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ON MI AND M2 STRENGTHS IN ^{140}Ce

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О M1- и M2-резонансах в ^{140}Ce

Проанализированы имеющиеся в литературе теоретические и экспериментальные данные о распределении силы M1- и M2-переходов в ядре ^{140}Ce при энергии возбуждения $E_x < 10$ МэВ. В рамках квазичастично-фононной модели ядра рассчитаны в приближении искаженных волн сечения возбуждения и формфакторы однофононных 1^+- и 2^--состояний и показано, что имеющиеся экспериментальные данные по (e,e')-рассеянию не противоречат присутствию в ядре ^{140}Ce заметной M1-силы. Указывается, что для выделения 1^+-состояний на фоне 2^--состояний необходимо выполнить измерения для меньших энергий электронов и меньших углов рассеяния, чем это было сделано Рихтером и др.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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On M1 and M2 Strengths in ^{140}Ce

Now one of the most interesting problems in the theory of GMR is the existence of the M1 resonance in medium and heavy atomic nuclei.

The simplest theoretical considerations [1] based on the nuclear shell structure predict the existence of 1^+ states with a large excitation probability from the ground state in nuclei. More refined models [2-7] predict that the excitation energy of these states in medium and heavy atomic nuclei is $6 \div 10$ MeV. Some experimental data, though not very reliable, seemed to confirm these assumptions [8-11]. However, the precise experiments on the inelastic scattering of slow electrons at large angles [12,13] threw doubt upon a pronounced concentration of the M1 strength at energies $E_x < 10$ MeV in nuclei with $A > 100$. For ^{208}Pb these results have been confirmed in the (γ, n) experiments [14]. The attempts [6,7,12,15,16] to explain "disappearance" of the M1 resonance by the interaction of 1p-1h states with more complex configurations are either unsuccessful,either disagree with recent experimental results or are of a preliminary nature.So far,there is no generally accepted explanation of these data.

Since the data on the (e,e')-scattering have been analyzed within the MSI model [13,17], it is instructive to study to what extent the results of the analysis depend on the assumptions of this model and to compare its predictions with those of other models. In this paper we shall analyse the data of ref. [13] on ^{140}Ce within the quasiparticle-phonon nuclear model (QPM) [6,18,19].

The nucleus ^{140}Ce is one of the nuclei in which the experimental data seemed to testify to the existence of the M1 resonance.The first indications,though very uncertain,have been obtained in the (e,e')-scattering [9]. These data are in agreement with the results of the (γ, n)-experiments [11] in which an anomalously large value of M1 radiative strength function $\langle k(M1) \rangle$ in ^{140}Ce has been found at the neutron binding energy. It is important that the same increase in $\langle k(M1) \rangle$ has also been observed in the neighbouring nuclei [10]; this was interpreted as a result of location of the M1 resonance near B_n in nuclei with $A \simeq 140$ [20]. However, in precise experiments of Richter et al. [13] in ^{140}Ce the states with $J^\pi = 1^+$ have not been observed. In the excitation energy region under study there were observed the 2^--states.

What are the theoretical predictions on the distribution of M1 and M2 strength in ^{140}Ce? The results of calculation of M1 and M2 resonances in this nucleus within the QPM [5,6,19], the theory of finite Fermi system [3,4] and MSI model [13,31] are given in the table. These results are obtained within the RPA. This table

Table

Experimental data and theoretical results for M1 and M2 resonances in ^{140}Ce

M1	E_x MeV	$B(M1)\,\mu_0^2$	g_s^*/g_s^{free}
exp. [9]	8.7 ± 0.3	35.5 ±17.8	-
theor. [5]	8.76	12.0	0.8
theor. [3]	8.42	11.5	n 0.44 p 0.37
		8.2	n 0.37 p 0.33
M2	ΔE_x MeV	$\Sigma B(M2)\,\mu_0^2$ fm ^{2}	g_s^*/g_s^{free}
exp. [13]	7.5 ÷ 10	6000 ± 600	-
theor. [19]	7.5 ÷ 10	4500	0.8
theor. [13]	7.5÷10	15100	1.0

also shows the experimental data, including those of Pitthan and Walcher [9] which have not been confirmed in the recent (e,e′)-experiments. Note, the theory predicts a considerably lesser B(M1)-value than that obtained in ref. [9]. The interaction with complex configurations studied in some nuclei with $A \simeq 140$ [6,20] does not cause a strong spreading of the M1-resonance in ^{140}Ce. The strength of M1-transitions turns out to be concentrated in the interval $\Delta E_x \simeq 1$ MeV at $E_x = 8.4$ MeV, one of the 1^+-states with energy $E_x = 8.45$ MeV having $B(M1) = 8.3\mu_0^2$. The main part of M2-strength is also concentrated at

these energies; however the M2-resonance is formed by many 2^--states in the interval $\Delta E_x = 3 \div 5$ MeV [19,21]. Thus, the M1- and M2-resonances are overlapped.

Now consider a probability for the one-phonon 1^+- and 2^--states in ^{140}Ce to be excited in the inelastic scattering of electrons. Figure 1 shows the differential cross sections of the (e,e′)-scattering with an electron energy E_0=50 MeV at different angles with excitation of 1^+- and 2^--states. The cross sections are calculated by the DWBA [22]; the expression for the nuclear current operator has been taken from ref. [23]. The wave functions of the 1^+- and 2^--states have been calculated in the RPA in the framework of the QPM. These wave functions have been used to calculate B(M1)- and B(M2)-values given in the table (see also refs. [6,19]). Note, the differential cross sections of electron scattering have been calculated for the same electron energies and scattering angles as in the experiment of the Darmstadt group [13]. Figure 1 shows that though the probability of excitation of the one-phonon 1^+ state in the order of magnitude coincides with that of individual one-phonon 2^--states, its contribution to the total cross section in the interval $7.5 < E_x < 10$ MeV is small due to a large number of 2^- states in this interval. A rapid decrease of the

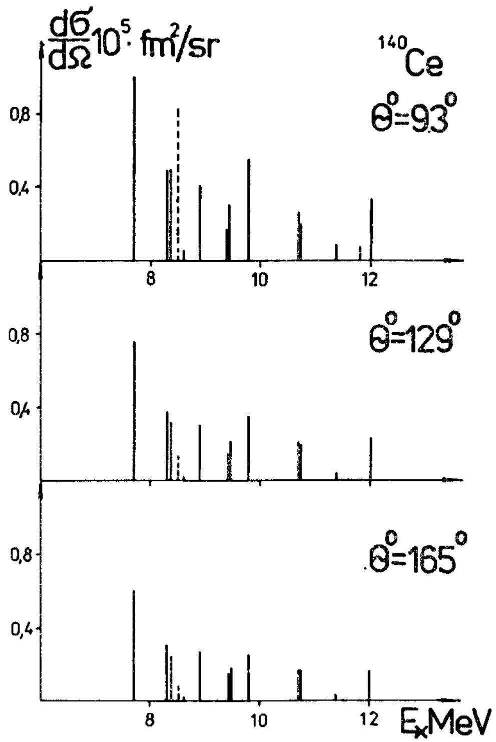

Fig.1. Differential cross sections of excitation of one-phonon 1^+ states (dashed line) and 2^- states (solid line) in ^{140}Ce in the inelastic electron scattering (E_0= 50 MeV) at different angles θ.

excitation cross section of the 1^+ state in comparison with the 2^- state with increasing scattering angle θ is also important. As a result, at $\theta^\circ=165^\circ$ the contribution of the 1^+ state to the total cross section is negligible. The reason is different behaviour of the transitional densities of 1^+- and 2^--states, the first being of the surface nature and the second of the volume nature.

In ref.[13] the spin and parity of excited states have been determined by comparing the experimental form factor with the form factors of different states calculated within the MSI model. Figure 2 shows the from factors of 1^+ and 2^- states cal-

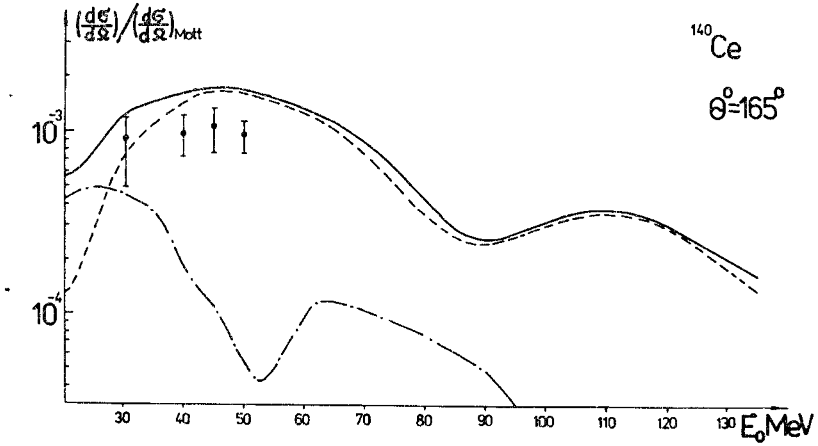

Fig.2. Form factors of one-phonon 1^+ states (dash-dotted line) and 2^--states (dashed line) in the excitation energy interval $7.5 < E_x < 10$ MeV. The solid line is the sum of M1 and M2 form factors. The experimental points are taken from ref.[13].

culated within the QPM. The M2 form factor is a sum of form factors of all one-phonon 2^- states in the interval $7.5 < E_x < 10$ MeV. Figure 2 also shows the experimental points from ref.[13]. As well as in the calculations within the MSI model, just the M2 form factor is similar to the experimental one. However, in ref.[13] the absolute value of the theoretical form factor has beer normalized by the experimental data, and in our calculations its absolute value is automatically obtained at the same values of g_s^* as the B(M2)-probability (see the table). The sum of M1 and M2 form factors (see fig.2) also is in satisfactory agreement with the experimental data. The sum of form factors does not decrease so sharply at small energies E_0 as the M2-form factor; this is in better agreement with the experimental data. At $E_0>60$ MeV the dashed and solid curves almost coincide owing to a rapid decrease in the M1 form factor.

In our opinion the results show that the conclusions of ref.[13] on the absence of noticeable M1 strength in ^{140}Ce cannot be final. The behaviour of the experimental form factor does not contradict the presence in ^{140}Ce of 1^+ states with a notable total B(M1)-value. The calculations show that for a more reliable separation of 1^+ states among 2^- states, it is necessary to perform measurements for lower energies of incident electrons and smaller scattering angles. According to our recent calculations[24] the excitation cross section of the M1 resonance increases for the nuclei with $A < 100$. This explains the detection of a certain part of M1 strength in such nuclei as ^{90}Zr and ^{58}Ni[13].

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