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EXCITATION OF MAGNETIC RESONANCES IN ^{90}Zr BY THE INELASTIC PROTON SCATTERING

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Recently, the new experimental data on 200 MeV proton inelastic scattering at forward angles for many nuclei have been published[1]. In all nuclei prominent resonance structures with a width $\Gamma \simeq 1\div3$ MeV have been observed at excitation energies $E_x \sim 8\div10$ MeV. An angular distribution showed them to be caused by the 1^+- state excitation. These results are of great interest especially in view of a rather unclear situation with the M1-resonance in heavy nuclei. A point of view on its quenching in medium and heavy nuclei has been formed under the influence of the slow (e,e')-scattering at backward angle experiments[2]. In these (e,e')-experiments no strong peaks caused by the 1^+- state excitation were observed in nuclei with $A>100$. So, a question arises: is there any contradiction between the (e,e')- and (p,p')-data, and what are the causes. It seems to us the answer lies in a reaction selectivity. That means one should examine excitation probabilities of states with different J^π in a reaction. Such an analysis of the (e,e')-data has been carried out in papers[3]. The RPA-calculations with a separable effective spin- and spin-isospin interaction showed that the M1-contribution to the electroexcitation cross section in heavy nuclei was reduced, as compared to the M2-contribution, by the reaction mechanism. Thus, it is rather difficult to distinguish the M1-resonance in heavy nuclei under the conditions of experiment[2] because of a masking effect of strongly excited 2^--states. In medium nuclei a part of the M1-strength can be lost in the background separation. These calculations allowed one to conclude that the M1-quenching is caused by the reaction mechanism rather than by the effects of the nuclear structure. It seems useful to calculate the excitation cross section of different magnetic resonances in the (p,p')-scattering in the framework of the same theoretical model. Such calculations for ^{90}Zr are presented in this paper.

To begin with we discuss shortly the theoretical aspects of the (p,p′)-calculations. The nuclear state structure is described in the quasiparticle-phonon model, the basic features of which are presented in the reviews[4]. The model Hamiltonian includes the mean field for protons and neutrons, the pairing interaction and effective separable forces by means of which phonon excitations with different J^{π} are generated. For example, 1^+ states are generated by $\vec{\sigma}\vec{\sigma}$-forces:

$$V(\vec{r}_1,\vec{r}_2) = \frac{1}{2}\left(\varkappa_0 + \varkappa_1 \vec{\tau}_1\vec{\tau}_2\right) \frac{\partial U}{\partial r_1}\frac{\partial U}{\partial r_2}\; \vec{\sigma}_1\vec{\sigma}_2 ,$$

where U is the central part of the average potential; $\varkappa_0$ and $\varkappa_1$ are the constants of the isoscalar and isovector interactions, respectively. The ground state of the even-even nuclei is assumed to be a phonon vacuum and the excited state wave functions are the superposition of different numbers of phonons. In the RPA the interaction between configurations with a different number of phonons is neglected, and so the excited states become purely one-, two-,...phonon states. In these calculations we take into account only the one-phonon states because the process of a direct excitation of more complex configurations is strongly reduced.

The inelastic proton scattering is described in the DWIA. Nowdays, this aprroximation is well accepted for the scattering of particles at intermediate energies (E_p = 100-800 MeV). The effective NN-interaction of projectile with target nucleons is taken in terms of the free NN t-matrix. For the free t-matrix we use a parametric form (a sum of the three Yukawa potentials) with the parameters from ref.[5] obtained from the N-N scattering amplitudes at 210 MeV. Exchange effects are treated approximately by means of the pseudopotential. In addition to the effective N-N interaction, an optical potential describing a projectile scattering in the nuclear field should be introduced. In the calculations we use two sets of optical parameters. First of them (OP1) was determined from the elastic proton scattering at 201 MeV on ^{90}Zr (ref.[6]). The other (OP2) corresponds to the energy dependent Nadasen potential[7] evaluated at 200 MeV. The (p,p′)-cross section is calculated by the DWUCK program[8]. Let us turn now to the results. In the RPA the M1-resonance in Zr consists of two one-phonon states with E_x~9 and 11 MeV. The main contribution to their structure comes from the configurations $(1g_{9/2}\ 1g_{7/2})_\nu$ and $(1g_{9/2}\ 1g_{7/2})_\pi$, respectively. The existence of the proton configuration is due to the pairing correlations in the proton system. It should be mentioned that the 1^+-state with E_x~11 MeV is characterised by a less value B(M1↑) and hence its excitation

probability at small q is weaker. Besides, it is strongly fragmented due to the interaction with two phonon states[9]. So, the main attention will be paid to the 1^+-state with E_x~9 MeV.

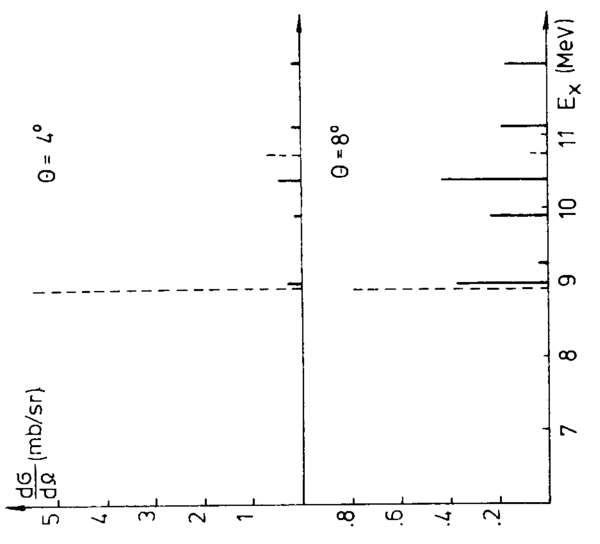
The first problem we are going to touch is an absolute value of the M1 excitation probability in the (p,p′)-reaction. The first estimations of it for ^{90}Zr have been obtained in ref.[10]. But these results were criticized in comment[11] for an incorrect assumption concerning the energy dependence of optical-model distortion effects used in calculations. Some estimations have been done by the authors of the (p,p′)-experiment[1], the M1-resonance in ^{90}Zr in this work has been described by the pure neutron configuration $(1g_{9/2}\ 1g_{7/2})_\nu$. It was shown that an attenuation factor $N = \sigma_{exp}/\sigma_{th}$ can vary in broad limits by optical potential parameters: the value σ_{th} obtained with OP2 is approximately 60% larger than σ_{th} obtained with OP1. Our calculations confirm this statement. Moreover, we have found that the factor N is in a strong dependence on the M1-resonance structure. While we get N=0.39 for the configuration $(1g_{9/2}\ 1g_{7/2})_\nu$ with OP1, the correlations lead to an increase in N. Under the $\vec{\sigma}\vec{\sigma}$-forces a large number of other 1p1h configurations is mixed with the main configuration $(1g_{9/2}\ 1g_{7/2})_\nu$. The contribution of these configurations to the M1 resonance wave function is weak, but their influence on the B(M1)- and σ_{th}-values is sizeable. We have calculated B(M1) and σ_{th} for different values of the parameter $\chi = \varkappa_0/\varkappa_1$ which is the ratio of isoscalar to isovector strength of the $\vec{\sigma}\vec{\sigma}$-interaction. The results are in table ($g_s^{eff}=0.8g_s^{free}$). For the pure isovector $\vec{\sigma}\vec{\sigma}$-interaction ($\varkappa_0$ =0) a noticable contribution

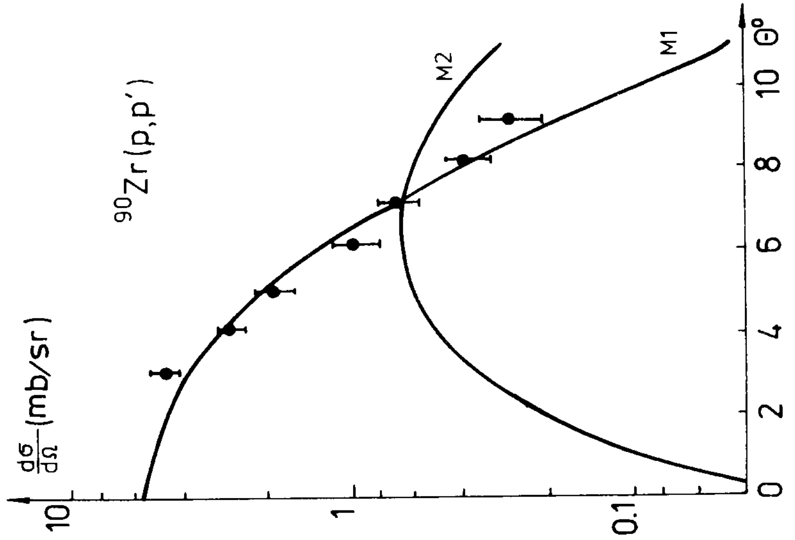
$\chi = \frac{\varkappa_0}{\varkappa_1}$	$(1g_{9/2}\ 1g_{7/2})_\nu$ contribution	E_x, MeV	B(M1↑), μ_0^2	$N = \frac{\sigma_{exp}}{\sigma_{th}}$
0.0	84.6%	8.5	4.8	0.754
0.5	96.3%	8.9	6.5	0.597
0.9	98.3%	8.9	7.4	0.542
1.0	98.4%	8.9	7.5	0.543
$\varkappa_0 = \varkappa_1 = 0$	100.0%	6.8	9.8	0.391

(~10%) comes from the configuration $(1g_{9/2}\ 1g_{7/2})_\pi$. If we take into account the isoscalar component of the $\vec{\sigma}\vec{\sigma}$-interaction, (π-ν)-correlations are reduced. As a results the $(1g_{9/2}\ 1g_{7/2})_\nu$ contribution increases. With the parameter χ =1, the (π-ν)-correlations vanish,

Fig. 1. M1- and M2-resonance excitation by 200 MeV protons. The experimental data are from ref./6/.

Fig. 2. 1^+-(dashed bars) and 2^--(full bars) state excitation probabilities by 200 MeV-proton scattering at $\theta=4^\circ$ and 8°.





and the 1^+ state with $E_x \simeq 9$ MeV becomes a purely neutron state. Together with the parameter χ, the attenuation factor N changes from 0.75 to 0.53, but even at $\chi=1$ its value is far from N=0.39 obtained for the pure $(1g_{9/2}\ 1g_{7/2})_\nu$ configuration. The results show that in this case an admixture of a large number of weak components may greatly influence on the final results. Thus, the exact value of the M1-quenching in the (p,p′)-reaction can be obtained only within correct microscopic calculations of σ_{th}. From this point of view the attenuation factors N from ref./1,6/ should be considered as preliminary ones.

As we have mentioned earlier the main aim of this work is to reveal the contribution of the states with different J^π to the (p,p′)-cross section under the conditions/1,6/. At very small angles only the $\Delta L=0$ transitions (this means the 1^+-state excitation) define the (p,p′)-cross section. At a zero angle the M1-resonance is excited by 200 MeV protons 130 times stronger as compared to the M2-resonance (Under the M1-resonance excitation we mean a sum of excitation probabilities of all J^π-states from the resonance location interval). The M2-resonance in ^{90}Zr is formed by 10-15 one-phonon 2^--states in the interval $8.5<E_x<14$ MeV. When θ increases the M1-excitation probability flows down, and the M2-excitation probability increases. The behaviour of $\sigma^{M1}_{th}(\theta)$ and $\sigma^{M2}_{th}(\theta)$ is shown in fig. 1. The calculations have been done with $\chi=0.9$. The experimental points are from ref./6/. The behaviour of $\sigma^{M1}_{th}(\theta)$ is in good agreement with the experiment. Fig. 1 also shows that the 2^--state contribution to the cross section is small up to the $\theta\sim6^\circ$, the contribution of the states with $J^\pi=1^-, 2^+, 3^\pm,\ldots$ from the interval $6<E_x<14$ MeV vanishes. The detailed spectra of the M1- and M2-state excitation for two values of $\theta=4^\circ, 8^\circ$ are exhibited in fig. 2.

Our calculations show that the experimental conditions/1,6/ are suitable to a large extent for the predominant excitation of the M1-resonance. The contribution of the 2^--states to the (p,p′)-cross section becomes important only at $\theta\gtrsim8^\circ$, where the M1-formfactor approaches its minimum. Thus, there is no contradiction between the (e,e′)- and (p,p′)-experiments/1,2/, on the contrary they are supplementary. The first one is suitable for the investigation of M2-states and the second for the investigation of M1-states.

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Пономарев В.Ю. и др. E4-83-497

Возбуждение магнитных резонансов в ^{90}Zr
в реакции неупругого рассеяния протонов

В импульсном приближении метода искаженных волн рассчитаны вероятности возбуждения однофононных 1^+- и 2^--состояний ядра ^{90}Zr в реакции неупругого рассеяния протонов с энергией 200 МэВ на малые углы. Показано, что для углов рассеяния $\theta < 6°$ сечение реакции определяется исключительно возбуждением M1-резонанса. Сделан вывод о дополнительности данной реакции реакции неупругого рассеяния медленных электронов на большие углы, где преимущественно возбуждаются 2^--состояния. Обсуждается величина подавления M1-резонанса, следующая из данных (p, p′)-реакции.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Ponomarev V.Ju. et al. E4-83-497

Excitation of Magnetic Resonances in ^{90}Zr
by the Inelastic Proton Scattering

The excitation probabilities of 1^+- and 2^--states in ^{90}Zr in the inelastic 200 MeV proton scattering at forward angles are calculated in the DWIA. It is shown that the main part of the (p, p′) -cross section at $\theta < 6°$ is due to the M1-resonance excitation. So, the (p, p′) -scattering is a supplementary tool for the magnetic resonance study in comparison with the inelastic slow electron scattering at backward angles, in which the M2-states are excited predominantly. The M1-quenching factor is discussed.

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

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