UNIVERSIDADE DE SÃO PAULO

INSTITUTO DE FÍSICA
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PROBING THE INTERIOR REGION OF THE HEAVY ION INTERACTION THROUGH ALAS

by

M.S. Hussein
Instituto de Física, Universidade de São Paulo

and

L.F. Canto and R. Donangelo
Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, R.J., Brasil

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PROBING THE INTERIOR REGION OF THE HEAVY ION INTERACTION THROUGH ALAS[†]

M.S. Hussein

Instituto de Física, Universidade de São Paulo
São Paulo, S.P. , Brasil

and

L.F. Canto and R. Donangelo

Instituto de Física, Universidade Federal do
Rio de Janeiro, Rio de Janeiro , R.J. , Brasil.

ABSTRACT

It is proposed that a careful study of the 180^{o}-excitation function of elastically scattered light heavy-ion systems may reveal important information concerning the ion-ion interaction at small distances. This is accomplished by demonstrating the sensitivity of the anomalous energy-window to the distance of closest approach of the corresponding multi-step α-particle transfer process.

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In a recent publication[1)], we proposed a multistep α-particle transfer model for the description of the anomalous back-angle heavy-ion elastic scattering. Specifically we associate the rise in the elastic angular distribution at back angles and the gross structure seen in the 180^{o}-elastic excitation function of the $^{16}O + ^{28}Si$ system, with the coupling of the elastic channel to several seemingly favored α-transfer channels.

The above couplings generate well-localized energy and angular momentum windowlike deviations $W_{\ell}^{i}(E)$ in the elastic scattering partial wave S-matrix element, i.e.

$$S_{\ell} = \overline{S}_{\ell} + \sum_{i} W_{\ell}^{i}(E) \qquad (1)$$

where $\overline{S}_{\ell}$ describes the "normal" elastic scattering, dominant at small angles and i runs over the important α-channels that couple favorably to the elastic one.

It was emphasized in Ref. 1) that the window nature of $W_{\ell}^{i}(E)$ both in angular momentum and energy, results from the interplay of absorption, accounted for by $\overline{S}_{\ell}$, and the short-ranged nature of the α-transfer process. A reasonable account of the average trend of the 180^{o}-excitation function of $^{16}O + ^{28}Si$ was obtained, following the above picture, by considering a $W^{1}(E)$ related to the process $^{16}O + ^{28}Si \to ^{12}C + ^{32}S \to ^{16}O + ^{28}Si$ and another, $W^{2}(E)$, related to the elastic transfer process $^{16}O + ^{28}Si \to ^{20}Ne + ^{24}Mg \to ^{24}Mg + ^{20}Ne \to ^{28}Si + ^{16}O$.

In the calculation of these window functions, the localization in angular momentum space is used to define a certain radius parameter, $\tilde{R}$ which was fixed previously in Ref. 2) to be 7.36 fm for both $W^{1}(E)$ and $W^{2}(E)$. This resulted[1)] in similar shapes for both windows and, more importantly, their peaking at roughly the same center of mass energy $E_{cm} \cong 23$ MeV, which is the energy where the 1977 data of Barrette et al[3] also seem to peak.

Subsequent extended measurement by Braun-Munzinger et al.[4] have shown that the 180°-excitation function rises to another peaking at $E_{cm} \cong 45$ MeV.

It is the purpose of this communication to point out that by relaxing the condition that $\tilde{R}$ should be equal for W^1 and W^2 and using instead a <u>smaller</u> "anomalous" radius for the elastic transfer window W^2, we are able to shift its position to energies close to the second peaking of the experimental data of Ref. 4). With this we demonstrate the very clear sensitivity of the contributing processes to different radial regions of the ion-ion interaction.

We have recalculated W^2 with a radius parameter $\tilde{R} = 5.8$ fm. Both the absorption factor $A(E)$ and the elastic transfer amplitude $C_{ii}^{(3)}$ that define[1] W^2 as $W^2 \approx A\,C_{ii}^{(3)}$, change in such a way as to shift the peaking to higher energies as fig. 1 shows clearly. We should mention at this point that the absorption factor was calculated within the linearized WKB approximation of Ref. 1). This approximation would clearly become less adequate as the radius parameter is reduced further. In fact, within this approximation the energy at which the peaking of W^2 occurs, saturates at $E_{cm} = 33$ MeV; reducing the value of the anomalous radius further does not change the peaking energy. We anticipate, however, that a better treatment of both $A(E)$ and $C_{ii}^{(3)}$ may shift the position of the peaking of W^2 to energies closer to those at which the average experimental 180°-excitation function peaks. A more accurate calculation of the anomalous windows following

the treatment of Frahn and Hussein[5], is in progress and will be reported elsewhere[6].

It is important to recognize at this point that the finer structure seen in the 180°-excitation function comes about, within our model, from the interference between the round-trip transfer window, W^1 and the elastic transfer window W^2. Even if these windows peak at different energies, as we emphasize in this communication, the interference between them is guaranteed. In fact, this interference generates a fine E-structure whose average amplitude decrease as we approach the region where the first peaking occurs, in qualitative agreement with data.

The sensitivity of our calculated window functions to the distance of closest approach of the corresponding transfer processes, is a possible indication that the anomalous back-angle data may furnish invaluable information concerning the ion-ion interaction at small separation distances. This fact is intimately related to the clear interplay between the quasi-elastic, α-transfer processes, and the elastic scattering.

An important consequence of our findings is connected with the question of de-averaging the $180^\circ \pm 5^\circ$ - excitation function data addressed by Frahn and Kauffmann[5]. These authors correctly pointed out that as a result of the quite common procedure of averaging the data points in an angular interval $-5^\circ \leq \Delta\theta \leq 5^\circ$ around $\theta = 180^\circ$, one would necessarily end up with <u>smaller</u> over-all excitation function than the 180°-one. Clearly when confronted with dynamical models that supply a 180°-excitation function, the data has to be de-averaged.

We would like to point out at this point that this de-averaging procedure <u>is model-dependent</u>. It depends crucially on the value of critical radius attached to the mechanism responsible for the energy-structure in the excitation function. Therefore, in the light of our multi-step α-transfer model, the results of Ref. (7) have to be revised. To show this we exhibit in fig. (2) the energy-dependent de-averaging function $D(E,\alpha)$ which has to multiply the averaged data, and whose form is given by[7)]

$$D(E,\alpha) = \left[\left(J_0[\alpha\tilde{\Lambda}(E)]\right)^2 + \left(J_1[\alpha\tilde{\Lambda}(E)]\right)^2\right]^{-1} \quad (2)$$

for the two values of the anomalous radius referred to above $\tilde{R}_1 = 7.36$ fm and $\tilde{R}_2 = 5.8$ fm. In eq. (2) J_0 and J_1 are the Bessel functions of order zero and one, respectively, and $\tilde{\Lambda}(E)$ is the angular momentum that specifies the position in ℓ-space of the anomalous window. $\tilde{\Lambda}(E)$ is related to the radius parameter $\tilde{R}$, through $\tilde{\Lambda}(E) = \frac{\sqrt{2\mu}}{\hbar}\tilde{R}(E-\tilde{E})^{1/2}$ with $\tilde{E}$ fixed to be 17.8 MeV[2)]. We used $\alpha = 5^\circ$ as a measure of the averaging interval. The two values of the anomalous radius referred to above correspond to those used in calculating the two window functions W^1 and W^2 (Fig. 1). By multiplying the data points of Ref. 4), in the energy range 20 MeV $< E_{cm} <$ 30 MeV with $D(E,5^\circ)$ calculated with $\tilde{R}_1 = 7.36$ fm and the points in the energy range $30 < E_{cm} < 50$ MeV by $D(E,5^\circ)$ with $\tilde{R}_2 = 5.8$ fm (see Fig. 2), we obtain a de-averaged 180°-excitation function that is more regular, with the second peaking at $E_{cm} = 45$ MeV attaining a value very close to the first major peaking at $E_{cm} \cong 23$ MeV. This is in constrast to the finding of Ref. 7) where there was a great disparity in favor of the second peaking.

In conclusion, we have presented evidence, within the recently proposed multi-step α-transfer model, in support

of a picture of the anomalous back-angle elastic scattering of light-heavy as a multi-step process that probes different regions of the system at different energies. In light of this the de-averaging of the 180°±5° - experimental excitation function discussed by Frahn and Kauffmann has to be reconsidered. It would be interesting to experimentally determine the dependence of the back-angle excitation function on the averaging angle-interval, α.

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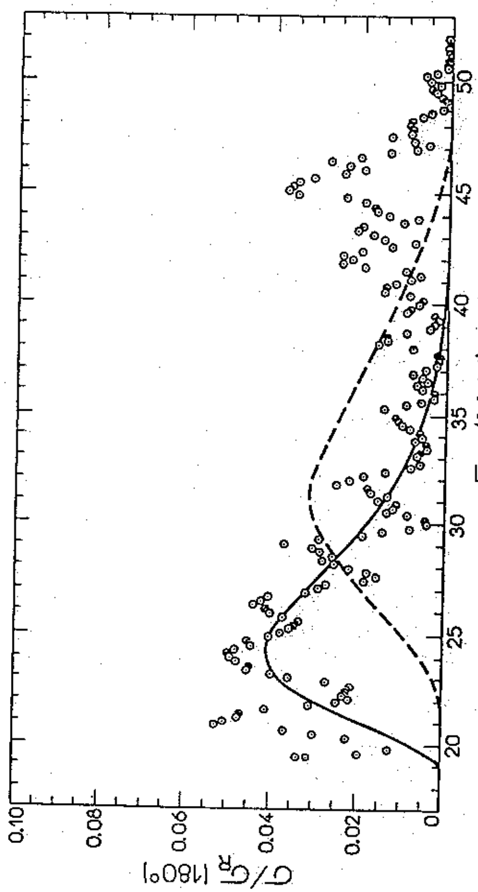
FIGURE CAPTIONS

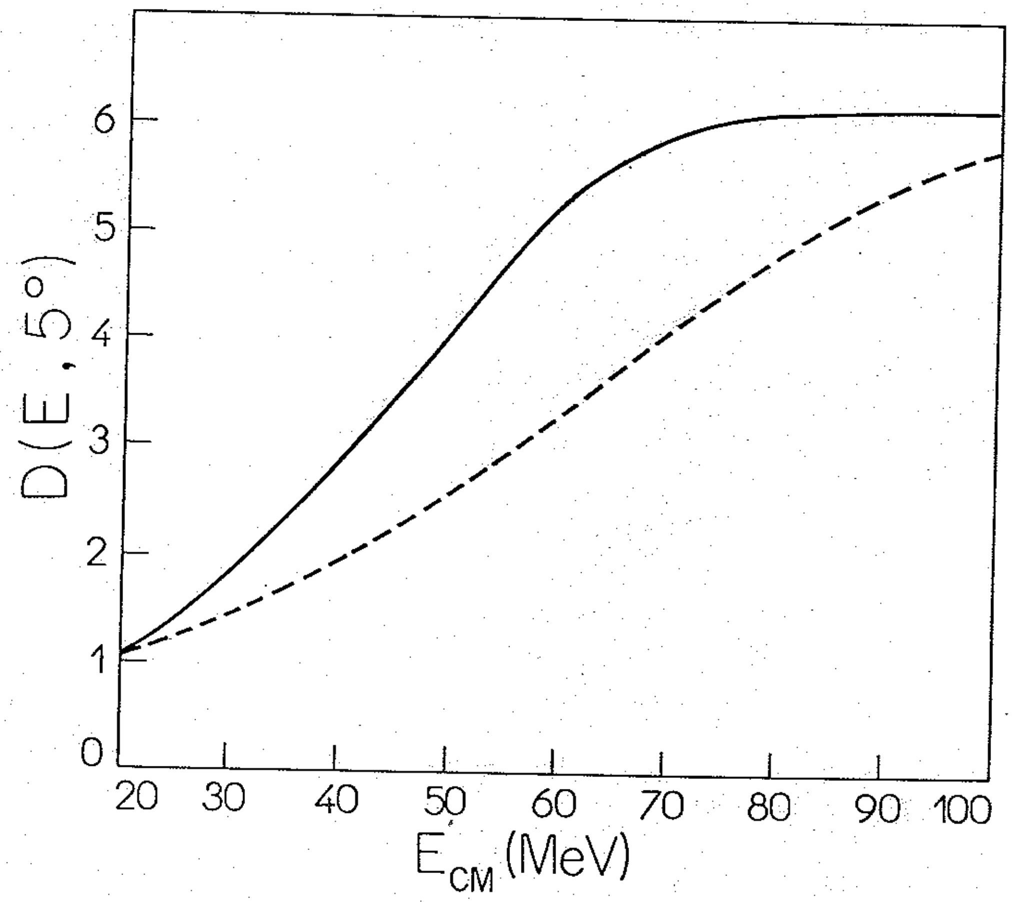
FIGURE 1 - The two window functions, W^1 and W^2 calculated with $\tilde{R} = 7.36$ fm (full curve) and 5.80 fm (dashed curve), respectively. Also shown are the data points of the $^{16}O + {}^{28}Si$ back-angle excitation function of Braun-Munzinger et al.[4].

FIGURE 2 - The de-averaging function $D(E,\alpha)$ vs E_{cm} for $\tilde{R} = 7.36$ fm (full curve) and $\tilde{R} = 5.8$ fm (dashed curve).



0.10
0.08
0.06
0.04
0.02
0
σ/σR (180°)
20
25
30
35
40
45
50
ECM (MeV)

Fig. 1



D(E, 5°)
0
1
2
3
4
5
6
20
30
40
50
60
70
80
90
100
ECM (MeV)

Fig. 2