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HIGH MULTIPOLE ISOVECTOR MODES AND CHARGE FLUCTUATIONS IN
HEAVY ION REACTIONS

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Abstract: The role of higher order isovector modes and of the mass asymmetry in the charge distributions of deep inelastic products is studied in the weak coupling limit.

An important development in the field of heavy ions relates the fragment charge fluctuations at fixed mass asymmetry to the thermal and quantal fluctuations of the axial component of the E1 mode associated with the intermediate complex. The allegedly contradictory findings of large⁽¹⁾ and small⁽²⁾ charge fluctuations at large and small mass asymmetries respectively and the related attempts to infer the relevant E1 phonon energies suffer from a lack of systematic understanding of the role played by the various giant isovector modes in the charge fluctuations.

We are proposing here a simple model that, while it may not be adequately realistic, is complete and points out important facts which have been overlooked.

We shall disregard the dynamical aspects of the problem and assume that the particular shapes considered in our model just precede the rapid division into two fragments. In particular, let us consider the axial isovector modes in a cylinder of length $2a$, radius r , which is suddenly split at a distance b from one of the bases. The standing isovector waves are clearly trigonometric functions and the boundary conditions require them to be cosine functions.

According to the Steinwedel-Jensen model⁽³⁾, the fluctuation of the charge density for the mode of order n is

$$\rho_Z = -\frac{1}{2} \rho_Z^0 a_n \cos k_n x \quad (1)$$

where ρ_Z^0 is the equilibrium charge density, a_n is the amplitude of the mode, x is the distance along the cylinder axis from one of the

bases, and the wave number k_n is given by $k_n = (\pi/2a) n$. The frequency of each mode is given by $\omega_n = k_n u$, where

$$u = \left(\frac{8X}{m} \frac{ZN}{A^2} \right)^{1/2} \approx 0.21c \quad (2)$$

is the isospin sound velocity, which is assumed to be frequency-independent; X is the liquid drop symmetry energy coefficient and m is the nucleon mass.

If we cut the cylinder at b , we can define the charge excess of one of the fragments by the relation

$$Z_n = \frac{-1}{2} \rho_z^0 a_n \pi r^2 \int_0^b \cos k_n x dx = \frac{-a_n Z}{2\pi} \frac{\sin[n\pi Q]}{n} \quad (3)$$

where the degree of symmetry $Q = b/2a$.

Since the transformation from the coordinate x to the variable Z_n does not involve time, we can conclude that Z_n oscillates harmonically, because a_n does. Classically, for a fixed value of Q , each Z_n is a separate normal mode.

Let us now determine the stiffness constant of each of these normal modes; we know the frequency already. We can do this by calculating the potential energy (disregarding coulomb forces for the moment)

$$V = X \int \frac{(\rho_n - \rho_z)^2}{\rho_0} d\tau = \frac{X a_n^2}{8} A \quad (4)$$

and substituting the amplitude a_n obtained from Eq. (3) into Eq. (4). The potential energy is indeed quadratic in Z_n :

$$V = (1/2) c_n Z_n^2 \text{ with}$$

$$c_n = X \frac{A}{Z^2} \pi^2 \frac{n^2}{\sin^2[n\pi Q]} \quad (5)$$

Note that the stiffness constant depends strongly on n . For any n some of the charge fluctuations average out and do not contribute to the fragment charge fluctuation; this is all the more true the larger n is, since it takes more energy to displace a given amount of charge into any given fragment. Even for the lowest mode ($n = 1$), some of the energy goes into polarizing the fragments rather than displacing charge. This is to be contrasted with the standard way in which c has been calculated so far, using a potential which neglects fragment polarization: $V = V_{LD}(1) + V_{LD}(2) + V_C(1,2)$, where $V_{LD}(1)$ and $V_{LD}(2)$ are the liquid drop energies of two touching spheres and $V_C(1,2)$ is their Coulomb repulsion. The stiffness constant follows as

$$c_{LD} = \left. \frac{\partial^2 V}{\partial Z_1^2} \right|_{\text{constant } A} \quad (6)$$

where Z_1 is the charge of one of the fragments. In Fig. 1, c_1 and c_{LD} can be compared as a function of Q . The large error introduced by neglecting the fragment polarization is obvious, especially at large asymmetries.

Notice also that for the special values of Q for which $\sin[n\pi Q]$ is zero the stiffness constant is infinite; no matter how much work is done, no charge displacement arises. This is true in particular at symmetry ($Q = 1/2$), where none of the even modes contribute to displacement.

After having identified the Z_n as classical normal modes, we can immediately quantize them. For each mode we obtain a phonon energy

$$\hbar \omega_n = \frac{\hbar u \pi}{2a} n \quad (7)$$

These phonon energies are very large even for the lowest modes, so that the limit $T/\hbar \omega_n \ll 1$ is typically encountered ($T \equiv$ nuclear temperature) and only zero-point fluctuations need to be considered.

For each mode n the zero-point charge width is given by

$$\sigma_n^2 = \frac{\hbar \omega_n}{2c_n} = \sigma_1^2(\text{symmetry}) \frac{\sin^2[n\pi Q]}{n} \quad (8)$$

From Fig. 1 and Eq. (8), one expects these widths to be smaller at large asymmetries than those calculated neglecting fragment polarization, and experiment^(1,2) indicates such an effect. The contribution of the n th mode to σ^2 goes like $1/n$, so that the contribution of the higher modes becomes less relevant the higher n is. However, the total charge width in this model diverges logarithmically.

$$\sigma^2 = \sigma_1^2(\text{symmetry}) \sum_n \frac{\sin^2[n\pi Q]}{n} \quad (9)$$

This is not surprising because we are assigning an infinite number of degrees of freedom to a system of finite particle number. Furthermore, it is likely that the higher-frequency modes "drown" in the doorway states directly coupled to them, as illustrated in Ref. 4, thus removing the collectiveness from the respective degrees of freedom. The location of the cutoff in n , or even whether a fully quantal treatment is warranted for the lowest mode, is most relevant.

The wavelength of the oscillations cannot be much smaller than the diameter of a nucleon; thus one obtains the following cutoff in n :

$$n_{\max} = 4.8 A^{1/3} \text{ for } \lambda_{\min} = 1.5 \text{ fm.}$$

A very important feature of this model is that the role of each mode strongly depends upon the asymmetry of the system. In Fig. 2(a) the normalized partial width is given as a function of asymmetry for a few values of n ; in Fig. 2(b), they are given as a function of n for a few asymmetries. At values close to symmetry, the lowest mode dominates, but with increasing asymmetry the higher n modes play an ever increasing role. The widths are zero when a half-multiple of the wavelength for a mode matches the value of b . In Fig. 3 the width arising from the first n modes is given for a few n values as a function of Q . This shows that an experimentally observed width, especially in asymmetric systems, may include the comparable contribution of several modes.

It is clear that any attempt to relate such width to a single E1 mode rather than to the combination of several isovector modes may be doomed to failure. The difficulties are compounded by the use of a stiffness constant which may dramatically depend on the form of the standing wave and which has been calculated incorrectly so far even for the lowest mode. The cylindrical geometry is likely to be a poor approximation, but the introduction of a neck to better simulate the separation of the fragments leads to complications which may involve non-linear and dispersive effects. Dynamics is especially important, since the salient feature of this problem is the configuration associated with the neck snapping.

In conclusion, information on the isovector modes from the measurement of the charge fluctuation at high temperatures can only be obtained by properly accounting for both the effect of mass asymmetry and the role of higher order modes.

REFERENCES

1. G. Wirth, W. Bröchle, H. Gägeler, J. V. Kratz, M. Schädel, I. Warneke, G. Hermann, M. Weis, R. Lucas, J. Poitou, Proceedings of the International Workshop on Gross Properties of Nuclei and Nuclear Excitations VII, Hirschegg, Austria, 1979, INKA-Conf-79-001-001/INKA-Conf-79-001-039, p. 13.
2. M. Berlinger, A. Gobbi, F. Hanappe, U. Lynen, C. Ngô, A. Olmi, H. Sann, H. Stelzer, H. Richel, and M. F. Rivet, preprint.

3. W. D. Myers, W. J. Swiatecki, T. Kodama, L. J. El-Jaick, E. R. Hilf, Phys. Rev. C15, 2032(1977).
4. L. G. Moretto, J. Sventek, G. Mantzouranis, Phys. Rev. Lett. 42, 563(1979).

FIGURE CAPTIONS

- Fig. 1. The stiffness constant for the oscillation of the charge excess is plotted against the degree of symmetry for $A = 100$. The dashed curve corresponds to the liquid drop potential for two touching spheres. The solid curve corresponds to the cylinder model for the lowest mode. The contributions of the Coulomb energy have been included for both.
- Fig. 2. The square of the normalized partial width is plotted (a) against the degree of symmetry at fixed n (b) against n at a fixed degree of symmetry.
- Fig. 3. The sum of the squares of the normalized partial width up to $n_{\max}$ is plotted against the degree of asymmetry.

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Fig. 1

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Fig. 2b

Fig. 2a

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Fig. 3

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