostly the result of interactions with free hydrogen H ($\mathrm{A_T} = 1$), and events with $1 < \mathrm{n_h} \leq 7$ are mostly the result of interactions with CNO, which is called a light group of nuclei ($\mathrm{A_T} = 14$). In addition, events with $\mathrm{n_h} \geq 8$ are considered to be in the category of interactions with AgBr and are called a heavy group of nuclei ($< \mathrm{A_T} > = 94$) [14].

Shower, grey, and black particle tracks are represented by n_s, n_g, and n_b, respectively, which indicate the number of charged particles produced in an interaction. Our previous paper contains further information about the measurement and scanning process for the charged particles that are emitted, angles, etc. [14].

3. GENERAL CHARACTERISTICS

3.1 The interaction of mean free path

By dividing the total scanned length by the total number of inelastic interactions within this length, one can determine the inelastic mean free path (m. f. p) λ. λ has an inverse relationship with the interaction cross section.

Along a scanned length of 152.65 meter in emulsion plates, a number of 1000 ^{7}Li- emulsion events has been found, giving rise to an experimental mean free path λ_{exp}=15.27±0.36 cm. The experimental value can be compared to the calculated mean free path (λ_{cal}=15.6 cm), this was calculated using the composition of the emulsion and applying the equation:

$$\lambda_{cal} = \left(\sum_i n_i \sigma_{\mathrm{P.T}}\right)^{-1} \qquad \textbf{(1)}$$

where n_i is the number of $i\underline{th}$ atom per unit volume in the emulsion and the interaction between two nuclei has a cross section $\sigma_{\mathrm{P.T}}$ is given by [19]:

$$\sigma_{P.T} = \pi r_0^2 \left(A_P^{1/3} + A_T^{1/3} - b\right)^2 \qquad \textbf{(2)}$$

With $r_o = 1.23\ fm$ and $b = 1.56 - 0.2(A_{\mathrm{P}}^{-1/3} + A_T^{-1/3})$, where A_p and $\mathrm{A_T}$ are the projectile and target mass numbers [19].

The mean free path of the experimental values λ_{exp} compared to the corresponding theoretical values calculated according to equations (1) and (2). The calculated values λ_{cal} was get on provide a satisfactory match with the experimental values, λ_{exp}.

3.2 The Characteristics of the Average Multiplicities

The study of the multiplicities of secondary particles (shower, grey, black, and heavy particles) produced from interactions of heavy ions reveals details on the mechanisms involved in the production of these particles. The nuclear interaction at high energy is a collision between the target's nucleons and the incident particle, or projectile. These collisions produce relativistic particles (such as pions) by the transfer of energy. The interacting nuclear matter is left in a very high local heated excited state.

The mean numbers of secondary charged particles released as a result of the interactions of different projectiles with the emulsion nuclei at (3-4.5)A GeV/c, $\langle n_s \rangle$, $\langle n_g \rangle$, $\langle n_b \rangle$ and $\langle n_h \rangle$ are listed in Table (1). From this table, one can see that the $\langle n_s \rangle$ increases with the projectile mass number at the same energy, except ^{7}Li interactions may be due to it's less energy than those of the others. There is a tendency for the $\langle n_g \rangle$ to increase as the projectile mass number does. The result is consistent with that previously reported [20], in which it is shown that the average multiplicity for the hadron-nucleon interaction is about equal to the ratio between $\langle n_s \rangle$ and the number of projectile nucleons directly taking part in the interaction. Moreover, it has been shown that $\langle n_g \rangle$ is a measure of the number of nucleons in projectile interactions and the equivalent number of intranuclear collisions [21]. At the specified energy range, the value of $\langle n_b \rangle$ is nearly independent of the projectile mass number, indicating that the excitation of the target nucleus and the ensuing evaporation of the particle and fragments appear to be independent of the initial phase of the collision.

Table (1): The average multiplicity values of secondary charged particles for various projectile interactions with emulsion nuclei at (3–4.5)A GeV/c

Projectile	$\langle n_s \rangle$	$\langle n_g \rangle$	$\langle n_b \rangle$	$\langle n_h \rangle$	Ref.
^{1}H	1.60±0.20	2.80±0.2	3.78±0.30	6.63±0.13	8, 22
^{2}H	2.77±0.07	3.90±0.10	4.60±0.20	8.50±0.30	8, 22
^{3}He	3.50±0.10	3.00±0.10	5.30±0.20	8.20±0.30	23
^{4}He	3.70±0.10	4.40±0.20	4.40±0.20	8.80±0.20	22
^{6}Li	5.09±0.29	4.23±0.21	4.91±0.30	9.14±0.37	24
^{7}Li	3.91±0.08	3.15±0.09	5.89±0.14	9.04±0.20	Present work
^{12}C	7.70±0.20	5.90±0.20	4.50±0.20	---------	22
^{16}O	9.40±0.30	6.40±0.20	4.40±0.10	---------	25
^{22}Ne	9.90±0.39	5.52±0.26	4.01±0.15	9.53±0.38	4
^{24}Mg	10.79±0.22	7.88±0.21	5.32±0.13	13.21±0.20	26
^{28}Si	11.93±0.43	6.23±0.26	5.27±0.2	11.50±0.44	4

To investigate the particle production, the dependence of the average shower particles $\langle n_s \rangle$ on the mass number of the projectile nucleus A_p has been studied. So, we have plotted the dependence of the average shower multiplicity $\langle n_s \rangle$ on the mass of the projectile A_p, which is shown in figure (1). From the figure, one can see that a linear dependence of $\langle n_s \rangle$ at high energy on the mass number of the projectiles A_p.

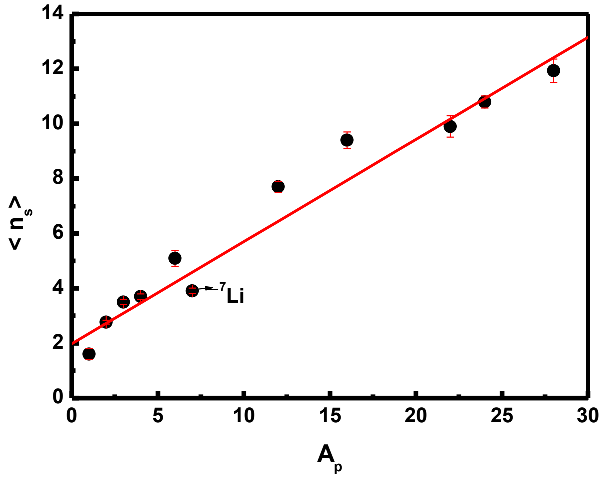

Fig. (1): Dependence of $\langle n_s \rangle$ in nucleus-nucleus collisions at high energy on the mass number of the projectiles A_p.

The variation of average shower particle multiplicities $\langle n_s \rangle$ in relation to heavy ionizing particles n_h for the interactions of ^{6}Li and ^{7}Li projectiles with emulsion nuclei at 4.5A GeV/c and 3A GeV/c respectively, is shown in figure (2). From this figure one can see that, with increasing of n_h the $\langle n_s \rangle$ increases, within the experimental error, up to n_h=17 at which all the nucleons from the incident beam interacted with target nuclei. In order to find out why the average multiplicity of shower particles, $\langle n_s \rangle$ in the plateau region is less for ^{7}Li than for ^{6}Li, the decrease in $\langle n_s \rangle$ associated with ^{7}Li which approximately equals 3.7 is due to a decrease in the number of ^{7}Li participant nucleons (often two neutrons)[27]. It is possible to produce neutrons and emit gamma rays [28], and ^{7}Li can fragment so that one of its components interacts with the target intensely while the other component disappears.

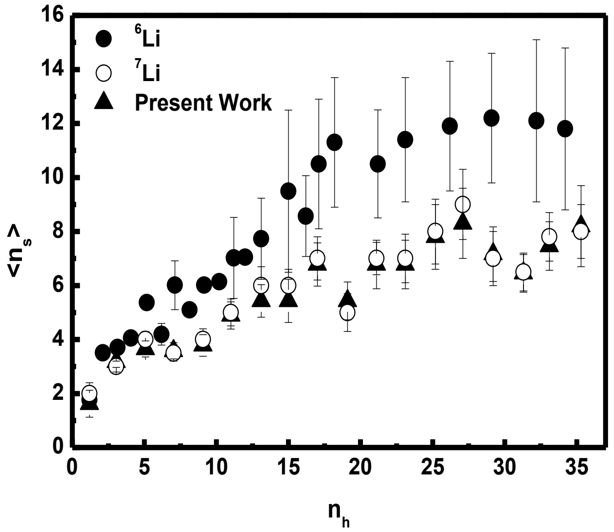

Fig. (2): Average multiplicity $\langle n_s \rangle$ as a function of n_h for the interactions of projectiles(●) ^{6}Li at 4.5A GeV/c, (○) ^{7}Li at 3.8A GeV/c and (▲) ^{7}Li(present work) at 3A GeV/c with emulsion nuclei.

4. COMPOUND MULTIPLICITY

The majority of high-energy nucleus-nucleus collision tests conducted in the last several years have been carried out to study the characteristics of the shower and grey particles produced in such collisions [29-31]. Because the grey particles are emitted at or soon after the passage of a leading particle (a hadron), it is importance to investigate them. They are therefore expected to keep some recollection of the reaction's history. Therefore, it would be beneficial to take into account the compound multiplicity of shower and grey particles, n_c in researching the process that gives rise to their production. Furthermore, the number of encounters made by impinging hadrons within the impacted nucleus, can be well measured by gray particles [31].

In this section, an effort is made to investigate some intriguing compound multiplicity characteristics in ^{7}Li-Em collisions at 3AGeV/c, where the compound multiplicity term is the sum of grey and shower particles taken together, ($n_c=n_g+n_s$). The primary reason for researching compound multiplicity in heavy-ion reactions is that the data and information from nucleus-nucleus collisions may help or might be used to improve the models for multiparticle production in hadron-nucleus and nucleus-nucleus collisions [6,9]. The behavior of the distribution of compound multiplicity that was obtained in the present work for ^{7}Li-Em interactions at 3A GeV/c in comparison with that for ^{16}O [25,31] and ^{12}C [22,32] at 4.5A GeV/c, is shown in figure (3). From this figure, it is evident that when projectile mass numbers increase, the distribution's peak moves in the direction of higher values of n_c. It is also evident that when projectile mass number increases, the compound multiplicity distribution widens. A comparable outcome has been noted in references [4,9]. Moreover, if the projectile nuclei are heavier than those of ^{7}Li, the average multiplicity of relativistic particles increases. These features of specific multiplicities $<n_s>$ values are in agreement with the model, which views the collision between a nucleus-nucleus as the disorderly accumulation of nucleon-nucleus collisions.

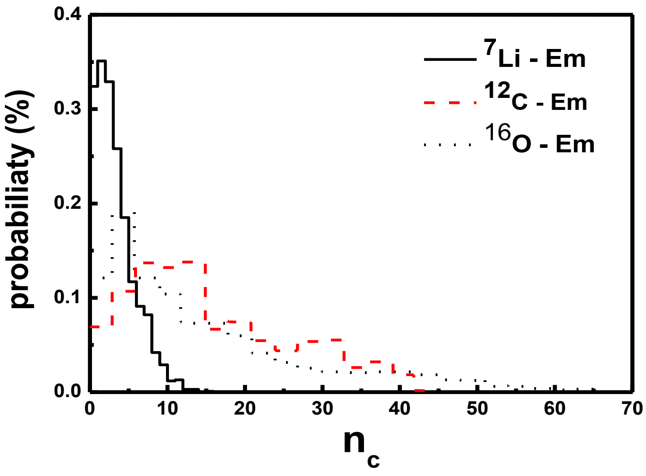

Fig. (3): Compound multiplicity distributions in nucleus-nucleus collisions at (3-4.5)A GeV/c.

4.1 Dispersion variation with average compound multiplicity

The relationship between the dispersion and the shower particle average value in high energy nucleus-nucleus collisions has been investigated. Additionally, a number of authors have investigated the relationship between the dispersion and the average multiplicity of the total number of shower and grey particles, taken together per interaction [4,8,25,33-35].

The average values of the compound multiplicity $\langle n_c\rangle$, the dispersion $D(n_i)=[(\langle n^2_i\rangle - \langle n_i\rangle^2)]^{1/2}$, were n_i equal n_s or n_c and the ratio $\langle n_c\rangle/D(n_c)$, for the experimental data of ^{7}Li-Em interactions at 3A GeV/c with the corresponding values for different projectile induced emulsion interactions at (4.1-4.5)A GeV/c are presented in Table (2). This table shows that as the projectile mass number increase, the average value of the compound multiplicity, $\langle n_c\rangle$, primarily increases as well. The ratio $\langle n_c\rangle/D(n_c)$ does not depend on the mass number of the projectile. Also, the table shows that the value of $\langle n_s\rangle$, and the dispersion $D(n_s)$ in comparison with projectiles. A consistent trend is seen using different projectiles, at nearly the momenta.

Table (2): Values of different parameters in nucleus–nucleus collisions at (3-4.5)A GeV/c .

Projectile	$\langle n_c\rangle$	$D(n_c)$	$\langle n_c\rangle/D(n_c)$	$\langle n_s\rangle$	$D(n_s)$	Ref.
^{1}H	4.44±0.66	———	———	———	———	8
^{2}H	5.42±0.09	———	———	———	———	34
^{7}Li	7.06±0.14	4.27±0.14	1.65±.06	3.91±0.08	2.46±0.08	Present work
^{12}C	12.08±0.24	7.50±0.24	1.61±0.24	7.60±0.13	4.32±0.13	33
^{16}O	14.87±0.30	13.72±0.23	1.08±0.04	———	———	25
^{22}Ne	15.42±0.61	17.38±0.52	0.89±0.07	9.90±0.39	10.87±0.17	4
^{24}Mg	19.50±0.50	19.23±0.22	1.01±0.05	11.10±0.33	10.14±0.23	35
^{28}Si	18.16±0.66	17.89±0.86	1.02±0.07	11.93±0.43	11.44±0.19	4

Plots of dispersion $D(n_i)$ vs. average shower multiplicity $\langle n_s\rangle$ and average compound multiplicity $\langle n_c\rangle$ for various interactions of projectiles with nuclear emulsion are shown in Figures (4a,b) (by using the data are given in table 2). From these figures, it may be seen that $D(n_i)$ has an almost linear dependence on the $\langle n_s\rangle$ and $\langle n_c\rangle$ [$(D(n_i)=a+b(\langle n_i\rangle)$], were $D(n_s)$ and $D(n_c)$ increases linearly with $\langle n_s\rangle$ and $\langle n_c\rangle$, respectively. The expansion in the source's dimensions at particle production is indicated by these increases in $D(n_i)$. The following relations were obtained to satisfactorily match the experimental data points using the least squares method.

$$D(n_s) = (1.08\pm0.01)\,\langle n_s\rangle + (-1.78\pm0.05) \qquad \textbf{(3)}$$

$$D(n_c) = (1.17\pm0.01)\,\langle n_c\rangle + (-4.04\pm0.1) \qquad \textbf{(4)}$$

It is found that $D(n_i)$ has a linear dependence on the average number, independent of the multiplicity distribution's particular form. So, the fact that the grey particles are emitted either during or soon after the leading particle's passage indicates that $D(n_i)$ is linearly related to $\langle n_s\rangle$ and $\langle n_c\rangle$. For this reason, the grey particles are of particular relevance. When p-p collisions occur, D (n_s) increases more slowly with $\langle n_s\rangle$ than when p-nucleus collisions occur [33].

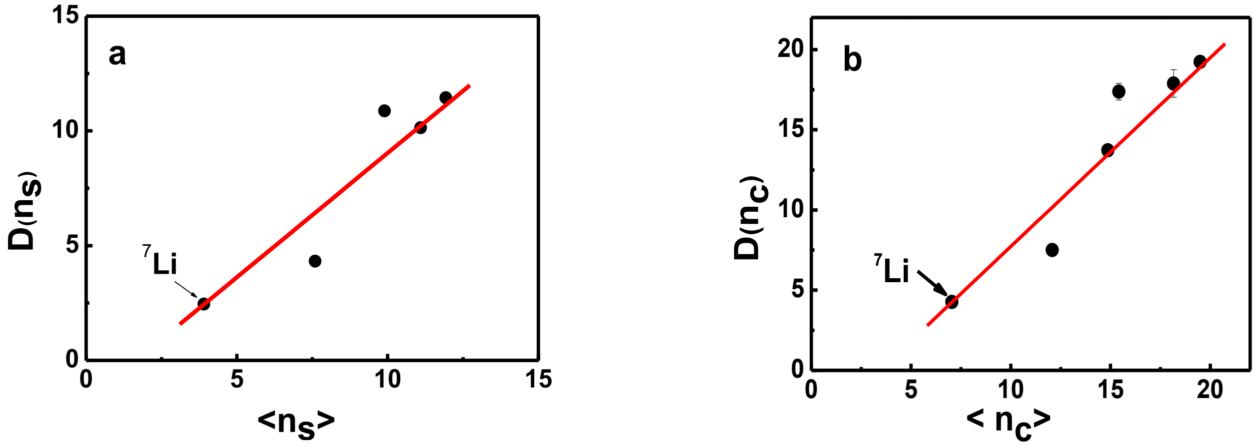

Fig. (4) a): Dependence of dispersion $D(n_s)$ on the average shower multiplicity $\langle n_s \rangle$;
b): Dependence of dispersion D (n_c) on the average compound multiplicity $\langle n_c \rangle$

4.2 Variation of the average compound multiplicity $\langle n_c \rangle$ with the different projectile and target mass numbers

Using the data of Table (2), the dependence of the average compound multiplicity $\langle n_c \rangle$ on the mass of the projectile A_p is shown in figure (5). The figure shows that when the projectile's mass increases, $\langle n_c \rangle$ increases rapidly. The following relation fits the experimental data:

$$\langle n_c \rangle = \alpha\, [A_p]^{\beta} \qquad \textbf{(5)}$$

The fitting parameters α and β are found to be (4.11±1.1) and (0.44±0.04) respectively, for ^{7}Li-Em at 3A GeV/c. This is in a reasonable agreement with the results obtained from different projectiles ($\alpha=4.20\pm0.76$, $\beta=0.49\pm0.30$) reported in [36] and with the results ($\alpha=4.35\pm0.27$, $\beta = 0.44\pm0.02$) reported in [4], For Zhang [25], the best fit is represented by ($\alpha=3.93\pm0.08$, $\beta=0.52\pm0.01$). Furthermore, the Abou-Mousse-reported values of these parameters as ($\alpha=3.88\pm0.65$, $\beta= 0.49\pm0.07$) [37], and ($\beta=0.47\pm0.02$) as reported by Singh *et al.*[38] are consistent with the values obtained in this work.

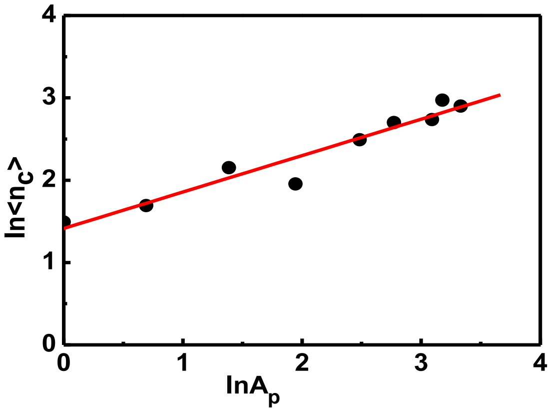

Fig. (5): Dependence of $\langle n_c \rangle$ in nucleus-nucleus collisions on the mass number of the projectile A_p.

In order to better understand the interactions between nuclei, it is easy to investigate particle production and the dependence of the average compound multiplicity (n_c) on the mass number of the target nucleus (A_T). The three primary categories of heavy ion reactions, H-nuclei, light CNO-nuclei, and heavy AgBr-nuclei are what make up the nuclear emulsion. It is appropriate to categorize the occurrence events that were observed to relate to their interactions with these various groups. So, we have divided the ^{7}Li-emulsion collision into ensembles of events, including interactions with free hydrogen (H), light target (CNO), and heavy target (AgBr) emulsion nuclei.

The approximate average mass numbers of these groups are (1, 14 and 94), respectively, and of emulsion is 70. The experimental events due to the interaction of ^{7}Li projectile with either hydrogen (H), the light group (CNO) and the heavy group (AgBr) have been separated. Florian et al. [39] and Fakhraddin et al. [40] they suggested a method to separate this groups. The criteria of previous articles [4,7,9, 14] has been followed in order to separate the events caused by interactions with emulsion nuclei. The following criterion is applied:

a) **AgBr** events, where $n_h \geq 8$, or $n_h < 8$ and at least with range, $L \leq 10$ µm

b) **CNO** events, where $2 \leq n_h < 8$ and no track with range, $L \leq 10$ µm, and $n_h = n_b = 1$, the secondary is moving backward and does not have a range of $L \leq 10$ µm.

c) **H** events, where $n_h \leq 1$; $n_h = n_g = 1$ (g particle moving forward and not falling into any of the previous classifications).

The average compound multiplicity for the charged secondary particles emitted from ^{7}Li interactions and also the results of the interactions of different projectiles with the three target groups at momentum (3–4.5)A GeV/c are listed in Table (3). This table illustrates how the average compound multiplicity, $\langle n_c \rangle$, increases quickly as the target mass number increases. On the other hand, as the target mass increases, the ratio $\langle n_c \rangle / D(n_c)$ gradually increases within statistical uncertainties. This observation is consistent with the findings of Khan et al. [36].

Table (3): The average values of $\langle n_c \rangle$, $D(n_c)$, and $\langle n_c \rangle / D(n_c)$ for the many interactions between nuclei and emulsion, as well as between the separate emulsion groups of nuclei (H,CNO, and AgBr).

Projectile	Target	$\langle n_c \rangle$	$D(n_c)$	$\langle n_c \rangle / D(n_c)$	Ref.
^{7}Li	H	1.84±0.19	2.42±0.29	0.76±0.12	Present Work
	CNO	4.94±0.11	5.25±0.25	0.94±0.05	
	AgBr	9.81±0.19	9.35±0.43	1.05±0.05	
	Em	7.06±0.14	4.27±0.14	1.65±0.06	
^{12}C	H	3.29±0.26	2.01±0.21	1.64±0.21	36
	CNO	9.27±0.23	3.88±0.21	2.39±0.14	
	AgBr	23.19±0.29	9.09±0.40	2.55±0.14	
	Em	16.17±0.18	10.51±0.34	1.54±0.05	
^{22}Ne	H	2.32±0.17	2.45±0.16	0.95±0.23	4
	CNO	8.55±0.44	6.56±0.14	1.30±.011	
	AgBr	32.00±1.35	18.06±0.60	1.77±0.06	
	Em	15.42±0.61	17.38±0.52	0.89±0.07	
^{28}Si	H	2.94±0.21	2.60±0.15	1.13±0.05	4
	CNO	10.31±0.52	7.27±0.18	1.42±0.13	
	AgBr	31.01±1.22	18.65±0.91	1.66±0.06	
	Em	18.16±0.66	17.89±0.80	1.02±0.07	

The dependency of $\langle n_c \rangle$ on the target mass number A_T, for a case of nucleus-nucleus collision, is shown in Figure (6). The following relation can be used to characterize such dependence:

$$\langle n_c \rangle = \alpha [A_T]^{\beta} \qquad \textbf{(6)}$$

It is also observed that when the target mass increases, so does the value of $\langle n_c \rangle$. Figure (6) displays the experimental data, which may be rather satisfactorily matched with a relation of the following form:

$$<n_c> = (1.87 \pm 0.12)\, A_T^{\,(0.34 \pm 0.03)} \qquad \textbf{(7)}$$

while this relation for the ^{12}C and ^{22}Ne(^{28}Si) interactions with nuclear emulsion, respectively as follow:

$$\langle n_c \rangle = (2.14 \pm 0.37)\, A_T^{(0.56 \pm 0.05)} \qquad \textbf{(8)}$$

$$\langle n_c \rangle = (2.80 \pm 0.39)\, A_T^{(0.52 \pm 0.04)} \qquad \textbf{(9)}$$

Comparing the fitting parameter from ^{12}C, ^{22}Ne and ^{28}Si [4,36], it is found that the present result is nearly consistent within errors with the corresponding ones.

Also, comparing the relation between the $\langle n_c \rangle$ and A_T, it is evident from the comparison of this value with the previous one between $\langle n_c \rangle$ and A_p that the projectile mass number has a greater impact on $\langle n_c \rangle$ than the target mass number.

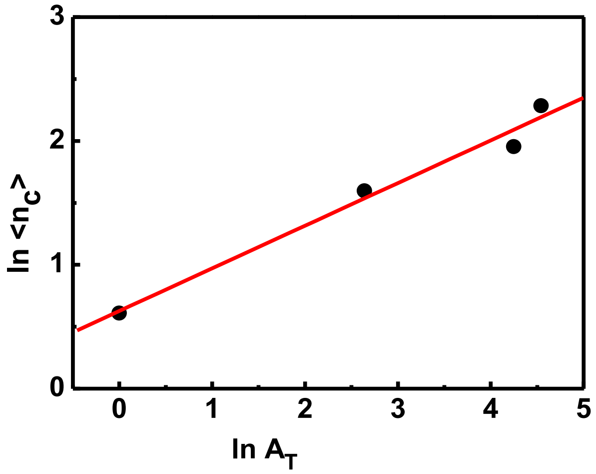

Fig. (6): Dependence of $\langle n_c \rangle$ in ^{7}Li-Em collisions on the mass of target A_T.

CONCLUSION

We have studied the interaction of ^{7}Li nuclei with emulsion nuclei at 3A GeV/c. The average multiplicity, multiplicity distributions, and compound multiplicity characteristics have been investigated. One can conclude the following key points:

1. The calculated values of mean free path λ_{cal} were found to be in good agreement with the experimental values, λ_{exp} .
2. The variation in average multiplicities of shower particles $\langle n_s \rangle$ increases with the projectile mass number at the same energy, except ^{7}Li interactions may be due to it's less energy than those of the others.

3. In which it is shown that the average multiplicity for the hadron-nucleon interaction is about equal to the ratio between ⟨n_s⟩ and the number of projectile nucleons directly participating in the interaction.
4. The value of ⟨ng⟩ shows a tendency to increase with the projectile mass number, which has been a measure of the number of nucleons in projectile interactions and the corresponding number of intranuclear collisions. This result is consistent with that previously obtained.
5. At the specified energy range, the value of ⟨n_b⟩ is nearly independent of the projectile mass number, indicating that the excitation of the target nucleus and the ensuing evaporation of the particle and fragments appear to be independent of the initial phase of the collision.
6. The compound multiplicity has been shown to be a good kinematical parameter for studying the interaction between nuclei.
7. In compound multiplicity, it is evident that when projectile mass numbers increase, the distribution's peak moves in the direction of higher values of n_c. It is also evident that when projectile mass number increases, the compound multiplicity distribution widens.
8. The average value of compound multiplicity mostly increases as the projectile mass number does, and increases rapidly with the increasing target mass number.
9. The impact parameter, or grouping of emulsion nuclei, determines the average value of compound multiplicity. These values increase with an increase in heavily ionizing tracks n_h or with decreasing impact parameter.
10. The dispersion of D(n_s) and D(n_c) increases linearly with ⟨n_s⟩ and ⟨n_c⟩, respectively, and as the target mass increases, the ratio ⟨n_c⟩/D(n_c) gradually increases within statistical errors.
11. The degree of target nuclei disintegration depends on how many secondary charged particles are produced in heavy-ion interactions; this reliance is not seen in hadron interactions with emulsion.
12. The ^{7}Li interaction's experimental data have been methodically compared to other interactions at various energies; the results are consistent with the corresponding results at almost the same energy.

ACKNOWLEDGEMENTS

This work was funded by the Deanship of Scientific Research (DSR), University of Jeddah, Jeddah, under grant No.(UJ-20-DR-106) The authors, therefore, acknowledge with thanks DSR technical and financial support.

REFERENCES

[1] Dong-Fang Wang, S. Z.-G. (2021). System size dependence of baryon-strangeness correlations in relativistic heavy ion collisions from a multiphase transport model. *Phys. Rev. C* 103, 024901, pp. 1-8.

[2] Praveen P. S.; Khan M. S. (2019). The study of multiparticle production in high energy nucleus-nucleus interactions. *Proceedings of DAE Symp. Nucl. Phys.* 64 (2019) 1059-1060

[3] Joint Institute for Nuclear Research | Science bringing nations together (JINR.ru)

[4] M. Mohery, and M. Arafa (2011) Some characteristics of the compound multiplicity in high energy nucleus-nucleus interactions", *Int. J. Mod. Phys. E* 20, 8 (2011)1735.

[5] W. Osman and M. Fayed, (2019), Comparative study for target fragmentation in ^{4}He and ^{6}Li interactions with emulsion nuclei at Elab = 3.7A GeV, *Canadian Journal of Physics*, 97, No 6, 2019.

[6] A. Andronic, P. B.-M. (2021). Hadron yields in central nucleus-nucleus collisions, the statistical hadronization model and the QCD phase diagram.; *Acta Physica Polonica B Proceedings Supplement*; 14, 2 (2021) 341-351.

[7] M. Mohery, (2014) Characteristics of the total disintegration events of emulsion heavy target nuclei caused by ^{16}O and ^{28}Si nuclei at high energies; *Can. J. Phys., 92, 1 (2014) 92*

[8] AABDDKKLMTU-B Collaboration, V. I. Bubnov, et al., *Z. Phys. A, 302, 2* (1981)133; *Sov. J. Nucl. Phys.* 33, 4(1981) 561.; BWDKLMT Collaboration, *Sov. J. Nucl. Phys.,* 29 (1979) 52, [*Yad. Fiz.* 29 (1979) 105.

[9] M. Mohery, E. M. Sultan, Shadiah S. Baz, (2015) Study of multiplicity correlations in nucleus-nucleus interactions at high energy; *Int. J. Mod. Phys.* E24, 6 (2015)1550048.

[10] El-Naghy, A ; Mohery, M ; Gad, KH; (2002) The percolation mechanism for fragmentation of nuclei using Monte Carlo technique ; *Acta Physica Hungarica New Series-Heavy Ion Physics;* Vol.15;1-2; Pp155-171

[11] Sahoo, P. et al. (2019) Limiting fragmentation in high-energy nuclear collisions at the CERN Large Hadron Collider. Phys. Rev. C 99,4, 044906, pp. 1-7.

[12] Grzegorz Wilk and Zbigniew Włodarczyk, (2018), Some intriguing aspects of multiparticle production processes. *International Journal of Modern Physics, A*, Vol. 33, No. 10, 1830008.

[13] L. Chkhaidze, G. Chlachidze, T. Djobava, A. Galoyan, L. Kharkhelauri, R. Togoo & V. Uzhinsky (2019), Study of azimuthal correlations in the target fragmentation region in p, d, He, C + C, Ta and C+Ne, Cu collisions at a momentum of 4.2, 4.5 and 10 AGeV/c, *The European Physical Journal A;* Vol. 55, 7.

[14] M.Mohery et al.; (2020) "The multiplicity characteristics of ^{7}Li-Em interactions as a function of noninteracting projectile nucleons" *International Journal of Modern Physics E*; Vol.29 Issue 8. 2050063.

[15] L. K. Marie and Y. M. Assran, (2017) "Characteristics of ^{6}Li and ^{7}Li Interactions with Emulsion at Dubna Energy"; *Arab Journal of Nuclear Sciences and Applications*; Vol.50, Issue 1, Page113-119.

[16] N. N. Abd-Allah, and M. Mohery, Elbadry M Zahran, Fu-Hu Liu (2004); Characteristics of black particles and forward-backward correlations in high energy nucleus-nucleus collisions, *Chinese Journal of Physics*, 42, 6, 684-693.

[17] Fu. Wang, (2014), Novel phenomena in particle correlations in relativistic heavy-ion collisions, *Progress in Particle and Nuclear Physics*, 74, Pp35-54.

[18] Barashenkov, V. S. and Toneev, V. D. (1972), Interactions of high energy particles and atomic nuclei with nuclei, *Atomizadt, Moscow*, 12 (1972); *Nuclear Physics A*, Vol 222, 1, (1974), Pp 204-220; https://doi.org/10.1016/0375-9474(74)90594-6.

[19] B. Jakobsson, and R .Kullberg (1976) "Interactions of 2 GeV / Nucleon ^{16}O with Light and Heavy Emulsion Nuclei " *Phys Scr.*, 13,327.

[20] A. El-Naghy, (1982) "Central heavy-ion collisions with emulsion at 4.2 GeV/c per incident nucleon" *Il Nuovo Cimento A* 71, 2 (1982) 245.

[21] M. K. Hegab and J. Hüfner, (1981) "How often does a high-energy hadron collide inside a nucleus" *Phys. Lett. B* 105, 103.& M. K. Hegab and J. Hüfner ; (1982) "The distribution of grey particles in very high-energy hadron-nucleus collisions", Nucl. Phys. A 384, 3, 353.

[22] A. El-Naghy, et al., (2002) "Comparative study for nucleus-nucleus interactions and modified cascade evaporation model at (4.1–4.5)A GeV/c" *Acta Phys. Hun. A*15 (2002) 131.

[23] M. M. Sherif and M. Mohery, (1991),"Multiparticle Production in ^{3}He-Emulsion Interaction at 4.5 A GeV/c" *Egypt. J. Phys*. 22 (1991) 125.

[24] M. El-Nadi, et al., (2004) "Some characteristic of ^{6}Li and ^{7}Li isotopes interactions with emulsion nuclei at 3.7- 4.5 A GeV/c", *Int. J. Mod. Phys. E*, 13, 3 (2004) 619.

[25] D. H. Zhang, et al., (2006) "Features of Compound Multiplicity in ^{16}O-Em Interactions at 4.5A GeV/c", *Chin. J. Phys*. 44, 6 (2006) 405.

[26] M. A. Jilany, N. N. Abd-Allah, A. Abd-El Daiem, (1995) "Interactions of relativistic ^{24}MgNuclei with emulsion at 4.5 A GeV/c per nucleon" *Int. J. Mod. Phys. E,* 4, 4, 815.

[27] M. El-Nadi, *et al.* (1998) "Backward slow protons production in the inelastic interactions of ^{6}Li and ^{7}Li nuclei with emulsion nuclei at Dubna energy" *The European Physical Journal A*, Vol. 3, pp 183–195.

[28] W. E. Meyerhof, (1989) "Elements of Nuclear Physics" M.C. Graw-Hill, New York.

[29] U. Singh; M. K. Singh and V. Singh; (2020) "Emission Characteristics of Charged Particle Production in Interactions of ^{84}Kr with the Nuclear Emulsion Detector at Relativistic Energy", *Journal of the Korean Physical Society*, Vol. 76, No. 4, pp. 297-300.

[30] N. G. Peresadko, et al.; (2018) "Measurement of the Mean Free Path of Relativistic 12C Nuclei Undergoing Coherent Fragmentation to Three Alpha Particles in a Nuclear Emulsion Filled with Lead Nuclei"; *Physics of Atomic Nuclei*, Vol. 81, No. 6, pp. 673–675.

[31] N. Abdallah, (2023) "Studies of angular distribution of the grey particles in ^{16}O-emulsion collision at 3.7A GeV" International Journal of Modern Physics E; Vol.32, Issue 2.

[32] Tufail Ahmad, (2021) "A study of ^{12}C and ^{28}Si interactions with heavy emulsion targets", *Chinese Journal of Physics*; Vol. 72, Pp 299-309.

[33] D. Ghosh, J. Roy and R. Sengupta, (1987) "Study of multi-particle production in the interaction of ^{12}C with photo emulsion nuclei at 4.5A GeV/c per nucleon" *Nucl. Phys. A* 468, 3-4, 719.

[34] E. S. Basova, et al., (1978) "A study of inelastic interactions of deuterons and alphas in an emulsion at~3.6 GeV/nucleon", *Z. Phys. A* 287, 393.

[35] N. N. Abd -Allah, S. A. H. Abou-Steit, M .Mohery and S. S. Abdel-Aziz, (2001) Characteristics of relativistic charged particles produced in ^{24}Mg-emulsion interactions at 4.5A GeV/C; *Int. J. Mod. Phys. E 10, 1* (2001) 55.

[36] M. S. Khan, et al., (1997) "Some interesting results on compound multiplicity in ^{12}C-nucleus reactions at 4.5 A GeV/c" *Can. J. Phys.* 75, 8 , 549.

[37] Z. Abou-Moussa,(2002) "Compound multiplicity in the collision of 4.1A GeV/c 22Ne nuclei with nuclear emulsion", *Can. J. Phys.* 80, 2, 109.

[38] B. K. Singh, et al.,(1992) Proc. DAE Symposium on nuclear physics, Bhabha, A.R. C. Bombay, India, 35B, 400.

[39] J. R. Florian, et al., (1976) "Interactions of 300-GeV protons with tungsten and chromium", *Phys. Rev. D* 13, 3, 558.

[40] S. Fakhraddin and M. A. Rahim, (2008) Multiplicity distributions of projectile fragments in interactions of nuclei with emulsion at 4.1–4.5 A GeV/c; *Phys. Scr.,* 78, 1 (2008) 015101; M. A. Rahim and S. Fakhraddin, Nucl. Phys. A831 (2009)39.