Classical and Statistical Analysis of $^{40}\text{Ar}(300\text{ MeV}) + ^{197}\text{Au}$ Deep Inelastic Interaction

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A model with two collective variables, $r$-the distance between nuclei and $\theta$-the deflection angle in the center-of-mass system, was used. In the classical frame, the time evolution of the nuclear composite system confirmed the Wilczynski model. It was obtained that for the interacting system $^{40}\text{Ar}(300\text{ MeV}) + ^{197}\text{Au}$, deep inelastic collisions correspond to $\lambda$-values in the range $126 \leq \lambda \leq 210$. This implies interaction times in the range $5 \times 10^{-22}\text{s}$ to $3.4 \times 10^{-21}\text{s}$ and energy losses from 30 to 160 MeV. The obtained $\lambda_{cr}$ value, $\lambda_{cr} = 125$ and the fusion cross section are in agreement with experimental data. Calculating the double differential cross section $d^2\sigma/d\theta dE$ in the statistical formalism one obtains a qualitative agreement with experimental data. The introduction of statistical fluctuations in calculating the angular distribution $d\sigma/d\theta$ determines a good description of experimental data. The energy dissipation up to $130\text{ MeV}$ (deduced from Wilczynski plot) is in good agreement with experimental data.

1. Introduction

In the last ten years, the interesting field of deep inelastic reactions was developed. To describe the involved large transfer of energy and angular momentum, new concepts and theories were elaborated [1-4].

In the collision of the projectile with the target, a composite nuclear system is formed [5], which can be described by two types of degrees of freedom: internal degrees taking into account the intrinsic motion and collective ones, describing the macroscopic quantities. As the interaction times ($10^{-20}$ $-10^{-22}\text{s}$) are sufficiently large compared with the relaxation times of intrinsic degrees ($\sim 10^{-23}\text{s}$) only the collective variables do not reach the thermal equilibrium, so that the time evolution of the collective variables has to be described.

The De Broglie wave length of the system ($\sim 0.05\text{fm}$) being small compared to its dimension ($\sim 10\text{fm}$) it is possible to neglect quantum effects and to apply classical theory.

2. The Classical Analysis of $^{40}\text{Ar}(300\text{ MeV}) + ^{197}\text{Au}$ System

The measurements of the collisions in the $^{40}\text{Ar}(300\text{ MeV}) + ^{197}\text{Au}$ system at $\theta_{lab}=20^\circ$, $30^\circ$, $40^\circ$ and $57^\circ$ were performed at U-300 heavy ions accelerator from JINR Dubna [6]. The interaction products were identified by the aid of an $E-\Delta E$ detector, built in IPNE-Bucharest. This detector consisted of a $\Delta E$ pulse ionization chamber in which an $E$ silicon detector was placed. The $3\%$ energy resolution of the ionization chamber allowed the separation of all the elements in the range $2<Z<22$. The experimental data were processed by using an IBM-370 computer and the experimental double differential cross-sections $d^2\sigma/d\theta dE$ were obtained. Figure 1(a, b) show the obtained cross sections for $Z=17$ and $Z=19$ elements.

To analyse the experimental data, we consider that in Ar + Au interaction a composite nuclear system is formed and its time evolution is described by two collective variables, $r$-the distance between the two
nuclei and \( \theta \)-the deflection angle in the center-of-mass system.

Supposing that the two nuclei have a spherical shape, we have chosen the proximity potential \[7\] to describe the nuclear interaction.

\[
V_N(s) = \frac{(A_1^{1/3} \times A_2^{1/3})/(A_1^{1/3} + A_2^{1/3})}{U(s)}
\]

where \( U_N(s) \) has a simple parametrization form.

\[
U_N(s) = \begin{cases} 
V_0 \exp(-0.27 s^2) & s > 0 \\
V_0 + 6.3 s^2 & s \leq 0
\end{cases}
\]

and

\[
s = r - r_0(A_1^{1/3} + A_2^{1/3}).
\]

In Fig. 2, the effective interaction potential, given by the sum of Coulomb, nuclear and centrifugal terms, for parameter values: \( r_0 = 0.99 \text{ fm} \) and \( V_0 = -31 \text{ MeV} \), is represented.

According to Gross-Kalinowski model \[3,4\], the energy dissipation is due to friction forces, so that we have taken a friction tensor of the form:

\[
\gamma_{ij} = \begin{pmatrix} c_r & 0 \\ 0 & r^2 c_\theta \end{pmatrix} f(r)
\]

when \( c_r \) and \( c_\theta \) are the radial and tangential friction coefficients and \( f(r) \) is a form factor:

\[
f(r) = (\partial V_N/\partial r)^2.
\]

In the classical formalism \[8\], the equations of motion are deduced from Lagrange equation, where the dissipation is introduced by means of Raleigh dissipation function: \( I = 1/2 \gamma_{ij} q_i q_j \), \( q_i \) and \( q_j \) representing the generalized coordinates of interesting degrees of freedom.

Using friction coefficients values

\[
c_r = 2.5 \times 10^{-23} \text{ s/MeV}
\]

\[
c_\theta = 0.006 \times 10^{-23} \text{ s/MeV}
\]

and an inertial tensor:

\[
m_{ij} = \begin{pmatrix} \mu & 0 \\ 0 & \mu r^2 \end{pmatrix}
\]

we have calculated classical trajectories for \( ^{40}\text{Ar}(300 \text{ MeV}) + ^{197}\text{Au} \). The obtained trajectories are shown in Fig. 3.