EFFECT OF PHONON EXCITATIONS OF NUCLEI ON THE CHARACTERISTICS OF GIANT PHOTOABSORPTION RESONANCE

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The effect of surface (phonon) excitations of a nucleus on the position and width of the collective dipole state is investigated. It is shown that phonon excitations are among the main sources of "friction" accompanying dipole oscillations of nuclei. Calculations are made for the Pb^{208} nucleus.

THE successful use of the shell model to explain the position of the giant resonance of photoabsorption in heavy and medium charges [1-3] has shown that the residual interactions between nucleons (pair correlations) play a decisive role in the formation of the collective dipole excitation of the nucleus.

It is known, however, that a strong bond exists in heavy nuclei between the nucleon single-particle motion and the surface oscillations of the nucleus —phonon excitations. To include the excitations of these collective degrees of freedom, the Hamiltonian of the nucleus should be represented in the form

$$H = H_0 + V + H_s + H_{sp},$$

where H_0 is the average single-particle potential, V is the potential of the paired residual interaction between nucleons, H_s is the energy of the surface oscillations, and H_{sp} is the interaction between the particle and the surface.

Thus, diagonalization of only the shell part of the total Hamiltonian $H_{shell} = H_0 + V$ is known not to give all the excited nuclear states that give rise to the giant resonance. In addition to states of the "particle-hole" type $|j_1^{-1}j_2:1^-\rangle$, an appreciable contribution to giant resonance is made also by single-phonon and multiphonon excitations, which are strongly mixed with the pure single-particle states. The question arises, how does this mixing influence the position and the width of the giant resonance.

Perturbation theory cannot be used here, for we deal with a chain of strongly coupled equations. The answer can be obtained in principle by diagonalizing the Hamiltonian H over the entire set of states $|j_1^{-1}j_2, NR:1^-\rangle$ (N is the number of the phonons and R their total momentum). Here, however, the order of the matrix would be appreciably larger than 100.

Another way is to use the generator procedure for constructing the collected dipole state, as proposed previously [2]. The wave function $\psi_{dip} \sim \hat{D}\Psi_0$, obtained by the action of the nuclear dipole-moment operator on the wave function of the ground state, describes the macroscopic characteristics of the giant resonance—its position and width.

Let us take the simplest abstract scheme and consider what effects can be expected when the phonon excitations are taken into account. Namely, we assume: a) that there exists a single shell level of photoabsorption E_0, and b) that the level E_0 is connected with the only single-phonon state by the interaction between the particle and the surface; the magnitude of the interaction is a, and the phonon energy is $\hbar\omega$ (in heavy nuclei, both a and $\hbar\omega$ are considerably smaller than E_0).

In the basis of the unperturbed states, Ψ_{dip} and H have the form

$$\Psi_{dip} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad H = \begin{vmatrix} E_0 & a \\ a & E_0 + \hbar\omega \end{vmatrix}.$$

From this we can readily obtain [$\sigma(E)$ is the photoabsorption cross section]

$$\bar{E} = \langle \Psi_{dip} | \hat{H} | \Psi_{dip} \rangle \equiv \int E\sigma(E)\, E^{-1} dE \Big/ \int \sigma(E)\, E^{-1} dE = E_0,$$

$$E_{dip} = \frac{1}{\bar{E}} \langle \Psi_{dip} | \hat{H}^2 | \Psi_{dip} \rangle$$

$$\equiv \int E\sigma(E)\, dE \Big/ \int \sigma(E)\, dE = E_0 + \frac{a^2}{E_0},$$

$$\Delta'^2 = \langle \Psi_{dip} | (\hat{H} - \bar{E})^2 | \Psi_{dip} \rangle = a^2,$$

$$\Delta^2 = \frac{1}{\bar{E}} \langle \Psi_{dip} | (\hat{H} - E_{dip})^2 \hat{H} | \Psi_{dip} \rangle$$

$$= a^2 \left[1 + \frac{\hbar\omega}{E_0} - \left(\frac{a}{E_0} \right)^2 \right].$$

Thus, the mean energy $\bar{E}$ does not change, the center of gravity of the absorption curve E_{dip} shifts by a small amount a^2/E_0, and the dispersion Δ^2 of the absorption curve is approximately equal to the square of the coupling constant a^2 and is very close to the dispersion Δ'^2 calculated from the $\sigma(E)/E$ curve.

The same result is obtained in a somewhat more complicated scheme, where we consider many single-particle transitions, but the single-particle levels are assumed to be degenerate, and the matrix elements of the residual interaction V are connected in unique fashion with the coefficients of the expansion of Ψ_{dip} in the single-particle functions:

$$V_{\lambda\lambda'} \sim \alpha_\lambda^+ \alpha_{\lambda'}$$

(if the phonons are not taken into account, this condition guarantees the presence of isolated photoabsorption resonance [2,4]). In this case

$$\bar{E} = E_0 + n\bar{V}, \quad E_{dip} = E_0 + n\bar{V} + a^2/(E_0 + n\bar{V}), \quad \Delta'^2 = a^2$$

(n is the number of single-particle excitations and $\bar{V}$ is the average matrix element of the pair interaction potential).

The actual calculations were made for the Pb^{208} nucleus. The parameters of the interaction between the particle and the "hole" with the surface were taken from the paper of Sliv, Sogomonova, and Kharitonov [5]. The calculation leads to the following results

	E_{dip}, MeV	Δ^2, MeV^2
Without account of phonon excitations[1,2]	13.4	2.7
With account of phonon excitation	13.6	5.2
Experiment[6]	13.5—14.0	4.5—5.0

We can thus draw the following conclusions:

1) Phonon excitations of the nucleon hardly affect the position of the giant photoabsorption resonance.

2) Phonon excitations must be included in the explanation of the width of the giant resonance. Their contribution to the dispersion of the dipole state is on the order of the square of the particle-surface coupling constant.

In the language of the hydrodynamic model [7] this means that the phonon excitations of the nucleus are one of the principal sources of the "friction" accompanying the dipole proton-neutron oscillations of nuclei.

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