ON THE M1 AND M2 STRENGTHS IN ^{140}Ce

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The available experimental and theoretical data on M1 and M2 states in ^{140}Ce are analyzed. Comparison of the experimental form factors of inelastic scattering of electrons at 165° with DWBA calculations within the quasiparticle–phonon model shows that the experiment does not contradict the existence of noticeable M1 transitions in ^{140}Ce.

At present, 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 6–10 MeV. Some experimental data, though not very reliable, seemed to confirm these assumptions [8–11]. However, 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 (γ, n) experiments [14]. The attempts [6,7,12,15,16] to explain the "disappearance" of the M1 resonance by the interaction of 1p–1h states with more complex configurations are either unsuccessful, or 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 (e, e′) scattering have been analyzed within the MSI model [13,17], it is instructive to study the extent to which the results of the analysis depend on its assumptions and to compare its predictions with those of other models. In this paper we shall analyze 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 (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 functions $\langle k(\mathrm{M1})\rangle$ in ^{140}Ce has been found at the neutron binding energy. It is important that the same increase in $\langle k(\mathrm{M1})\rangle$ 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 $A \approx 140$ [20]. However, in precise experiments by Richter et al. [13] in ^{140}Ce the states with $J^\pi = 1^+$ have not been observed. In the excitation energy region under study the 2^- states were observed.

What are the theoretical predictions on the distribution of the M1 and M2 strength in ^{140}Ce? The results of a calculation of the M1 and M2 resonances in this nucleus within the QPM [5,6,19], the theory of finite Fermi systems [3,4] and the MSI model [13,31] are given in table 1. These results are obtained within the RPA. This table also shows the experimental data, including those of Pitthan and Walcher [9] which have not been confirmed in the recent (e, e′) experiments. Note that the theory predicts a considerably smaller B(M1) value than that obtained in ref. [9]. The interaction with complex configurations studied in some nuclei with $A \approx 140$ [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

Table 1
Experimental data and theoretical results for M1 and M2 resonances in ^{140}Ce.

M1	E_x (MeV)	B(M1) (μ_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)**	**ΣB(M2) (μ_0^2fm^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

interval $\Delta E_x \approx 1$ MeV at $\bar{E}_x = 8.4$ 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 the M2 strength is also concentrated at these energies; however the M2 resonance is formed by many 2^- states in the interval ΔE_x $\approx$ 3–5 MeV [19,21]. Thus, the M1 and M2 resonances overlap.

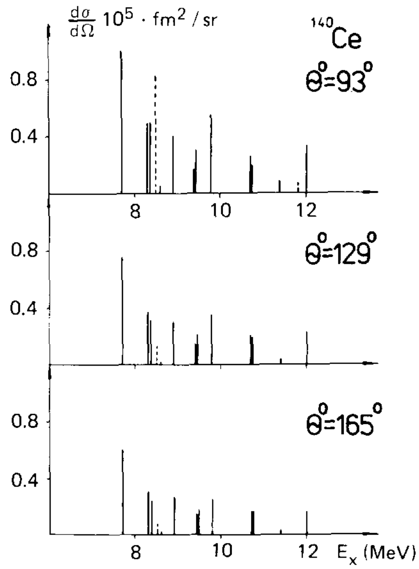

Fig. 1. Differential cross sections for excitation of one-phonon 1^+ states (dashed line) and 2^- states (solid line) in ^{140}Ce in inelastic electron scattering (E_0 = 50 MeV) at different angles θ.

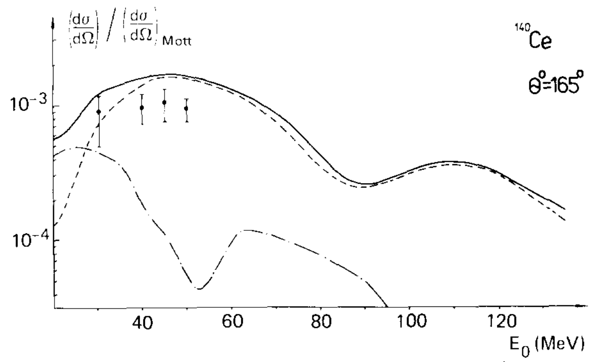

Fig. 2. Form factors of one-phonon 1^+ states (dash-dotted line) and 2^- states (dashed line) in the excitation energy interval $7.5 < E_x < 10$ MeV. The solid line is the sum of the M1 and M2 form factors. The experimental points are taken from ref. [13].

Now consider the probability for the one-phonon 1^+ and 2^- states in ^{140}Ce to be excited in inelastic scattering of electrons. Fig. 1 shows the differential cross sections of excitation of 1^+ and 2^- states in (e, e$'$) scattering with an electron energy E_0 = 50 MeV at different angles. 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 the B(M1) and B(M2) values given in table 1 (see also refs. [6,19]). Note that 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]. Fig. 1 shows that though the probability of excitation of the one-phonon 1^+ state coincides with that of individual one-phonon 2^- states within an order of magnitude, its contribution to the total cross section in the interval $7.5 < E_x < 10$ MeV is small due to the large number of 2^- states in this interval. The rapid decrease of the excitation cross section of the 1^+ state in comparison with that of the 2^- state with increasing scattering angle θ is also important. As a result, at $\theta = 165°$ the contribution of the 1^+ state to the total cross section is negligible. The reason is the different behaviour of the transitional densities of 1^+ and 2^- states, the first being of surface nature and the second of 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. Fig. 2 shows the form factors of 1^+ and 2^- states calculated within the QPM. The M2 form factor is the sum of the form factors of all one-phonon 2^- states in the interval $7.5 < E_x < 10$ MeV. Fig. 2 also shows the experimental points from ref. [13]. Just as in the calculations with the MSI model, the M2 form factor is similar to the experimental one. However, in ref. [13] the absolute value of the theoretical form factor was normalized by the experimental data, while in our calculations its absolute value is automatically obtained at the same values of g_s^* as the $B(\mathrm{M2})$ probability (see table 1). The sum of the M1 and M2 form factors (see fig. 2) also is in satisfactory agreement with the experimental data. Besides, 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 a 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 noticeable total $B(\mathrm{M1})$ value. The calculations show that for a more reliable separation of 1^+ states from 2^- states, it is necessary to perform measurements at lower energies of the incident electrons and smaller scattering angles. According to our recent calculations [24] the excitation cross section of the M1 resonance increases for nuclei with $A < 100$. This explains the detection of a certain part of the M1 strength in such nuclei as ^{90}Zr and ^{58}Ni [13].

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