INCLUSIVE INELASTIC SCATTERING WITH LIGHT PROJECTILES AND THE GIANT RESONANCES BACKGROUND

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The inclusive ^{208}Pb(α, α') reaction at a bombarding energy of 65 MeV is analysed utilizing the model of heavy ion collisions proposed by Broglia, Dasso and Winther The quantal effects associated with the zero-point motion of the surface vibrations are found to be important Although the probability to excite each state is small, about 60% of the inelastic cross section corresponds to the excitation of more than a single mode, indicating a strong coupled situation which cannot be described in the DWBA This result supports the findings of Bertsch and Tsai

In recent years our understanding of the nuclear response function has been widened in a major way through the systematic identification of giant resonances other than the well known dipole giant resonance (cf e g ref [1]) Important developments have also taken place in the detailed microscopic understanding of the surface modes in terms of particle–hole excitations (cf e g refs [2,3]) Within the same model it seems now possible also to calculate the width of the giant modes (cf e g ref [4] and references therein) One of the central problems which awaits solution is that of separating the direct excitation of a state from its background

In this letter we aim at giving a partial answer to this problem by analysing the ^{208}Pb(α, α') inclusive inelastic reaction at 65 MeV [5] We describe the reaction utilizing the model of heavy ion collisions proposed by Broglia et al [6], where the relative motion is described in terms of classical equations and where the nuclear degrees of freedom are described in terms of low-lying surface vibrations and damped giant resonances In this model the background is due to the combined excitation of several states

The spectrum of ^{208}Pb utilized in the calculations is shown in table 1 No internal degrees of freedom were given to the alpha particle nor have we considered the particle transfer channels The quantal fluctuations associated with the zero-point motion of the surface modes are taken into account as discussed in ref [7] Thus, for each impact parameter the set of coupled equations (4)–(9) of ref [8] are solved – setting $F_{\mathrm{MD}} = 0$ – for a range of initial conditions of the deformation parameters $\alpha_{\lambda\mu}$ of ^{208}Pb and corresponding conjugate momenta, determined by the zero-point energy distribution associated with the low-lying modes No zero-point motion was given to the giant resonances The ion–ion potential utilized in the calculations was of the proximity type [9] It should be noted, however, that the influence of the repulsive core on the different results was found to be small

A three-dimensional version of the Wilczynski plot for the reaction under discussion is shown in fig 1a A conspicuous feature of this plot is that a very large

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Table 1
Multipolarity, energy, percentage of the energy weighted sum rule and width of the states utilized to describe the surface modes of ^{208}Pb For more details cf ref [12]

λ^π	E (MeV)	EWSR (%)	Γ
0^+	12 00	100	2
2^+	4 08	10	0
	10 00	86	3
3^-	2 62	12	0
	5 34	3	0
	17 00	80	4
4^+	4 32	3	0
	5 70	2	0
	24 00	75	4
5^-	3 20	1	0
	5 48	1	0
	17 00	40	4

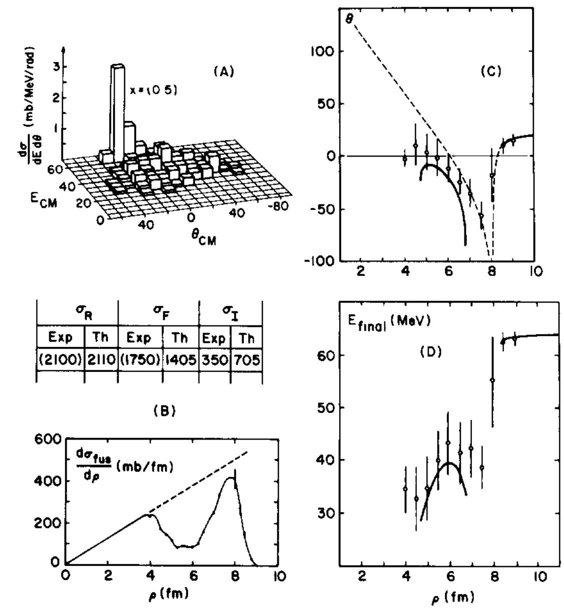

Fig 1 Scattering angle, energy loss and fusion cross section as a function of the impact parameter In (a) a three dimensional version of the Wilczynski plot is displayed In (c) and (d) the deflection function and the energy loss are shown The "error bars" correspond to the standard deviations, while the continuous lines are the results calculated without including fluctuations The elastic deflection function is displayed in (c) as a dashed line In (b) the fusion cross section is shown as a function of ρ The difference between $d\sigma_{fus}/d\rho$ and the straight line gives the inelastic cross section The theoretical and experimental values for the reaction (σ_R), fusion (σ_F) and inelastic (σ_I) cross sections are given in tabulated form in mb

fraction of the inelastic events lead to negative scattering angles, and thus to a positive polarization [‡1] for the gamma-rays emitted by ^{208}Pb The predicted values of P_γ for angles just behind and just ahead of the grazing angle $\theta = 20°$ are $P_\gamma(30° \pm 5°) = +0\ 70$ and $P_\gamma(10° \pm 5°) = +0\ 27$

The deflection function and corresponding energy loss as a function of the impact parameter are shown in figs 1c and 1d The fusion cross section displays a rather marked structure as shown in fig 1b This structure should reflect itself in the decay of the compound system

In fig 2a we display the semiclassical differential cross section integrated over all angles as a function of the center of mass energy in the exit channel The average energy loss which is about 20 MeV is somewhat larger than the experimental value (≈15 MeV) This can be seen from fig 2b which shows $(d^2\sigma(\theta = 25°)/dE\, d\theta)$ in comparison with the experimental data Utilizing the results used in plotting $d\sigma/dE$ we obtain the occupation numbers $\langle N(n, \lambda, \rho)\rangle$ for each impact parameter and for each of the n different vibrational states of multipolarity λ Assuming the population of each mode to be governed by a Poisson distribution

$$P_m(n, \lambda, \rho) = \langle N(n, \lambda, \rho)\rangle^m / m! \exp\{-\langle N(n, \lambda, \rho)\rangle\},$$

valid for interactions linear in the deformation amplitudes, and utilizing the transmission coefficients $t(\rho)$ which can be obtained from fig 1b, we can calculate the differential cross section $d\sigma/dE$ associated with the excitation of any combination of states with arbitrary occupation numbers For example, the differential cross section for exciting the state with energy $W = \Sigma_i m_i \hbar\omega_i$, where $i \equiv (n, \lambda)$ identifies one of the states shown in table 1 and m_i is the corresponding occupation number, can be written as

$$\frac{d\sigma}{dE} = 2\pi \int \rho\, d\rho\ t(\rho)\, P(E, \rho), \tag{1}$$

[‡1] We use here the convention of ref [11] where the polarization is measured relative to the direction $\boldsymbol{k}_i \times \boldsymbol{k}_f$, $\boldsymbol{k}_i$ and $\boldsymbol{k}_f$ being the wavevectors in entrance and exit channel, respectively

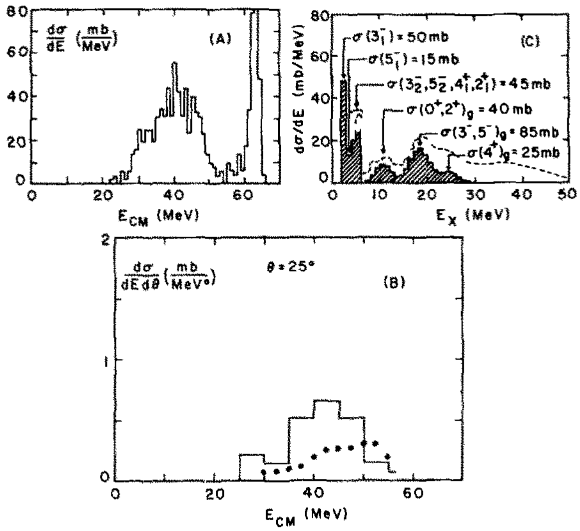

Fig 2 The inclusive semiclassical inelastic cross sections as a function of the energy are shown in (a) and (b) integrated over angles and for $\theta = 25°$, respectively The dots in (b) are the experimental points In (c) the continuous line represents the semiquantal cross section for the excitation of single states The spin and parity and associated cross sections are also shown The dashed line is the total inelastic cross section of the inclusive type The difference between the two curves gives the background

where

$$P(E, \rho) = \sum_{\{m_i\}} \delta(E - W) \prod_{m_i, i} P_{m_i}(i, \rho) \qquad (2)$$

The sets of numbers $\{m_i\}$ all give rise to the same energy W The resulting cross section (1) was distributed around the energy E according to a gaussian distribution of width $\Gamma(E) = (\Sigma_i m_i \Gamma_i^2)^{1/2}$, where Γ_i is the width associated with each mode The calculations were carried out utilizing Monte-Carlo techniques where the random numbers follow the Poisson distribution characteristic of each state

The results are displayed in fig 2c Increasing the number of the events with which the occupation numbers $N(\lambda, n, \rho)$ are calculated from 10^3 to 2×10^3 no appreciable change was observed in these results A more accurate method to obtain the spectrum would be to use the Wigner transformation to reconstruct the diagonal quantal density matrix elements This would however require a further increase in the statistics, with which the occupation numbers are determined, by two orders of magnitude, ruling out at present such a possibility

About 40% of the ^{208}Pb(α, α') inclusive reaction corresponds to the excitation of single quantal states, and 60% to the excitation of two or more states (background) This result agrees with the DWBA analysis of Tsai and Bertsch [11]

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References

[1] F E Bertrand, Ann Rev Nucl Sci 26 (1976) 457
[2] A Bohr and B R Mottelson, Nuclear structure (Benjamin Reading, MA, 1975)
[3] G F Bertsch and S F Tsai, Phys Rep 18C (1975) 125
[4] G F Bertsch, P F Bortignon, R A Broglia and C H Dasso Phys Lett 80B (1979) 161
[5] G Chenevert et al , Phys Rev Lett 27 (1971) 434
[6] R A Broglia, C H Dasso and A Winther, Phys Lett 53B (1974) 301, 61B (1976) 113
[7] H Esbensen et al , Phys Rev 41 (1978) 296
[8] R A Broglia et al , Phys Rev Lett 41 (1978) 25
[9] J Błocki et al , Ann Phys 105 (1977) 427
[10] W Trautmann et al , Phys Rev Lett 39 (1977) 1062
[11] S F Tsai and G F Bertsch, Phys Rev C11 (1975) 1634
[12] R A Broglia, O Civitarese, C H Dasso and A Winther, Phys Lett 73B (1978) 405