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Электровозбуждение гигантских мультипольных резонансов в ^{90}Zr

В рамках полумикроскопической модели изучается электровозбуждение уровней гигантского резонанса в ^{90}Zr. Вычисления проводились как в однофононном приближении, так и с учетом фрагментации уровней. Результаты обоих вычислений согласуются в пределах экспериментальных ошибок. С этими же параметрами вычислено дифференциальное сечение нижайшего 2^+ уровня. Удовлетворительное согласие с экспериментом в широкой области ядерных возбуждений и электронных переданных импульсов подтверждает корректность рассматриваемой полумикроскопической модели.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Electroexcitation of Giant Multipole Resonances in ^{90}Zr

The electroexcitation of giant multipole resonances in ^{90}Zr is studied within the semimicroscopic model. The calculations were performed using both the one-phonon approximation and fragmentation procedure. Both calculations are well within experimental errors. The same parameters were used to calculate electron scattering on the lowest 2^+ level. A satisfactory agreement demonstrates the validity of the treated model in a broad interval of nuclear excitations and electron momenta transfer.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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1. INTRODUCTION

A possibility of the adequate theoretical description of the nuclear giant multipole resonances is of great interest. One of the powerfull tools for this purpose is an inelastic electron scattering/1/. These experiments give enough information for the determination of the nuclear transition density. On the other hand, it can be calculated using a specific nuclear model. So, there is a possibility to check this model.

In the present work the nuclear charge transition densities of the giant E1 and E2 resonances in ^{90}Zr are calculated in the framework of the well-known semimicroscopic model/2/. Using these densities the differential inelastic electron cross sections are obtained within the phase analysis method/3/. First the calculations were performed using the one-phonon approximation. At the latter stage the level fragmentation was taken into account. The fragmentation results in 10-15% decreasing of the one-phonon differential cross sections, although both are within the experimental errors. The same set of parameters was used to describe the electron excitation differential cross section of the lowest 2^+ level. A reasonable agreement with experiment supports the universality of the treated model (i.e., its applicability for both small and large excitations).

2. ONE-PHONON APPROXIMATION

The transition density, corresponding to the excitation of the level with the angular momentum L is

$$\rho_L(r) = \langle \Psi_f \| \hat{Q}_L \| \Psi_i \rangle ,$$

where

$$\hat{Q}_{LM}(r) = \sum_{\alpha\beta} \langle \alpha \,|\, O_{LM} \,|\, \beta \rangle a^+_\alpha a_\beta$$

$$O_{LM}(r) = \sum_{i=1}^{z} \frac{\delta(r - r_i)}{r^2} Y^*_{LM}(\vec{r}_i) .$$

Here Ψ_i, Ψ_f are the wave functions of the initial and final nuclear states. Using the RPA method one easily obtaines the transition density for the one-phonon state. The calculational results for some of the most strong levels are presented in fig. 1. In the same figure the densities of the Tassie hydrodynamical model are drawn, which were used in ref./5/ to fit the electroexcitation of the E1 giant resonance with an energy of 16.65 MeV and E2 resonance with an energy of 14.0 MeV. These calculations show that the maximum of the dipole transition density is shifted relatively to the quadrupole one by about 0.5 fm to the large radii. The model under consideration reproduces this result remarkably well. The observed E2 resonance is described by the two one-phonon levels: E_1 = 13.7 MeV and E_2 = 14.0 MeV (fig. 2). The excitation form factors squared for these levels, their sum, and experimental data are plotted in the left side of fig. 3. Whereas in the right side similar results are given for the E1 resonance. One observes an excellent agreement with the experimental data. Note that the calculational procedure did not contain any fitting parameters. All parameters of the used semimicrosco-

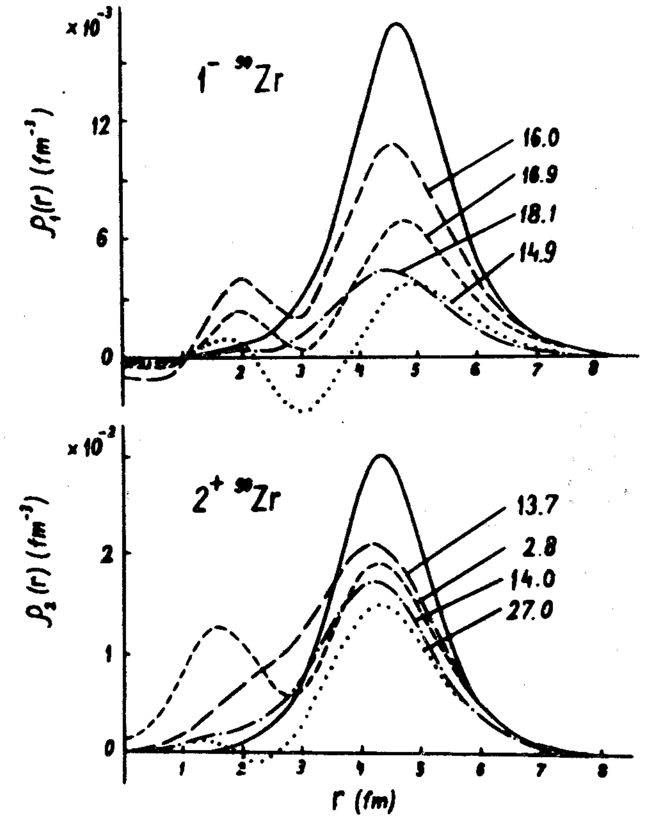

Fig. 1. Transition densities for the strongest one-phonon 1^- and 2^+ levels of the giant resonance region in ^{90}Zr. The numbers near the curves are the energy (in MeV) of these levels. The solid curves are phenomenological transition densities of the Tassie model applied in ref./5/ to the description of the giant resonances in the treated nucleus. The transition density for the lowest 2^+ level is drawn for comparison.

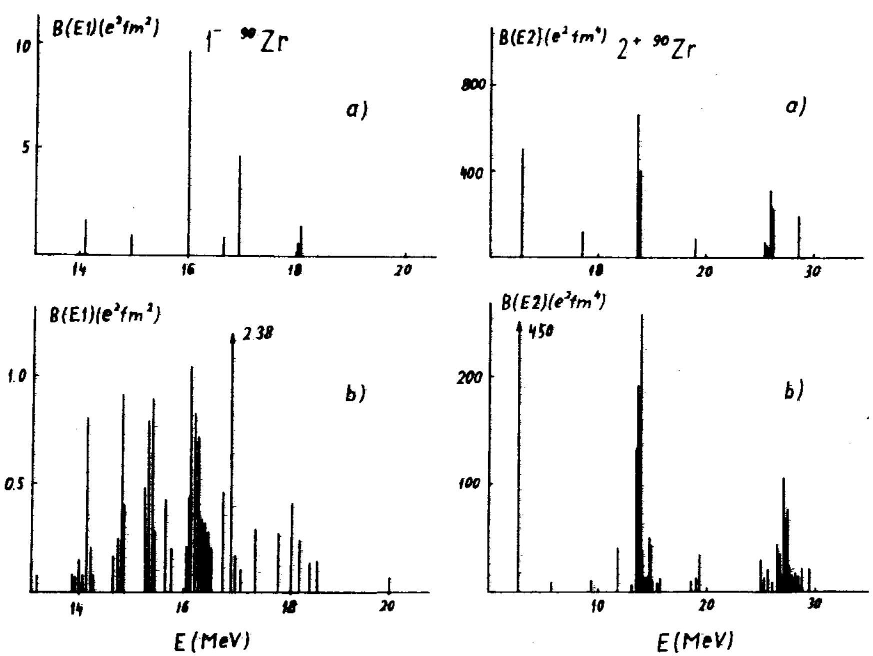

Fig. 2. The strengths of the E1 and E2 transitions calculated in ref. [4] in one-phonon approximation (at the top) and by using the fragmentation procedure (at the bottom).

pic model (the average field, pairing, isoscalar and isovector constants) were exactly the same as in ref. [4]. The parameters of the ground state density were taken from the electron scattering experiments.

3. THE FRAGMENTATION EFFECTS

The quasiparticle-phonon interaction results in the fragmentation of the one-phonon states. The wave function of the excited state is given by [4]:

$$\Psi_\nu (JM) = \{ \sum_i R_i^\nu (J) Q^+_{JMi} + \sum_{\substack{\lambda_1 \lambda_2 \\ i_1 i_2}} D^{\lambda_1 i_1}_{\lambda_2 i_2} (J) [Q^+_{\lambda_1 \mu_1 i_1} \; Q^+_{\lambda_2 \mu_2 i_2}]_{JM} \} \Psi_0 ,$$

where Q^+_{JMi} is the creation phonon operator. The secular equation for the energies and the coefficients R and D may be found in ref. [7]. These calculations show that the giant E1 resonance composed in the one-phonon approximation from seven levels in the energy interval from 14 to 18 MeV, is spreaded over few tens of levels, whereas two levels of the E2 resonance are spreaded over a large number of states in the interval from 14 to 18 MeV. The calculations of the transition densities and form factors for such a great amount of levels require too much computer time. The situation is happily saved due to the fact, that one-phonon levels giving the

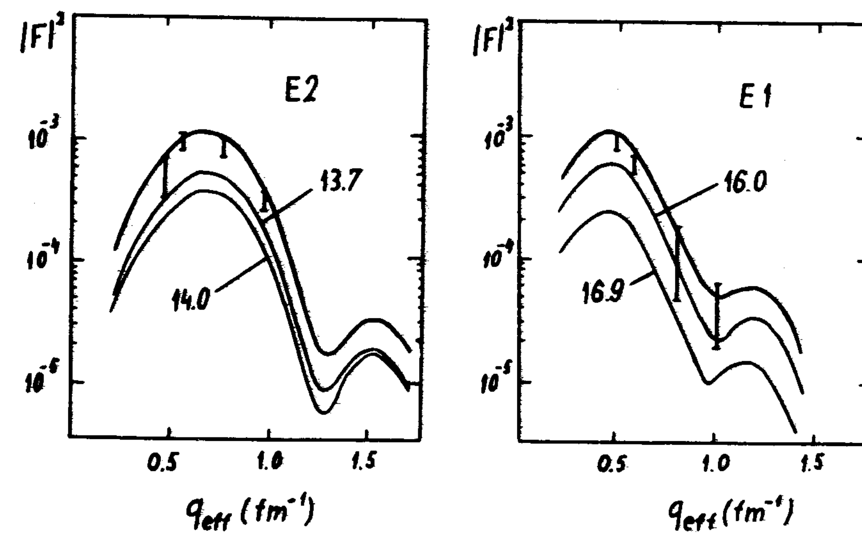

Fig. 3. Form factors squared for the strongest one-phonon levels of the giant E1 and E2 resonances. The upper curves were obtained when all the levels of the giant resonance region were taken into account. The experimental data are from ref. [5].

main contribution to the giant resonance have approximately the same (up to normalization) transition densities (fig. 1). As the transition density of the fragmented state is a linear combination of the one-phonon densities, the form (not the magnitude) of the transition densities is the same for all fragmented states. After these preliminaries the differential cross section for the excitation of the giant resonance is equal to

$$\frac{d^2\sigma}{d\Omega\, d\omega} = \overline{\left(\frac{d\sigma}{d\Omega}\right)}_{\omega} b(EL,\omega), \tag{3.1}$$

where $\overline{\left(\frac{d\sigma}{d\Omega}\right)}_{\omega}$ is the differential cross section of the strong level nearest to the energy ω. Calculations show that all strong levels of the giant resonance have approximately the same (up to normalization) differential cross-sections (form factors). This is shown in fig. 3., $b(EL,\omega)$ is the strength function of the giant resonance

$$b(EL,\omega) = \frac{1}{2\pi} \sum \frac{B_i(EL)\Delta}{(\omega-\omega_i)^2 + \Delta^2/4}.$$

This quantity may be obtained without calculating the energies and the wave function for each of the individual levels /4/. There are additional arguments /8/ in favour of (3.1). These are due to the fact, that the details of the transition densities structure are not very important for distances less than L/q_{max} (where L is transition multipolarity, q_{max} is the greatest momentum transfer observed in experiment). Finally, note that (3.1) assumes the equality of the electron energy losses for energy level, contributing to the giant resonance. As the average electron energy is about 100-200 MeV and the average width of the giant resonance is about 4 MeV, this assumption practically is fulfilled. Summing in (3.1) over all levels in the interval from 12 to 16 MeV for the quadrupole giant resonance and in the interval from 14 to 18 MeV for the dipole one, one obtaines the

differential inelastic electron cross sections (fig. 4). These cross-sections taking into account the fragmentation effects, are not very far from the one-phonon cross-sections. Both are within the experimental errors. Quantitatively, this is illustrated in Table 1, where the total reduces probabilities (calculated with or without fragmentation) are presented for every energy interval. In the same Table one may find the B(E2) value for the lowest 2^+ level /4/. The angular distribution of the electrons, scattered by this level is shown in fig. 5. The experimental data are taken from ref. /9/. Although the parameters of the given model were the same as for the giant resonance region, the agreement with experiment is quite satisfactory.

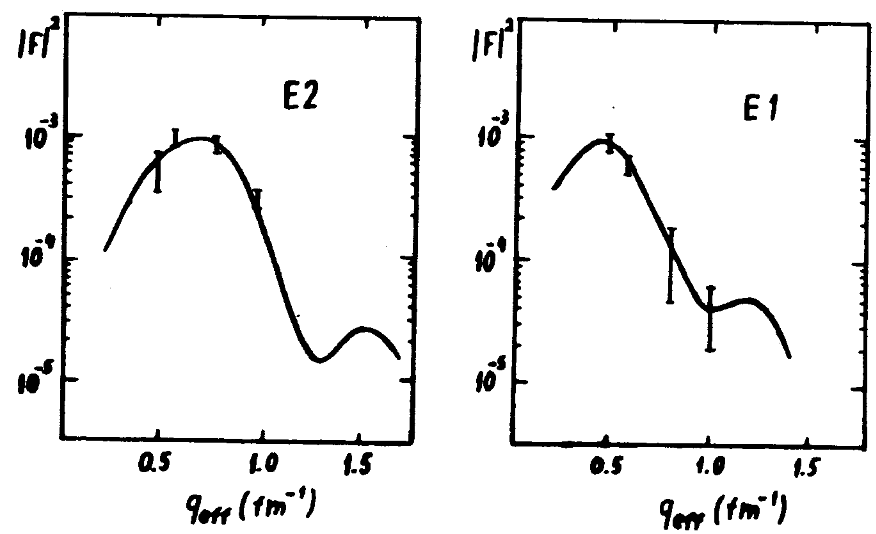

Fig. 4. Form factors squared for the E1 and E2 resonances when fragmentation was taken into account.

Table 1

I^{π}	ΔE (MeV)	$\Sigma B(EL)$ 1ph approx.	$\Sigma B(EL)$ with fragm.	$\Sigma B(EL)$ exp.
1^-	13-15	19.6	18	17 ± 5
2^+	12-16	1085	955	990 ± 300
2^+	2.186	540	450	720 ± 90

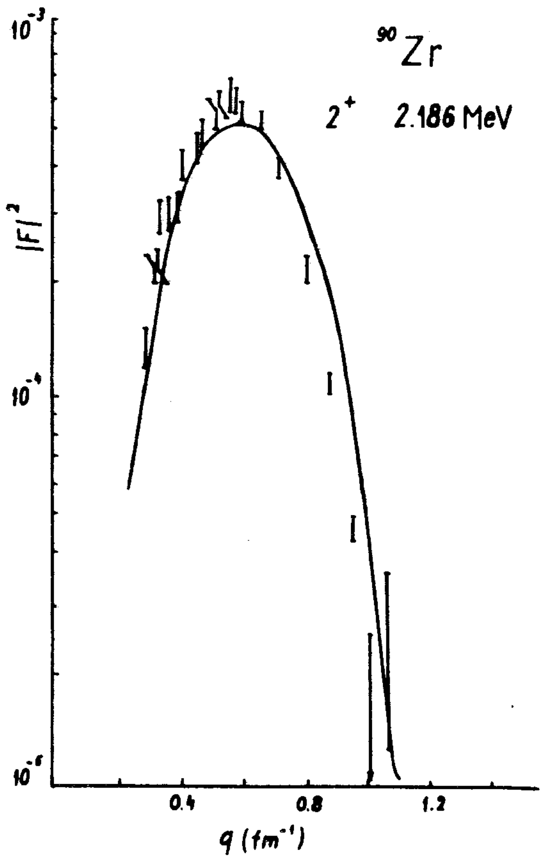

Fig. 5. Form factor squared of the lowest 2^+ level in ^{90}Zr. The parameters of the semimicroscopic model are the same as for giant resonance region. The experimental data are from ref. /9/.

4. CONCLUSION

The present calculations show the validity of the considered semimicroscopic model for very broad interval of the nuclear excitations and electron momentum transfer. Its correctness for the description of the electromagnetic transition probabilities was clearly demonstrated earlier in ref. /10/.

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