THE NUCLEUS EXCITATION BY ELECTRON INELASTIC SCATTERING

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It is supposed to describe the dipole resonance with the help of the shell model, and the quadrupole resonance – with the help of the dynamic collective theory with the aim of the explanation of the simultaneous appearance of the giant dipole and quadrupole resonance in nuclei at the inelastic electron scattering in experiment. Moreover, Tassi model is used for the oscillation of the surface of nucleus shell. The matrix element of transition of excited nucleus is calculated in distorted-wave approximation. The form-factors of dipole and quadrupole excitations had been calculated for ^{60}Ni nucleus. The GDR and GQR energies and also deformation parameters at the proton and neutron transition in nucleus are defined.

The inelastic electron scattering on the nuclei at the different energies allows us to study comprehensively angular, energetic, mass and other distribution of particles-products, energy of final nucleus and canals of its decay. The carried out analysis of these large body of data allows to achieve the real information about nucleus construction.

In experimental works on the inelastic electron scattering on the nuclei it is established, that the prominently expressed maximums, which are called as giant dipole, quadrupole and monopole resonances are observed in energetic and angular dependencies of the cross-section of this process. Also resonances of more high multipolarities are observed in some nuclei [1].

The explanations of experiment data on the excitation mainly of giant resonances were carried out in frameworks of half-classis hydrodynamic and shell nuclear models. The join development of both approaches allows us to describe not only formation processes of giant multipole resonances at inelastic electron scattering on nuclei, but the canals of the decay of giant resonances in reactions with the emanation of different particles.

After the appearance of giant resonances, the nucleus is in the strongly excitated state, i.e. the nucleus heats. At the taking away of the introduced excitation in evaporation form, the nucleus emanates the separate nucleons and their combinations. The nucleus with most probability emanates the one nucleon, the nucleus with low probability emanates two and more number nucleons and moreover, the process of nucleus cooling is carried out.

The cross-sections of giant dipole and quadrupole resonances for light and average nuclei are achieved by the sum of emanated neutrons and protons.

The ratio of cross-sections of reactions with nucleon emanations depends on structure of giant dipole resonance (GDR) and giant quadrupole resonance (GQR), i.e. on width, energetic state and resonance amplitude.

Thus, we can conclude, that detail definition of main parameters of GDR and GQR (state, value and form) for different nuclei allows us to do the right choice about decay production of final nucleus.

That's why we use the theory of distorted-wave high-energetic approximation (DHEA), developed in [2] for the inelastic electron scattering on nuclei with the aim of the exact calculation of amplitude of process of inelastic electron scattering on nuclei. The workings out this theory for real type of charge densities show, that this theory works to a high accuracy [3].

For the study of giant resonances the transition matrix element is written in following form [2]:

$$T_{if} = -4\pi e^2 < f\left|\sum_{\alpha=1}^{A}\frac{1-\tau_z}{2}D(\mathbf{x}_\alpha)\rho(\mathbf{x}_\alpha)\ell^{i\mathbf{q}\mathbf{x}_\alpha}d\mathbf{x}_\alpha\right|i> \quad (1)$$

Here

$$D(\mathbf{x}_\alpha) = \frac{R(\mathbf{x}_\alpha)}{q_{eff}^2(\mathbf{x}_\alpha)}. \quad (2)$$

For the calculation of (1) the nucleus will be considered as the system, consisting on the nucleon and core. Moreover, nucleon transition on the one from high-excitated states will reveal the effective electric charge, taking under the consideration the relative movement of nucleon with mass m_N, charge $(1-\tau_z)/2$ and radius-vector $\mathbf{x}_1$ and the core with mass $m_N(A-1)$, charge $Z-(1-\tau_z)/2$ and radius-vector $\mathbf{x}_{ост}$, where radius is vector of the inertion center of nucleus is expressed as $\boldsymbol{R}_0=\{\mathbf{x}_1+\mathbf{x}_{ocm}(A-1)\}/A$.

Further, expressed in (1) the coordinates of particles through relative coordinate of particle-shell, we have the possibility to write the transition matrix element in the form of sum of matrix element of single-particle transition

$$T_{if}^{час} = -4\pi e^2 < f\left|\int D(\mathbf{x}')\rho_{час}(\mathbf{x}')\ell^{i\mathbf{q}\mathbf{x}'}d\mathbf{x}'\right|i.> \quad (3)$$

and transition matrix element of nucleus core -

$$T_{if}^{ocm} = -4\pi e^2 < f\left|\int D(\mathbf{x}'')\rho_{ocm}(\mathbf{x}'')\ell^{i\mathbf{q}\mathbf{x}''}d\mathbf{x}''\right|i> \quad (4)$$

Where $\mathbf{x}'=\varepsilon_h\mathbf{x}$, $\mathbf{x}''=\varepsilon_{sh}\mathbf{x}$, here $\mathbf{x}=\mathbf{x_1}-\mathbf{x}_{sh}$ defines the relative state of nucleon and core

$$\varepsilon_{час} = \frac{1-\tau_z}{2}\frac{A-1}{A} \quad (5)$$

-effective charge of nucleon,

$$\varepsilon_{ocm} = (Z - \frac{1-\tau_z}{2})(-\frac{1}{A}) \quad (6)$$

- effective electric charge of nucleus core.
- At the calculation of (3) the wave functions of beginning and final states of nucleons are expressed in the form

$$\frac{1}{2} u_{nlj}(x') \sum_{\mathbf{m_l} m_s} < lm_l \frac{1}{2} m_s \Big| jm > i^l \mathrm{Y}_l(\theta.\varphi)\chi_{1/2}(m_s)\,, \quad (7)$$

which are solutions of Schrödinger equation with oscillated potential.

The Danos and Grainer dynamic collective theory (DCT), joined with Tassi model [2], in which it is supposed, that spherical core surface in excitated state deforms vacillating with the aim of study of giant multipole resonances in excited nucleus core. The elementary excitations, appearing at the movement of protons relatively neutrons, are carried out with the oscillation frequency of surface of nucleus core.

In this theory the total proton (neutron) density are present in the form of sum of equilibrium density and fluctuation density, responsible for transitional part of density, which has the form

$$\rho^{tr}(\mathbf{x}'',t) - \sum_{\lambda\mu} \alpha_{\lambda\mu}(t)\rho_{\lambda\mu}(x'')\mathrm{Y}^*_{\lambda\mu}(\hat{x}'')\,. \quad (8)$$

Here $\alpha_{\lambda\mu}$ is parameter, defining the form of distribution of nucleon density on the surface of nucleus core.

The radial multipole transitional density $\rho_{\lambda\mu}(x'')(\mu=0)$ has the form [2].

$$\rho_\lambda(x'') = \frac{\nabla_x x''^{\lambda+k_\lambda}}{(\lambda+k_\lambda)c^{\lambda+k_\lambda-2}} \nabla_x^{(\lambda)} \rho_p(x'')\,, \quad (9)$$

where $k_\lambda = 2\delta_{\lambda 0}$

$$\nabla_x^{(\lambda)} \rho_p(x'') = x''^{-3} \nabla_{x''}[x''^3 \rho_N(x'')] \quad \lambda = 0$$

$$= \nabla_{x''} \rho_N(x'') \quad \lambda \geq 1\,. \quad (10)$$

The distribution of nucleon density in nucleus in equilibrium state is chosen in Fermi function form:

$$\rho_N(x'') = \rho^{(0)} \frac{sh\, {}^c\!/_d}{ch\, {}^c\!/_d + ch\, {}^{x''}\!/_d} \quad (11)$$

where $c = 1.05A^{1/3}(Fm)$.

The final expression for the cross-section of inelastic electron scattering is expressed through the given transition probabilities

$$\sigma_{i\to f} = (2e^2 k\cos\theta/2)^2 \frac{2j_f+1}{2j_i+1}\{B(j_i \to j_f) + \sum_\lambda \frac{B(E\lambda)}{2\lambda+1}\} \quad (12)$$

Where

$$B(j_i \to j_f) = \left| \int D(\mathbf{x}')\ell^{i\mathbf{qx}'} u_f(\mathbf{x}')u_i(\mathbf{x}')d\mathbf{x}' \right|^2 \quad (13)$$

-is given single-particle transition probability, and

$$B(E\lambda) = \left| \alpha_\lambda \int D(\mathbf{x}'')\rho_\lambda(\mathbf{x}'')\ell^{\mathbf{iqx}''} \mathrm{Y}_{\lambda 0} d\mathbf{x}'' \right|^2 \quad (14)$$

-is given transition probability of nucleus core.

Here

$$\alpha_\lambda = \sqrt{\frac{\hbar\omega_\lambda}{2C_\lambda}} \quad (15)$$

$$\hbar\varpi_\lambda = \hbar\sqrt{\frac{C_\lambda}{B_\lambda}}\,. \quad (16)$$

We obtain the following expressions for so-called hardness parameter C_λ and mass parameter B_λ with the help of DCT.

$$C_\lambda = 8K \int \frac{\left|\rho_\lambda(x'')\mathrm{Y}^*_{\lambda 0}\right|^2}{\rho_N(x'')} d\mathbf{x}'' \quad (17)$$

Here K is constant in mass Bete-Weizzekera formula.

$$B_\lambda = \frac{m_N ZN}{\lambda c^{\lambda-2} A^2} \rho^{(0)} \int \left|\nabla\rho_\lambda(x'')\mathrm{Y}^*_{\lambda 0}\right|^2 d\mathbf{x}''\,. \quad (18)$$

The mechanisms of appearance of giant dipole and quadrupole excitations are considered in ^{60}Ni nucleus.

The subshells of different parity are in complex nuclei inside the external shell, that's why the transitions can be between subshells inside the one shell and between subshells of neighbour shells, i.e. the change of parity is need at the single-particle dipole transition. That's why in ^{60}Ni nuclei, if the final proton participates in single-particle transition, so $1f_{7/2} \to 1g_{9/2}$ takes place, if final neutron participates, so $3P_{3/2} \to 2d_{5/2}$ takes place.

The energy of single-particle level of harmonic oscillator with spin-orbital interaction is defined with the help of following known expression.

$$E_{nlj} = \frac{\hbar^2}{ma^2}(2n+l+3/2) - 20\mathbf{ls}A^{-2/3}\,. \quad (19)$$

The oscillator parameter a is free at the calculation of cross-section process.

The form-factors of dipole and quadrupole resonances in ^{60}Ni nucleus have been calculated for the electron scattering with incident energy 200 MeV. Moreover, the nucleus characteristics parameters at proton and neutron nucleus transitions are defined correspondingly.

p-transition: $\hbar\omega_1$=16.2 MeV, $\hbar\omega_2$=14.1 MeV, deformation parameters α_2 = 0.19.

n-transition: $\hbar\omega_1$ = 20.1 MeV, $\hbar\omega_2$ = 10.3, α_2 = 0.16.

As it is seen, the values of energy of quadrupole resonances, appearing in excited core, are less, than values of energies of dipole resonances, obtained as in proton transition, so in neutron one.

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ВОЗБУЖДЕНИЕ ЯДЕР НЕУПРУГИМ РАССЕЯНИЕМ ЭЛЕКТРОНОВ

С целью объяснения одновременного появления в эксперименте гигантских дипольных и квадрупольных резонансов в ядрах, при неупругом рассеянии электронов, предлагается дипольный резонанс описывать с помощью оболочечной модели, а квадрупольный – динамической коллективной теорией. При этом для колебания поверхности остова ядра применяется модель Тасси. Матричный элемент перехода возбужденного ядра вычислен в искаженно волновом приближении. Форм-факторы гигантского дипольного и квадрупольного возбуждений были рассчитаны для ядра ^{60}Ni. Определены энергии ГДР и ГКР, а также параметры деформации при протонном и нейтронном переходах в ядре.

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ELEKTRONLARIN QEYRİ -ELASTİKİ SƏPİLMƏSİLƏ NÜVƏLƏRİN HƏYƏCANLAŞMASI

Təcrübədə elektronların nüvədən qeyri-elastiki səpilməsi zamanı onlarda dipol və kvadrupol nəhəng rezonanslarının yaranmasının nəzəri izahı təbəqəli nüvə modeli və dinamik kollektiv nəzəriyyə əsasında verilmişdir. Nüvə özəyinin səthinin rəqsinin izahı üçün Tassi modelindən istifadə olunmuşdur. ^{60}Ni nüvəsində yaranmış NDR və NKR – ın enerjisi, həmçinin həyəcanlaşma zamanı proton və neytron keçidlərində deformasiya parametrləri təyin edilmişdir.

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