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preprint

IFUSP/P-249

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ABSTRACT

A simple estimate of the ratio of the total quasi-elastic cross-section to the total reaction cross section of heavy ions is made and compared to the experimentally deduced values for the system $^{16}O + ^{27}Al$. The slow energy dependence of the ratio is stressed.

December/1980

A clean and clear separation among the different contributions to the total reaction cross section of heavy ions, associated with fusion, deep inelastic and quasi-elastic events, is an important first step needed in confronting the data with the predictions of the different theories and models of these processes. Usually one extracts the total nuclear reaction cross section, σ_R, from elastic scattering data by use of the quarter-point recipe. Furthermore, through measurements of the cross-sections for the important quasi-elastic processes one could then estimate the total quasi-elastic cross-section, σ_{QE}. The difference, $\sigma_R-\sigma_{QE}$, is then attributed to fusion and deep inelastic contributions. In the present note we suggest that the ratio σ_{QE}/σ_R may be considered as energy-independent, and present experimental evidence that supports our contention.

Among the important features of heavy-ion-induced reaction processes that distinguish them from light-ion reactions is the existence of well-defined ℓ-windows for the various contributions. This localization in ℓ-space which peaks at an angular momentum close to the grazing value, ℓ_g, is a result of several effects, the most important of which are strong volume-absorption and short de-Broglie wave length that characterizes the radial motion of the two nuclei. All surface processes, e.g. inelastic, transfer, break-up, etc., share the above features, differing only in finer details related primarily to the form factors, which only define the outer part of the ℓ-windows Since the peakings of the ℓ-windows occur close to ℓ_g, it is therefore expected that the angle -integrated total quasi-elastic cross section constitutes that part of the total reaction cross-section which is sensitive mainly to the nuclear surface region. In ℓ-space, the surface region may be characterized by a diffuseness, Δ, and a "ℓ-radius", Λ. It becomes clear therefore that the quasi-elastic contribution to σ_R should be proportional to $(2\pi\Lambda)\Delta$. This is easily seen from the explicit form of σ_{QE}

$$\sigma_{QE}=\frac{\pi}{k^2}\sum_{\ell_0(E)}^{\infty}(2\ell+1)T_\ell(E) \qquad (1)$$

where $T_\ell(E)$ are the transmission coefficients in the elastic channel and $\ell_0(E)\sim\ell_g(E)$. Since these coefficients drop rapidly to zero at $\ell\sim\ell_g+2\Delta$ we replace the upper limit by $\ell_0+\Delta$ and approximate the $T_\ell(E)$ in the interval $\ell_0\leq\ell\leq\ell_0+\Delta$ by unity. We then have

$$\sigma_{QE} \simeq \frac{\pi}{k^2}\left[(\ell_0+\Delta+1)^2-(\ell_0+1)^2\right]$$
$$\simeq \frac{1}{k^2}(2\pi\Lambda)\Delta \quad ; \quad \Lambda\equiv\ell_0+\tfrac{1}{2} \tag{2}$$

Within the same approximation, the total reaction cross-section, σ_R, is given by $\left(\frac{\pi}{k^2}\right)\Lambda^2$. Therefore we obtain the approximate expression for σ_{QE}/σ_R

$$\frac{\sigma_{QE}}{\sigma_R} \simeq 2\,\frac{\Delta}{\Lambda} \tag{3}$$

where higher-order terms in $\frac{\Delta}{\Lambda}$ have been dropped.

Although we do not expect equation (3) to be very accurate, it does, however, indicate an important fact namely σ_{QE}/σ_R is asymptotically independent on energy since both Δ and Λ depend on energy only through their proportionality to the local wave number of relative motion*.

The above considerations can be most clearly seen in figure 1 where we have plotted the ratio of the experimentally deduced σ_{QE} to σ_R vs the center-of-mass energy for the system ^{16}O + ^{27}Al. We base our analysis on this not-so-heavy system as the measured elastic data are true elastic and not "contaminated" by quasi-elastic processes that are difficult to resolve as is the case for heavier systems.

The values of σ_{QE}/σ_R were obtained from several

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* We might mention that semiclassically the ratio $\frac{\Delta}{\Lambda}\propto(1-E_B/2E)/(1-E_B/E)$ where E_B is the Coulomb barrier height and E, the center of mass energy.

sources[1,2,3] (see caption to figure 1). We have fitted the "data points" to the expression $\frac{\sigma_{QE}}{\sigma_R} = b\,\frac{\Delta}{\Lambda}$ with Δ and Λ extracted from elastic scattering data of $^{16}O + ^{27}Al$ at E=45.6 MeV[4] using the Frahn-Rehm closed-form theory[5]. The numerical value of b which best fits the data is 2.84. This is larger, by a factor 1.4, than the factor 2 appearing in equation (3). The over-all qualitative agreement, i.e., the constancy with respect to E, of Eq. (3) with the data is quite good considering the very simple picture used to derive it. We should stress that a more refined evaluation of σ_{QE}/σ_R by Frahn[6] gives a value for b = 3.87.

We interpret the above agreement of the formula for σ_{QE}/σ_R (obtained above assuming small value of Δ/Λ) with the data as a manifestation of the localization, around ℓ_g, in ℓ-space of the quasi-elastic processes. The ratio σ_{QE}/σ_R at high energies is thus simply proportional to the geometrical surface region. As Kauffmann has demonstrated[7], simple relations between the parameters Δ and Λ on the one hand and the parameters of underlying optical potential on the other hand may be established through which σ_{QE}/σ_R may be reexpressed as proportional to a/R where a (R) is the diffuseness (radius) of the real part of the potential (assuming the validity of surface transparency). These observations suggest a simple consistency check on the ratio a/R which can be fixed by the simultaneous measurements of σ_{QE} and the elastic cross-section.

In conclusion, we suggest that the above constancy of σ_{QE}/σ_R at high energies may provide a simple and straightforward mean of estimating $\sigma_R - \sigma_{QE}$. This should be of great value for studies involving deep inelastic processes.

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FIGURE CAPTION

FIGURE 1

The ratio $\frac{\sigma_{QE}}{\sigma_R}$ plotted vs $\frac{E_{C.M.}}{E_B}$, where E_B is the energy of the Coulomb barrier. The experimental values of σ_{QE} as well as of σ_R were taken from Refs. 1), 2), 3) (special care was taken in separating the quasi-elastic contribution to σ_R, see Ref. 8). In the work of Ref. 1 (pe-79), σ_{QE} was found to be dominated by inelastic contributions and σ_R was constructed by summing the measured fusion cross section, σ_{FU}, plus σ_{QE}. The dashed line corresponds to the average value of σ_{QE}/σ_R and it equals to 11.3×10^{-2}. By comparing this to $b\frac{\Delta}{\Lambda}$, with Δ and Λ extracted from elastic scattering data, (see text) we obtain for b the value 2.84.

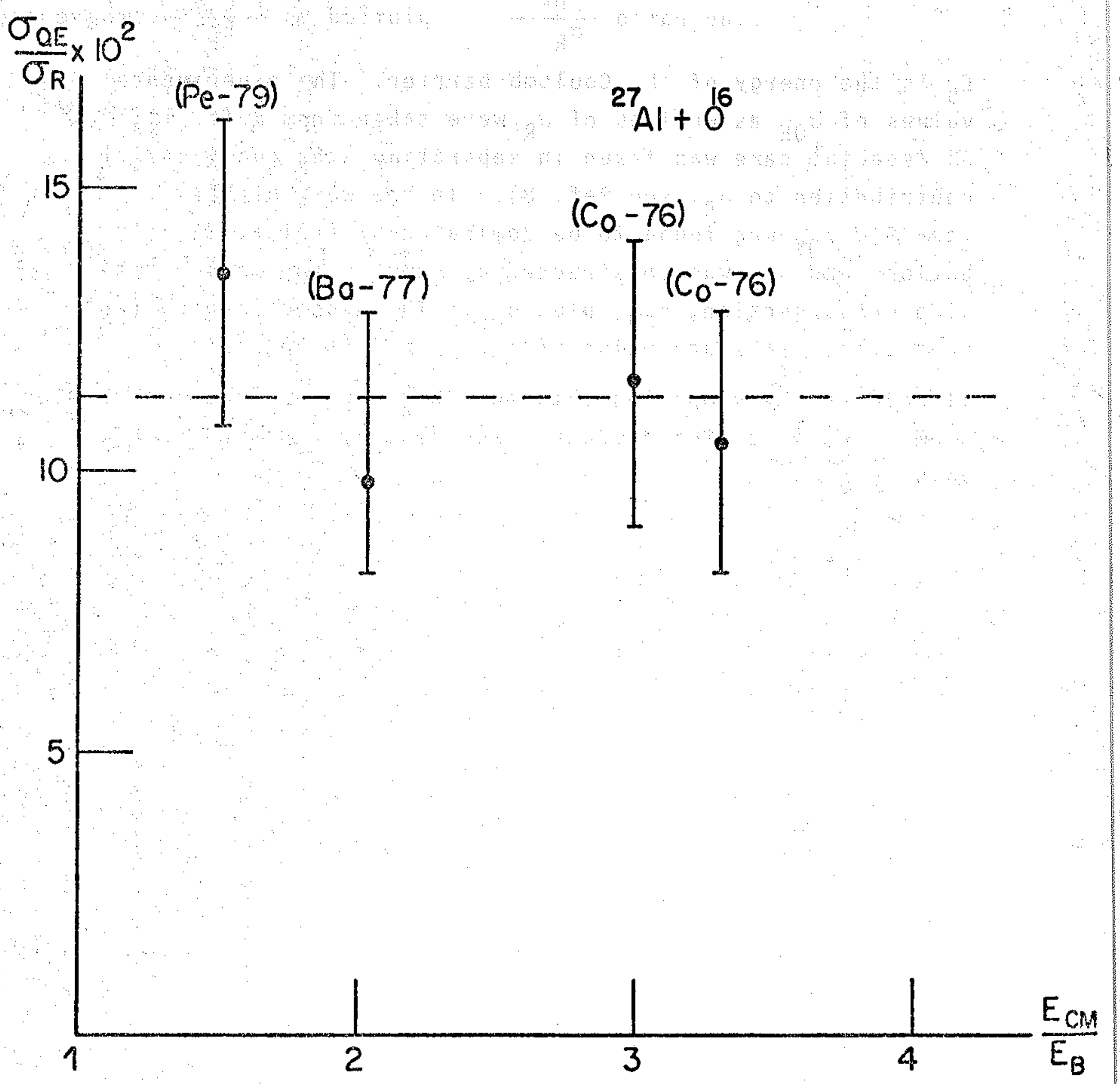

FIG. 1