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HIGH ENERGY STRUCTURES IN INCLUSIVE INELASTIC SCATTERING BETWEEN HEAVY-IONS

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Abstract. The inelastic processes of several projectiles on ^{208}Pb target have been calculated in order to see if the multiphonon excitation can give rise to structures in the inclusive energy spectra. In all cases the excitation functions show a quite smooth energy dependence.

1. INTRODUCTION.

In this talk I will concentrate on the interpretation of the high energy structures seen in the inclusive inelastic spectra of heavy-ion reactions that have been discussed in detail by N. Frascaria [1]. In particular I will try to see if these structures, may be interpreted as due to the multiple excitation of the giant states as suggested in ref.[2].

To do this I will use the surface excitation model of ref [3] where the inelastic channels corresponding to the excitation of both the low-lying collective states and the high-lying giant resonances are explicitly included in the calculations. The effect of the particle-transfer processes are taken into account in term of an absorbitive potential which depopulate the initial mass partition along the trajectory.

In section 2 the model will be briefly reviewed while the applications will be discussed in section 3. The conclusions are collected in section 4.

2. THE THEORY.

The relative motion of the two ions is described in terms of classical trajectories. Because of the short-range nature of the nuclear interaction is very important to follow the evolution of the nuclear surfaces along the trajectories. This is done introducing for each fragment the surface degrees of freedom associated with the excitation of the isoscalar

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modes (low-lying and giant states) and these are treated as dumped harmonic oscillators.

The nuclear forces are introduced through e surface-surface interaction of the proximity type that determine the relative motion and provides the main mechanism for the excitation of the surface modes. The electrostatic interaction between the ions is taken into account up to the monopole-multipole terms.

The system is thus described by the Hamiltonian

$$\begin{aligned} H = & \frac{p_r^2}{2m} + \frac{p_\phi^2}{2mr^2} \\ & + \sum_{n,\lambda\mu} \left\{ \frac{|\Pi_{n,\lambda\mu}(a)|^2}{2D_{n,\lambda}(a)} + \frac{1}{2} C_{n,\lambda}(a) |\alpha_{n,\lambda\mu}(a)|^2 \right\} \\ & + \sum_{n,\lambda\mu} \left\{ \frac{|\Pi_{n,\lambda\mu}(A)|^2}{2D_{n,\lambda}(A)} + \frac{1}{2} C_{n,\lambda}(A) |\alpha_{n,\lambda\mu}(A)|^2 \right\} \\ & + U^N(\vec{r}, \alpha_{n,\lambda\mu}) + U^C(\vec{r}, \alpha_{n,\lambda\mu}) \end{aligned}$$

and by the following Rayleigh function that describe the damping of energy from deformation to the thermal bath (uncorrelated particles motion)of the two ions

$$\mathcal{F}_{vib} = \sum_{n,\lambda\mu} \frac{2\Gamma_{n,\lambda} D_{n,\lambda}}{\hbar} |\dot{\alpha}_{n,\lambda\mu}|^2$$

where the sum must be extended over all modes of target and projectile. The variables p_r and p_ϕ are the conjugate momenta to the r and ϕ coordinates of relative motion and m is the reduced mass of the system. The deformation parameters $\alpha_{n,\lambda\mu}(i)$ are introduced in the usual way by expanding the surfaces of the ions in multipole

$$R^i(\hat{r}) = R_0^i \left[1 + \sum_{n,\lambda\mu} \alpha_{n,\lambda\mu}(i) Y^*_{\lambda\mu}(\hat{r}) \right]$$

where R_0^i is the equilibrium radius of nucleus ($i \equiv a, A$), and the $\pi_{n,\lambda\mu}(i)$ are the momenta conjugate to the deformation parameters. The parameters $D_{n,\lambda}(i)$ and $C_{n,\lambda}(i)$ correspond to the mass and restoring force parameters. They are related to the energy $\hbar\omega_{n,\lambda}$ and the strength of the modes included in the calculation. The width $\Gamma_{n,\lambda}(i)$ of the modes enter in the description through the Rayleigh function defined above.

The nuclear potential U^N, taken to be of the proximity type[4], is a function of the distance s between the two surfaces, this is written

$$s = r - R_0^a \left[1 + \sum_{n,\lambda\mu}^{(a)} \alpha_{n,\lambda\mu}(a) Y^*_{\lambda\mu}(-\hat{r}) \right] - R_0^A \left[1 + \sum_{n,\lambda\mu}^{(A)} \alpha_{n,\lambda\mu}(A) Y^*_{\lambda\mu}(\hat{r}) \right]$$

and thus provide the coupling terms between the relative and intrinsic motion. An additional coupling term is provided by the electrostatic interaction.

A quantum mechanical solution of the above problem can only be obtained by a series expansion of the interaction $U^N(\vec{r}, \alpha_{n,\lambda\mu})$ up the the first order in the deformation parameters. In the first order coupling limit the results coincide with the classical solution of the problem. Inspired by this result we have decided to consider the deformation parameters as classical vibrators and to solve the corresponding system of coupled equations of motion (they are the usual Hamilton equations modified by the presence of dissipative term arizing from the Rayleigh function). To show the shape's evolution of the two ions, in Fig 1. is shown, for the reaction $^{40}Ar + ^{208}Pb$ at 390 MeV of bombarding energy, a pictorial representation of a tajectory calculation leading to a scattering angle of 27°.

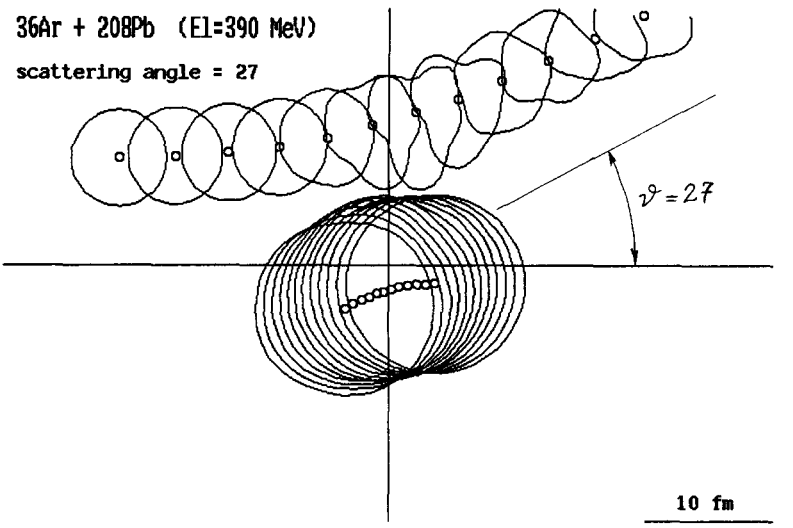

Fig. 1

Reactions where either exchange of particle or particle transfer followed by evaporation take place contribute to the cross section associated with the entrance-channel mass partition. Treating particle transfer as a depopulation mechanism through an imaginary potential one can estimate the absolute cross section in the inelastic channel. In this approach the particle transfer does not affect the trajectory of relative motion.

The average occupation number $\langle N(\rho)\rangle$ for each mode n excited in a collision with impact parameter ρ is

$$\langle N(\rho)\rangle = \frac{E_n(\rho)}{\hbar\omega_n}$$

where $E_n(\rho)$ is the excitation energy deposited in the mode n during the collision. The probability for having a number of ν_n phonons is given:

$$P_{\nu_n}(\rho) = \frac{\langle N_n(\rho)\rangle^{\nu_n}}{\nu_n} \exp\{-\langle N_n(\rho)\rangle\}$$

and the probability for a given energy-loss E at that impact parameter is

$$P(\rho, E) = \sum_{\{\nu_n\}} \delta \left(E - \sum_n \nu_n \hbar\omega_n \right) \prod_n P_{\nu_n}(\rho)$$

where the first sum is over all the families of occupation number ν_n.

The double-differential cross section (excitation function) can now be written as

$$\frac{d\sigma^2}{dEd\Omega} = \sum_\rho \frac{\rho |d\rho/d\vartheta|}{2\pi \sin\vartheta dE} P(\rho, E) T(\rho)$$

where the sum extends over all impact parameters that feed the chosen scattering angle $\vartheta(\rho)$. The coefficient $T(\rho)$, given by,

$$T(\rho) = \exp\left\{ \frac{2}{\hbar} \int_{-\infty}^{+\infty} W_{tr}(r) dt \right\}$$

describe the probability that the system has to remain in the initial mass partition. The function $W_{tr}(r)$ is the imaginary part of the ion-ion potential due to the mass transfer degrees of freedom.

Table 1

^{208}Pb			
λ	$E(MeV)$	$\Gamma(MeV)$	$\%EWSR$
0^+	13.6	2.0	100
2^+	4.1	–	16
	10.8	2.7	62
3^-	2.6	–	17
	17.0	5.0	80
4^+	4.3	–	6
	10.9	2.5	23
	24.0	7.0	70
5^-	3.3	–	5
	20.0	9.0	40

The excitation function discussed above in calculated in practice by using a Monte-Carlo technique. Since the average occupation numbers ν_n are very small this procedure may introduce some uncertainty in the high energy tail of the excitation function.

It is apparent from the way we construct our spectra that with the term multiphonon we intend not only the multiple excitation of a given mode but also the mutual excitation of different modes, this last component is the most important in building-up the cross-section at large excitation energy.

3. APPLICATIONS.

As I said in the introduction we would like to check if the multiphonon excitation can give rise to appreciable structure in the high energy part of the excitation function. In order to do that is important to have a good description of the spectra of the two ions and particularly of the target. In Table I, we show the spectra of ^{208}Pb that will be used throughout the calculation. This spectra has been obtained by analyzing the excitation function of $16O + ^{208}Pb$ at 400 MeV[5] where a good pick-to-background ratio allows a good determination of the giant states in the low energy part ($E \leq 25$ MeV) of the spectra. This has been utilized[6] to study the inclusive inelastic scattering for the reaction $^{36}Ar + ^{208}Pb$ at 390 MeV of bombarding energy.

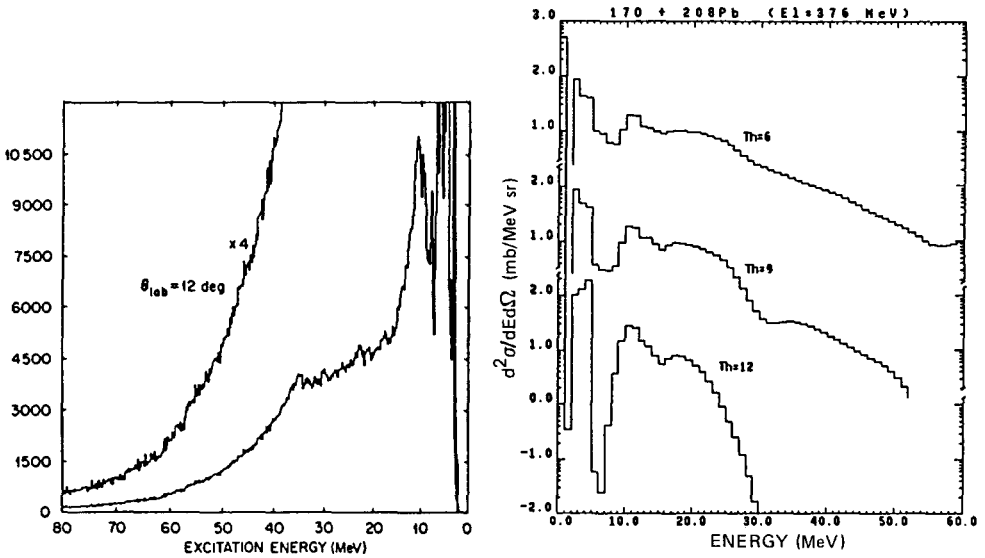

Fig. 2

In the following we will use the same spectra to analyze others excitations functions obtained from the scattering of ^{17}O, ^{20}Ne and ^{40}Ar on the ^{208}Pb target. Let us start from the ^{17}O. Because of the very low evaporation threshold of the projectile the excitation function contains only target excitations, so we decided to consider the ^{17}O as a spherical

object. The calculated spectra, for three angle close to the grazing, are shown in Fig 1. in comparison with the experimental data of ref.[7]. The imaginary potential does not influence (this it appens when the spectra are dominated by the nuclear brach of the deflection function) the shape of the spectra and it is use here as a normalization factor.

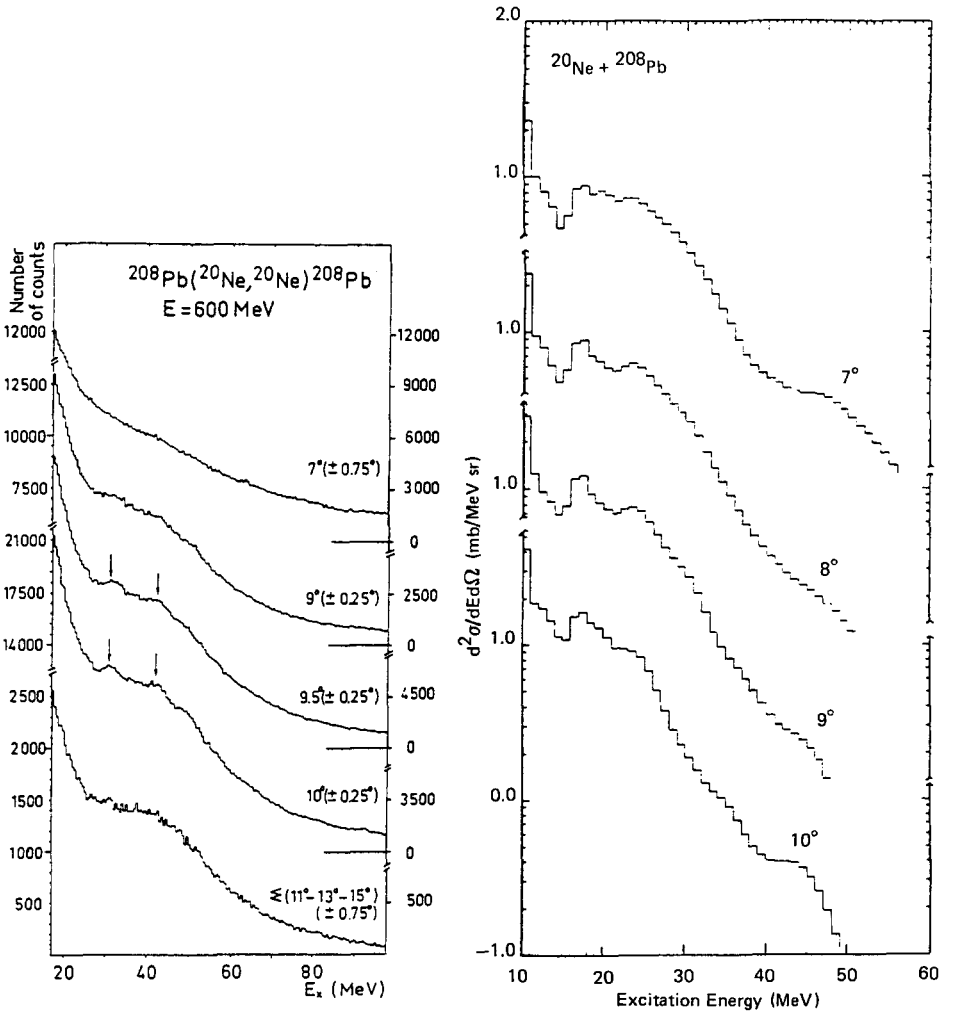

Fig. 3

In the case of the reaction of ^{20}Ne at 500 and 600 MeV of bombarding energy we have used for the projectile the universal response function discussed in ref.[3]. For several angles close to the grazing the calculated excitation functions are shown in Fig 3. in comparison with the experimental data[8]. Only the 600 MeV is shown since very

similar spectra are obtained for the lower energy. The theoretical spectra do not show any evidence for structures derived from the multiphonon excitation in accordance with the experimental finding that the structures at 31 and 43 MeV correspond to pick-up processes followed by evaporations.

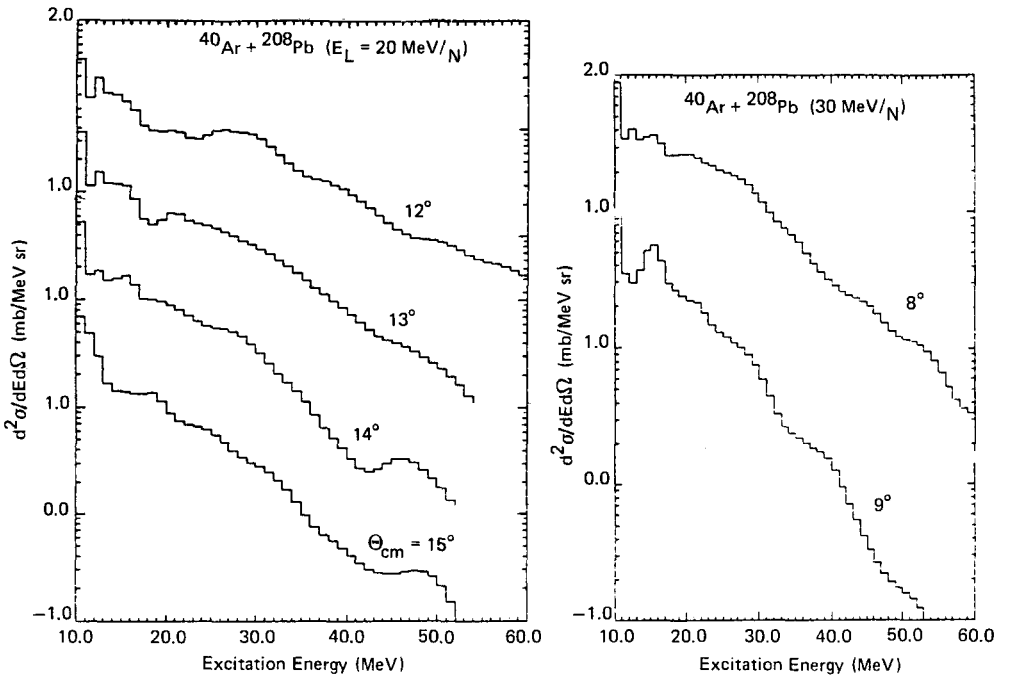

Fig. 4

For the reaction of ^{40}Ar on ^{208}Pb we study the evolution on the spectra as a function of the bombarding energy. Also in this case we have used the universal response function for the spectra of ^{40}Ar. The calculated cross section are shown in Fig 4. for 20 and 30 MeV/N. In the region of large energy loss the spectra is clearly build-up from the multiphonon excitation (no direct excitation can contribute to this region) but no evident bumps in due to this mechanism beside the one at low excitation energy.

4. CONCLUSIONS.

The inelastic processes of several projectiles on ^{208}Pb target have been calculated in order to see if the multiphonon excitation can give rise to structures in the inclusive energy spectra. In all cases we have seen that the multiphonon excitation explain a large fraction of the cross section at large energy-loss but does not seem to give rise to any appreciable

structures in the spectra. This is essentially due to the fact that all the giant states are excited with low probabilities corresponding to average occupation numbers $\langle N \rangle$ much smaller then 1.

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