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SUBSTRUCTURES IN PHOTO-ABSORPTION CROSS SECTIONS OF ^{206,208}Pb

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The experimental study of the energy dependence of the photo-absorption $\sigma_{\gamma t}$ cross sections in the region below the giant dipole resonance (GDR) has shown that the behaviour of $\sigma_{\gamma t}$ differs from the Lorentz extrapolation of the GDR into the low-energy region. The substructures in the cross sections $\sigma_{\gamma t}$ have been observed /1/ for natural Sn, for ^{90}Zr, ^{135}Ba and ^{140}Ce. A substructure, having a width of several hundred keV at 8 MeV in the photoneutron cross sections of ^{117,119}Sn has been observed /2/. The substructures have been found /3/ in the dipole photoabsorption cross sections of the nuclear neighbours of ^{208}Pb below the neutron emission threshold B_n. The measured elastic photon scattering cross sections for ^{206,208}Pb in the excitation energy region from 9.6 to 12 MeV /4/ confirm the existence of substructures in ^{208}Pb. In ^{206}Pb these substructures were not observed. The photoneutron cross sections for ^{208}Pb have been measured /5/ in the region from 8 to 13 MeV. They also indicate the existence of substructures in this energy region.

The energy centroid and width of the GDR in spherical nuclei /7,8/ are well described within the quasiparticle-phonon nuclear model (QPM) /6/. The energy dependence of the photo-absorption cross sections and the substructures in $\sigma_{\gamma t}$ in ^{90}Zr, ^{138}Ba and ^{140}Ce have been studied in ref. /8/. The influence of the GDR on $\sigma_{\gamma t}$ in the low-energy region was also investigated. It has been shown in ref. /9/ that the substructures in $\sigma(\gamma, n)$ at energy of about 8 MeV in ^{117,119}Sn are caused by the E1 transitions $3s_{1/2} \to 2p_{1/2}$, $3s_{1/2} \to 2p_{3/2}$.

In this letter within the QPM we calculate the electric dipole strength distribution, the photo-absorption cross sections in ^{206,208}Pb and compare them with the experimental data.

The QPM Hamiltonian includes the average field as the Saxon-Woods potential, the pairing interaction and the multipole and spin-multipole isoscalar and isovector forces.

The wave function for the highly-excited states of doubly even spherical nuclei is

$$\Psi_{\nu}(JM) = \{ \sum_{i} R_{i}(J\nu) Q^{+}_{JMi} + \sum_{\lambda_1 \lambda_2 i_1 i_2} P^{\lambda_1 i_1}_{\lambda_2 i_2}(J\nu) [Q^{+}_{\lambda_1 \mu_1 i_1} Q^{+}_{\lambda_2 \mu_2 i_2}]_{JM} \} |0\rangle , \quad (1)$$

where $|0>$ is the phonon vacuum, $Q^{+}_{\lambda\mu i}$ is the phonon creation operator, and ν is the number of an excited state. The coefficient $R_i(J\nu)$ and the state energies η_ν are determined by solving relevant equations given in refs./6,7/. An approximation for the reduced E1 transition probability from the ground to the excited state, described by the wave function (1), has the form

$$B(E1;\, 0^{+}_{g.s.} \to 1^{-}_{\nu}) = |\sum_{i} R_i(1\nu) <0||M(E1)\, Q^{+}_{1\mu i}\, ||0>, \qquad (2)$$

where $<0||M(E1)Q^{+}_{1\mu i}||0>$ is the reduced matrix element of the E1 transition from the ground state to the excited one-phonon 1^- state calculated in the RPA.

Following ref./6/ we introduce the strength function

$$b(E1;\eta) = \frac{1}{2\pi} \sum_{\nu} \frac{\Delta}{(\eta-\eta_\nu)^2 + \frac{1}{4}\Delta^2} B(E1;\, 0^{+}_{g.s.} \to 1^{-}_{\nu}) \,. \qquad (3)$$

The average dipole photo-absorption cross section is related to $b(E1;\eta)$ by /8/

$$\sigma_{\gamma t}(E_x) = (4.025\, E_x/\Delta) \int_{E_x - \frac{1}{2}\Delta}^{E_x + \frac{1}{2}\Delta} b(E1;\eta)\, d\eta \ \text{mb}\,. \qquad (4)$$

Here E_x is the E1 transition energy in MeV, and $b(E1;\eta)$ is in $e^2 fm^2$/MeV. The parameter Δ corresponds to the energy interval of averaging. In our calculations Δ=0.2 MeV. The Hamiltonian parameters are fixed in ref./10/ so as to describe the energies and transition probabilities to the low-lying states and the integral characteristics of the giant multipole resonances in ^{206,208}Pb. To exclude the dipole spurious states we use the method of ref./11/.

Our calculations of the integral characteristics of the GDR in the RPA for ^{208}Pb give the following values: $\bar{E}_{GDR}$ = 13.4 MeV, σ_0=2880 MeV.mb, σ_{-1}=213 mb, σ_{-2} = 16.2 mb·MeV^{-1}. The experimental values are /12/: $\bar{E}_{GDR}$ = 13.43 MeV, σ_0=3059 MeV mb, σ_{-1}=229 mb, σ_{-2}=17.6 mb·MeV^{-1}. Almost the same values of the GDR integral characteristics are obtained for ^{206}Pb.

The sums of B(E1) -values in some energy intervals calculated in the RPA and with the wave functions (1) and the available experimental data /3,13,14/ for ^{208}Pb are given in the table. Two experimental values of B(E1) show their lower and upper estimate. As is seen from the table, the total E1 strength is described correctly in the energy interval up to 10.14 MeV. For the energies below B_n the calculated E1 strength is two or three times as less as the experimental one, whereas for the energies of (8.3-10.1) the B(E1) -value

Table

Distribution of E1-strength in ^{208}Pb

ΔE, MeV	ΣB(E1) e^2 fm^2				
	Experiment			Calculation	
	Ref./13/	Ref./3/	Ref./14/	RPA	Q +QQ
4.842-7.332	1.04-1.63	1.33	-	0.15	0.41
7.332-8.332	0.698-0.747	-	0.42-0.51	0.9	0.51
8.332-10.14	0.268-0.937	-	-	2.4	1.76
ΣB(E1)	2.01-3.31	-	-	3.45	2.68

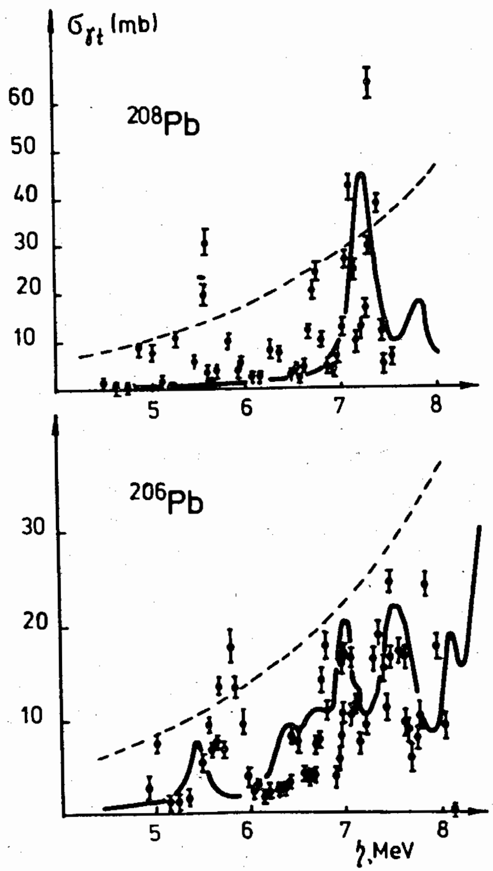

Fig.1. Photo-absorption cross sections $\sigma_{\gamma t}$ for ^{206,208}Pb. Dots are the experimental data from refs./1,3/, solid curve is the calculations within the QPM, dashed curve is the Lorentz extrapolation of the GDR with the parameters from refs./4,12/.

is overestimated. It is seen from the table that the two-phonon components redistribute the dipole strength in a proper way. Perhaps, such a distribution of strength is caused by our choice of residual effective forces.

The dipole phoro-absorption cross sections $\sigma_{\gamma t}$ in ^{206,208}Pb for the excitation energies (4.5-8) MeV are shown in fig.1. It is seen from fig.1 that $\sigma_{\gamma t}$ of ^{208}Pb have pronounced substructures at $E_x \approx 5.5$ and 7.3 MeV. In ^{206}Pb there are

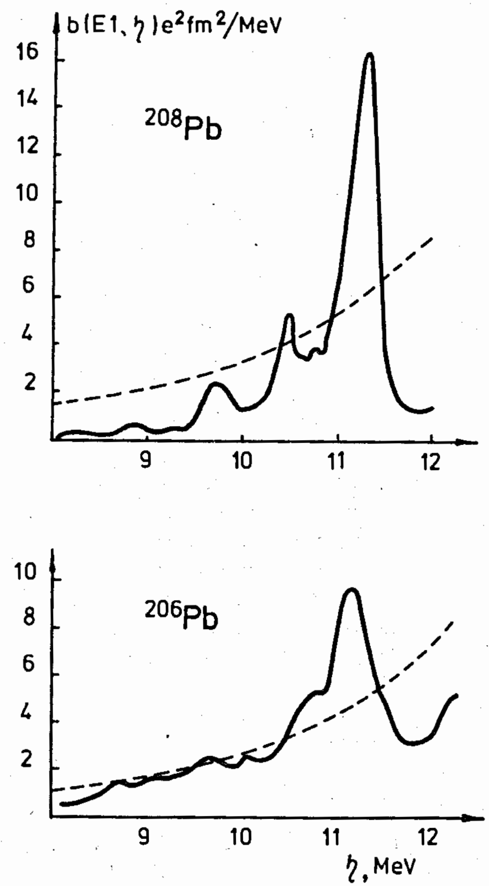

Fig.2. E1-strength functions $b(E1;\eta)$ for ^{206,208}Pb. Solid curve is the calculations within the QPM, dashed curve is the Lorentz extrapolation of the GDR with the parameters from refs. /4,12/.

also several substructures. The Lorentz extrapolation of the GDR does not describe $\sigma_{\gamma t}$ correctly in this energy region. As is seen from fig.1 our calculations reproduce correctly the substructure in the cross section $\sigma_{\gamma t}$ for ^{208}Pb at $E_x \approx 7.3$ MeV. The calculated cross sections $\sigma_{\gamma t}$ in ^{206}Pb show the existence of several substructures, that is in agreement with experiment. In contrast with ^{208}Pb in ^{206}Pb there is a substructure at $E_x \approx 5.5$ MeV, that is somewhat lower than the experimental energy $E_x \approx$ ≈ 5.8 MeV. According to the RPA calculations the 1^- collective state is located in ^{208}Pb at 7.3 MeV. The two-phonon components slightly change the distribution of the dipole strength of this region, and the 1^- state appears as a substructure in $\sigma_{\gamma t}$. In ^{206}Pb there are four 1^- states near 7.3 MeV due to the pairing. The two-phonon components influence strongly the distribution of the strength in ^{206}Pb. This is due to the fact that in ^{206}Pb the density of the two-phonon 1^- states is four times as large as in ^{208}Pb and the interaction between one- and two-phonon states is more strong. The lowest 1^- solution in the RPA in ^{206}Pb lies at $E_x \approx 6.2$ MeV. If the two-phonon components are taken into account, a part of strength is pushed down, and as a result, a substructure appears at $E_x = 5.5$ MeV.

The elastic photon scattering observed for ^{208}Pb clearly implies some fine structure in the energy dependence of the

total photon interaction cross section /4/. There are substructures at $E_x \approx 10.04$, 10.6 and 11.27 MeV. In ^{206}Pb such substructures are not observed in the energy region of (9.6-12) MeV. The strength functions calculated by us for ^{206,208}Pb are shown in fig.2. It is seen from fig.2 that in ^{206}Pb there are substructures at $E_x = 9.7$, 10.5 and 11.3 MeV and a substructure at $E_x' = 10.8$ MeV which is not pronounced. In ^{206}Pb up to 10 MeV the calculated cross sections are close to the results of the Lorentz extrapolation. However, at $E_x \approx 11.2$ MeV there is a pronounced peak. Different behaviour of $b(E1)$ in ^{206}Pb and ^{208}Pb is a result of the influence of two-phonon components on the distribution of the dipole strength and agrees qualitatively with the experimental data /4/. The analysis of the ^{208}Pb(γ, n) reaction spectrum /5/ confirms the existence of a substructure at 9.2, 9.8, 10.3, 10.7, 11.2 and 11.6 MeV. In the energy region of (9.85-11.75) MeV the experimental value for the integral photo-absorption cross section is (445 ± 7) MeV·mb /5/. The Lorentz extrapolation of $\sigma_{\gamma t}$ gives the value 430 MeV mb. In our calculations it is 434 MeV mb, which is close to the experimental value. It has been mentioned in ref. /5/ that the substructures in $\sigma_{\gamma t}$ at $E_x \approx 9$ and 10 MeV may be related to the isoscalar E2 resonance. In our RPA calculations the resonance is located at $E_x = 9.2$ MeV with $B(E2) = 6720$ e^2fm^4, that is in agreement with the experimental value /15/ $B(E2) = 7320$ e^2fm^4 for the energy interval of (9.03-10.06) MeV. Perhaps the substructure in $\sigma_{\gamma t}$ in the region of 9 MeV in ^{208}Pb is caused by the isoscalar E2 resonance.

Thus we have shown that the substructures in the photo-absorption cross sections in ^{206,208}Pb are caused by the fragmentation of one-phonon 1^- states and can successfully be described within the QPM. We have also explained the smoothing of substructures in $b(E1)$ in the excitation energy region of (9.6-11.0) MeV in ^{206}Pb in contrast with ^{208}Pb.

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Соловьев В.Г., Стоянов Ч., Воронов В.В. E4-81-422
Подструктуры в сечениях фотопоглощения ^{206,208}Pb

Приведенные вероятности E1-переходов и полные сечения фотопоглощения $\sigma_{\gamma t}$ в ^{206,208}Pb рассчитаны в квазичастично-фононной модели ядра. Показано, что в зависимости $\sigma_{\gamma t}$ от энергии в интервале 5-8 МэВ на ^{206,208}Pb имеются подструктуры, обусловленные частично-фрагментированными однофононными состояниями. Поведение $\sigma_{\gamma t}$ сильно отличается от лоренцевской экстраполяции ГДР, что подтверждается экспериментальными данными.

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Substructures in Photo-Absorption Cross Sections of ^{206,208}Pb

The reduced E1-transition probabilities and total photo-absorption cross sections $\sigma_{\gamma t}$ in ^{206,208}Pb are calculated within the quasiparticle-phonon nuclear model. Substructures, caused by the fragmented one-phonon states, are observed in the energy dependence of $\sigma_{\gamma t}$ in the interval from 5 to 8 MeV in ^{206,208}Pb. The behaviour of $\sigma_{\gamma t}$ differs from the Lorentz extrapolation of the giant dipole resonance, that is confirmed by the experimental data.

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

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