EXTRACTING THE WIDTH OF GIANT RESONANCES FROM THE ANALYSIS OF HEAVY ION INELASTIC SCATTERING

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The energy and percentage of the energy-weighted sum rule associated with low-lying collective modes and with the giant resonances, are input parameters of the coherent surface excitation model of heavy ion reactions of Broglia, Dasso and Winther. In the present letter we study how the magnitude of structures in the energy spectra associated with the excitation of giant resonances depend on the spreading widths of these modes.

The coherent surface excitation model [1] describes reactions between heavy ions in terms of the degrees of freedom of the two interacting nuclei. They are the low-lying collective modes and the damped giant resonances.

These vibrations are assumed, for simplicity, to be harmonic. They are characterized by the restoring force C, the mass parameter D and the damping coefficient γ. These quantities are related to the nuclear structure of each of the two ions through the equations

$$\hbar\omega_{n\lambda}(i) = \hbar(C_{n2}^{(i)}/D_{n\lambda}^{(i)})^{1/2} , \qquad (1)$$

$$f_n^{(i)}(\lambda) = S^{-1}(\lambda)(3A(R_i^{(0)})^2/4\pi)^{\lambda} \times (2\lambda+1)\hbar^2/2D_{n\lambda}^{(i)} , \qquad (2)$$

and

$$\gamma_{n\lambda} = 2\Gamma_{n\lambda}^{(i)}D_{n\lambda}^{(i)}/\hbar \quad (i = \mathrm{a, A}) . \qquad (3)$$

The quantity $\hbar\omega_{n\lambda}^{(i)}$ is the energy of the nth vibration of multipolarity λ of nucleus i, while $f_n^{(i)}(\lambda)$ measures the fraction of the isoscalar energy-weighted sum rule $S(\lambda)$ associated with the mode $(n\lambda i)$ (oscillator strength). The width of the mode is denoted by Γ. It is zero for low-lying states and coincides with the full width at half maximum for the giant resonances. The quantities (1)–(3), together with the masses and charges of the two ions and the bombarding energy are the parameters of the model.

One has a rather accurate knowledge of the low-lying collective modes and of some of the giant resonances, obtained mainly from the analysis of inelastic scattering in grazing collisions with light projectiles. These modes can be viewed as correlated particle–hole excitations, and a detailed microscopic picture has been achieved in the framework of the random phase approximation (cf. e.g. refs. [2–5] and references therein).

Examples of such calculations are displayed in fig. 1. They show the isoscalar $\lambda = 2$ and $\lambda = 3$ response function of ^{208}Pb. In (A) and (B) we display the distribution of oscillator strength predicted by a RPA calculation where the single-particle levels and wave functions were generated by a modified harmonic oscillator potential [6]. The response function displayed in (C) and (D) was obtained with single-particle levels and matrix elements produced in a self-consistent Hartree–Fock calculation with a Skyrme III interaction [3].

Examining these figures one sees in addition to the low-lying collective states that most of the energy-weighted sum rule lies concentrated in a higher energy interval. A rather safe assignment can be made for the centroid and accumulated strength for these giant modes (i.e. $E \approx 10$ MeV, $f \approx 0.8$ for the quadrupole modes, $E \approx 20$ MeV, $f \approx 0.5$ for the octupole modes). An esti-

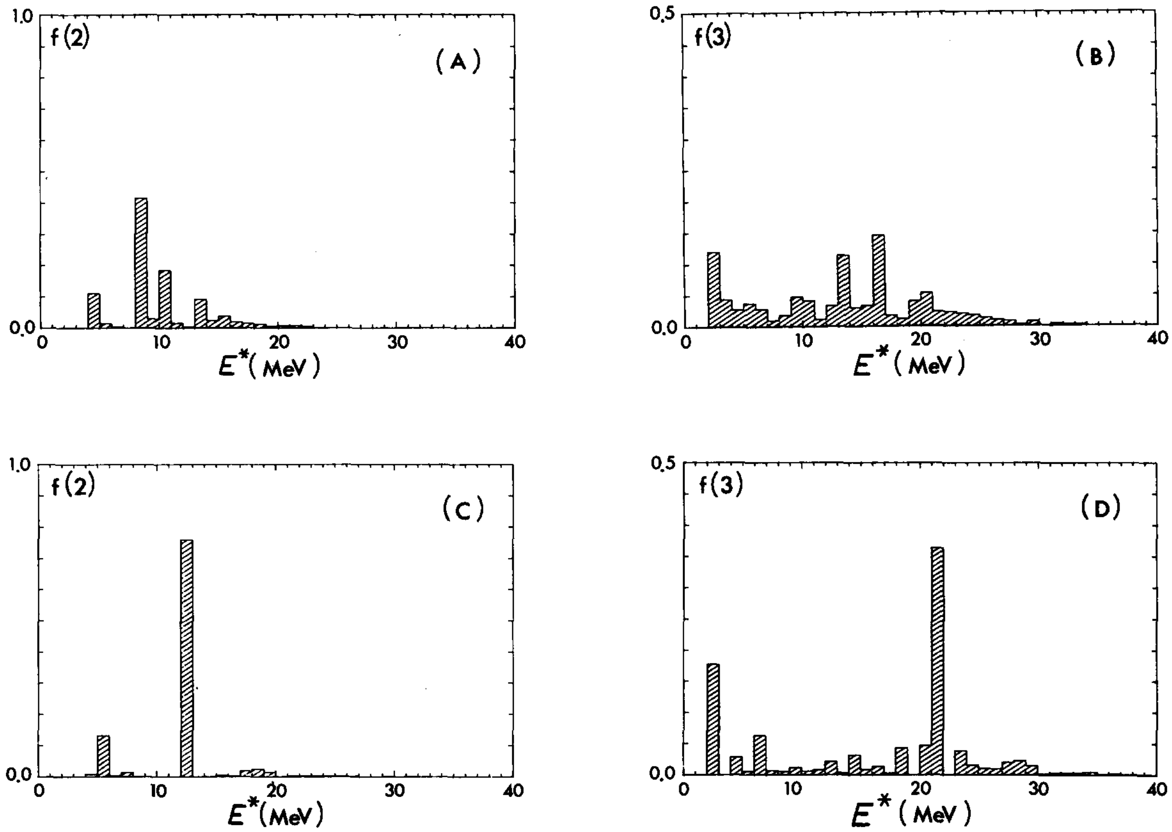

Fig. 1. Oscillator strength for the quadrupole and octupole modes of ^{208}Pb. The results showed in (A) and (B) correspond to RPA calculations where single-particle levels and matrix elements of a modified harmonic oscillator were utilized. Those shown in (C) and (D) correspond to a RPA calculation which makes use of a Hartree–Fock basis determined by a Skyrme III interaction.

mate of the eventual spreading width is, on the other hand, far more uncertain. This is because, aside from the coupling of the collective modes to more complicated two-particle–two hole states, the strength distributions have different degrees of fragmentation already at the RPA level. For example, while the calculations carried out in the Hartree–Fock basis predict a strong concentration of the octupole strength in basically a single root, those based on the harmonic oscillator potential lead to a rather wide strength distribution.

The uncertainty in the spreading widths of the high-lying modes (particularly for the higher multipolarities) does not affect much the results of calculations carried out in the framework of the model of ref. [1]. In fact, different assumed widths change the balance of energy associated with deformation and temperature at a given time during the collision, but since macroscopic deformations of the surface due to high-frequency modes are small, the magnitude of Γ has no important dynamical consequences. Also, it is our experience that the total amount of energy dissipated into a mode (i.e. probability of excitation) is a rather insensitive quantity to the size of the width, provided $\Gamma \ll \hbar\omega$.

Constructing the distribution of cross section as a function of excitation energy the question however becomes relevant, as the obtained excitation probability has to be distributed over an energy interval that is directly related to the size of Γ. In what follows we illustrate the sensitivity of the results of the coherent surface excitation model to the assumed energy and width of the giant resonances.

Utilizing the nuclear spectra and the widths quoted

Table 1
Three sets of input parameters describing the surface modes of ^{208}Pb. The differences in the spectra mostly reflect the uncertainty in the estimated width of the giant modes.

λ^{π}	A		B		C		% EWSR
	E(MeV)	Γ(MeV)	E(MeV)	Γ(MeV)	E(MeV)	Γ(MeV)	
0^+	13.6	3.0	13.6	3.0	13.6	3.0	100.0
2^+	4.1	0.5	4.1	0.5	4.1	0.5	16.0
2^+	10.8	2.7	10.8	2.7	10.8	2.7	82.0
3^-	2.6	0.5	2.6	0.5	2.6	0.5	15.0
3^-	20.0	5.0	17.0	5.0	17.0	8.0	80.0
4^+	4.3	0.5	4.3	0.5	4.3	0.5	4.6
4^+	10.9	2.5	10.9	2.5	10.9	2.5	23.0
4^+	24.0	6.0	24.0	7.0	24.0	10.0	72.0
5^-	3.3	0.5	3.3	0.5	3.3	0.5	2.0
5^-	21.0	6.0	20.0	9.0	20.0	12.0	39.0

in table 1, the inelastic scattering of ^{16}O on ^{208}Pb was calculated for a bombarding energy of 315 MeV (cf. ref. [7]). The resulting excitation functions are displayed in fig. 2 for the grazing angle $\theta_{\mathrm{CM}} \approx 14°$. It is noted that the position and width of the giant monopole and quadrupole resonance of ^{208}Pb are experimentally known (cf. refs. [8–10] and references therein). The width of the $\Delta N = 2$ component of the $\lambda = 4$ giant resonance is expected to be somewhat larger than that of the giant quadrupole but still of the same order of magnitude. Thus, the nuclear structure parameters of the group of giant modes of ^{208}Pb around 11 MeV are reasonably well known.

Concerning the input data for the $\lambda = 3$ and $\lambda = 5$ giant modes the choices in table 1 reflect the uncertainties discussed in connection with fig. 1. For example, the $\lambda = 3$ giant mode in ^{208}Pb would be about 17 MeV in fig. 1 (C) and about 21 MeV in fig. 1 (D). There exist even experimental results supporting either value for the position of the giant octupole in Pb [11,12]. We have assumed, as suggested by the microscopic calculations, larger values of the width for the states in table 1B than for those in table 1A. In table 1C we have kept the same spectrum as in table 1B but assumed very large spreading widths. The results of the model for the different spectra range from producing a clear peak at about 22 MeV in fig. 2(A) to a complete washed-out structure in that energy region in fig. 2(C).

During the last year, two rather similar experiments

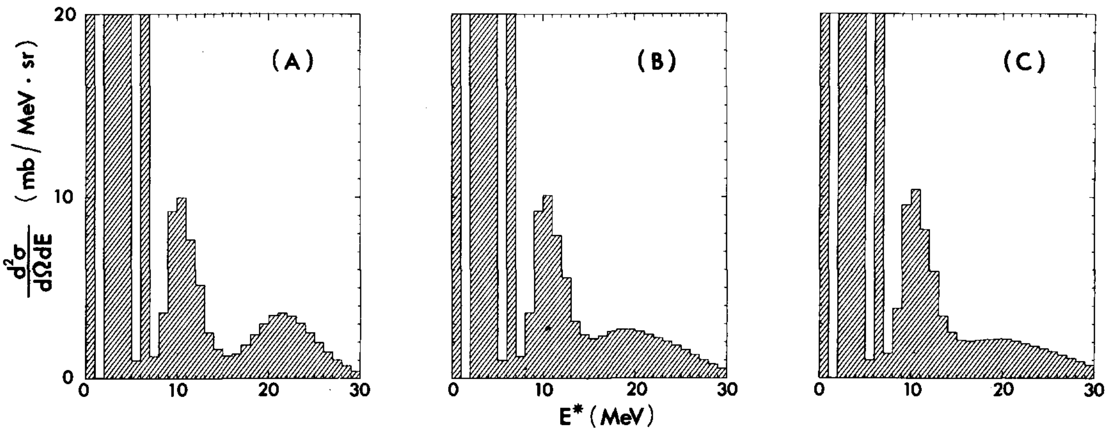

Fig. 2. Distribution of cross section as a function of energy for the reaction ^{16}O + ^{208}Pb at 315 MeV at an observation angle of $\vartheta_{\mathrm{CM}} = 14°$. Figs. (A–C) result from the spectra of energies and widths indicated in the corresponding columns of table 1.

aimed at studying the response function of ^{208}Pb have been reported, containing some contradictory results. In the first [13], a structure was observed at an energy of ~22 MeV, which was identified with the giant octupole resonance. In the second experiment [14], no structure in the inelastic spectrum was found above 11 MeV.

If the structure reported by Doll et al. [13] is not associated with a direct process, as seems to be implied by the results of Garg et al. [14], one can conclude, from the analysis presented in fig. 2, that the widths Γ_3, Γ_4 and Γ_5 are larger than ~7 MeV. This result will test the ability of the different nuclear structure models used to calculate the damping of giant resonances.

The coherent surface excitation model which provides a unified description of heavy ion reactions, seems to be able to describe the excitation of single quantal states. This is implied by the agreement obtained [7] for the cross sections and angular distributions associated with the 2.62 MeV octupole vibration and with the GQR of ^{208}Pb. It thus seems possible to use the model to extract detailed information about the nuclear response function from the analyses of inelastic heavy ion reactions (cf. also ref. [15]); in particular the position and width of giant resonances.

References

[1] R.A. Broglia, C.H. Dasso and A. Winther, Phys. Lett. 53B (1974) 301; 61B (1976) 113; Proc. Intern. School of Physics Enrico Fermi on Nuclear structure and heavy ion reactions, eds. R.A. Broglia, C.H. Dasso and R. Ricci (North-Holland, Amsterdam), to be published.
[2] G.F. Bertsch, Nature 280 (1979) 639.
[3] G.F. Bertsch and S.F. Tsai, Phys. Rep. C18 (1975) 125.
[4] J. Speth, in: Giant multipole resonances, ed. F. Bertrand (Harwood, New York, 1980) p. 33.
[5] A. Bohr and B.R. Mottelson, Nuclear structure, Vol. II (Benjamin, Reading, MA, 1975).
[6] D.R. Bes, R.A. Broglia and B. Nilsson, Phys. Rep. 16C (1975) 1.
[7] R.A. Broglia, G. Pollarolo, A. Vitturi, C.H. Dasso and H. Esbensen, Phys. Lett. 89B (1979) 22.
[8] F. Bertrand, Ann. Rev. Nucl. Sci. 26 (1976) 457.
[9] D.H. Youngblood, in: Giant multipole resonances, ed. F. Bertrand (Harwood, New York, 1980) p. 113.
[10] M. Buenerd et al., Phys. Lett. 84B (1979) 305; ISN 80.18 (1980).
[11] H.P. Morsch et al., Phys. Rev. Lett. 45 (1980) 337.
[12] T.A. Cavey et al., Phys. Rev. Lett. 45 (1980) 239.
[13] P. Doll et al., Phys. Rev. Lett. 42 (1979) 366.
[14] U. Garg et al., Phys. Lett. 93B (1980) 39.
[15] R.A. Broglia, C.H. Dasso, H. Esbensen, A. Vitturi and A. Winther, Nucl. Phys. A345 (1980) 263.