GIANT RESONANCE IN Pb^{208} *PHOTODISINTEGRATION*

V. V. BALASHOV, V. G. SHEVCHENKO, and N. P. YUDIN

Nuclear Physics Institute, Moscow State University

Submitted to JETP editor July 12, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 1929-1933 (December, 1961)

The cross section for dipole absorption of gamma rays by Pb^{208} nuclei is calculated using the shell model. It is shown that when residual pair interactions between nucleons are taken into account the giant resonance energy is approximately doubled. The calculations agree with experimental results.

It has become clear that the principal shortcoming of the single-particle model of photonuclear reactions [1] lies in the sharply reduced giant resonance energies that are calculated when nucleon-nucleon correlations in the nucleus are neglected.

The calculations for the photodisintegration of O^{16} and Ca^{40} in [2] and [3], with interactions between nucleons taken into account, have shown that the shell model can furnish a comprehensive description of the photodisintegration of light nuclei in the giant resonance region. It was shown that a mixture of states in light nuclei does not essentially shift giant resonance as compared with the "diagonal approximation" (a term used in our earlier work [3]). This is understandable since in light nuclei the average separation between levels of the "zero approximation" considerably exceeds the average value of nondiagonal matrix elements between single-particle dipole states. In heavy nuclei giant resonance represents a large number of single-particle transitions. Therefore, while the initial assumption of the Brown-Bolsterli scheme [4] is a highly idealized procedure for light nuclei, it can be expected that the dipole absorption curve for heavy nuclei will reflect the characteristic features of this scheme.

In the present work the shell model has been used to calculate the dipole cross section for γ-ray absorption by Pb^{208}. With regard to the photodisintegration of Pb^{208} it is noteworthy, first of all, that the diagonal approximation (which takes into account only the diagonal part of the interaction between a particle and a hole) does not yield results essentially different from those obtained with Wilkinson's single-particle model. In this approximation the dipole absorption curve has a broad peak at 5.5—8 Mev (Fig. 1), while the experimental giant resonance energy is 13.5—14 Mev. [5]

The $J = 1^-$ energy levels and the corresponding wave functions were calculated by diagonalizing the interaction matrix based on the single-particle states given in Table I. The single-particle levels were determined from experimental data for neighboring nuclei and from extrapolations based on the single-particle model. [6] The matrix elements for the interaction between a particle and a hole were calculated assuming the following δ in-

Table I. Zero-approximation energies

Single-proton states	E, Mev	Single-proton states	E, Mev	Single-neutron states	E, Mev	Single-neutron states	E, Mev
$1h_{11/2}^{-1}\,1i_{13/2}$	6,4	$2d_{5/2}^{-1}\,2f_{5/2}$	10,0	$1i_{13/2}^{-1}\,1j_{15/2}$	6.7	$2f_{7/2}^{-1}\,3d_{5/2}$	8.5
$3s_{1/2}^{-1}\,3p_{3/2}$	7.5	$2d_{5/2}^{-1}\,2f_{7/2}$	6.6	$3p_{1/2}^{-1}\,3d_{3/2}$	6.6	$2f_{5/2}^{-1}\,2g_{7/2}$	7.3
$3s_{1/2}^{-1}\,3p_{1/2}$	9,0	$1g_{7/2}^{-1}\,2f_{7/2}$	8,3	$3p_{3/2}^{-1}\,3d_{3/2}$	7.5	$2f_{7/2}^{-1}\,2g_{7/2}$	9.6
$2d_{3/2}^{-1}\,3p_{3/2}$	8,0	$1g_{7/2}^{-1}\,2f_{5/2}$	11,8	$3p_{3/2}^{-1}\,3d_{5/2}$	6.3	$2f_{7/2}^{-1}\,2g_{9/2}$	6.6
$2d_{3/2}^{-1}\,3p_{1/2}$	9.5	$1g_{9/2}^{-1}\,2f_{7/2}$	11.7	$3p_{1/2}^{-1}\,4s_{1/2}$	6.0	$1h_{9/2}^{-1}\,1i_{11/2}$	7.9
$2d_{5/2}^{-1}\,3p_{3/2}$	9.8	$1g_{9/2}^{-1}\,1h_{9/2}$	10.8	$3p_{3/2}^{-1}\,4s_{1/2}$	7.9	$1h_{9/2}^{-1}\,2g_{9/2}$	7.1
$2d_{3/2}^{-1}\,2f_{5/2}$	8.2	$1g_{7/2}^{-1}\,1h_{9/2}$	7.5	$2f_{5/2}^{-1}\,3d_{3/2}$	7.4		
				$2f_{5/2}^{-1}\,3d_{5/2}$	6.2	$1h_{9/2}^{-1}\,2g_{7/2}$	10.1

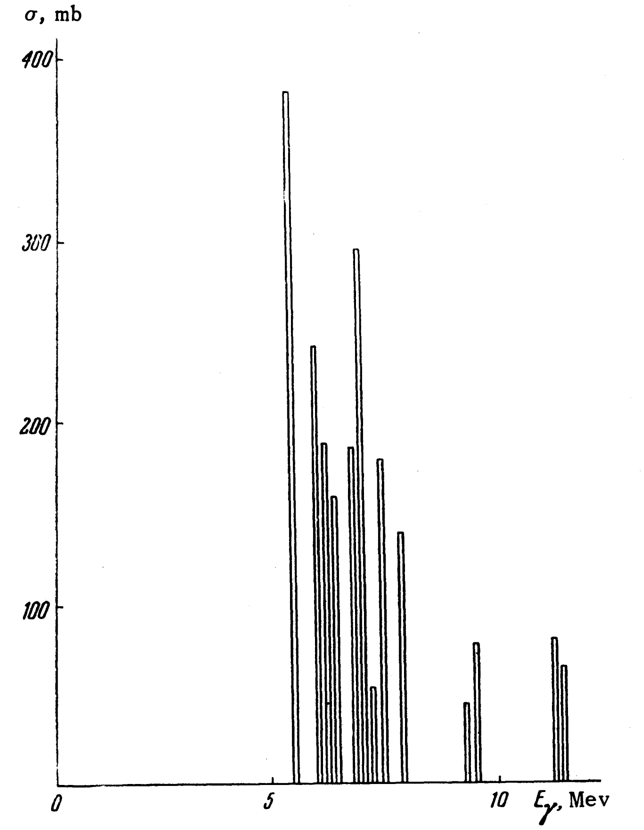

FIG. 1. Histogram of main dipole transitions in Pb^{208} in the diagonal approximation.

teraction between nucleons:

$$V_{12} = -g\,[(1-\alpha) + \alpha\sigma_1\sigma_2]\,\delta(\mathbf{r}_1 - \mathbf{r}_2);$$

oscillator functions were used in calculating the radial integrals ($r_0 = \sqrt{\hbar/m\omega} = 2.13 \times 10^{-13}$ cm). The interaction amplitude g was taken to be 1220 Mev-f^3 in accordance with calculations of the lowest Pb^{208} levels.[6] Figure 2 and Table II give the calculated cross sections for photoabsorption into 1^- levels, using $\alpha = 0.135$ (for Soper forces).[7]

Unlike the light nuclei O^{16} and Ca^{40}, where the ground and excited dipole states differ in isotopic spin, in heavy nuclei the single-particle dipole excitations contain some admixture of "spurious states" corresponding to the excitation of motion of the nuclear center of gravity. The spurious states were distinguished after diagonalization by calculating the matrix element $|\psi_i|\mathbf{R_A}|\psi_0|$ for each of the derived dipole states ψ_i (ψ_0 is the ground-state function). It was found that ~85% of the spurious states are included in a level corresponding formally to the negative energy E = −4.7 Mev. This level was excluded; thus the remaining states include about 0.5% spurious states for each level.

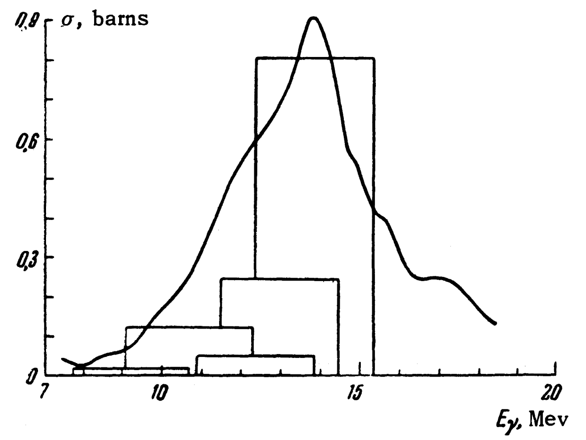

FIG. 2. Experimental and calculated (for Soper forces) integral cross sections for the main dipole transitions in Pb^{208}. The column width is arbitrary.

Table II

E, Mev	σ_{tot}, mb-Mev	E, Mev	σ_{tot}, mb-Mev
9.2	45.2	6.6	24.9
9.3	23.6	7.8	30.7
13.8	2384.2	10.4	24.0
13.0	718.1	12.4	147.8
10.5	361.4	6.6	30.2

In order to determine how giant resonance is influenced by the properties of nucleon-nucleon interactions a similar calculation was performed with Wigner forces ($\alpha = 0$). The results are in sharp disagreement with experiment (Fig. 3).

It must be remembered that the foregoing calculations were based on a number of more or less crude assumptions, such as point interactions, oscillator functions etc. Therefore a detailed quantitative comparison with experiment is hardly justified. However, we can draw the following general conclusions.

1. When residual interactions in Pb^{208} are taken into account an isolated "dipole state" is formed, corresponding to the experimental giant resonance energy. The occurrence of this state when the energy matrix is diagonalized results from the high density of single-particle dipole states in the given nucleus. The average separation of single-particle levels (~0.2 Mev) is smaller than the nondiagonal matrix elements (~0.3 Mev).

2. The high density (approximate degeneracy) of single-particle levels is not a sufficient condition for the appearance of an isolated strongly correlated dipole state (the Brown-Bolsterli effect). The character of the configuration mixture depends substantially on the relative magnitudes of the dif-

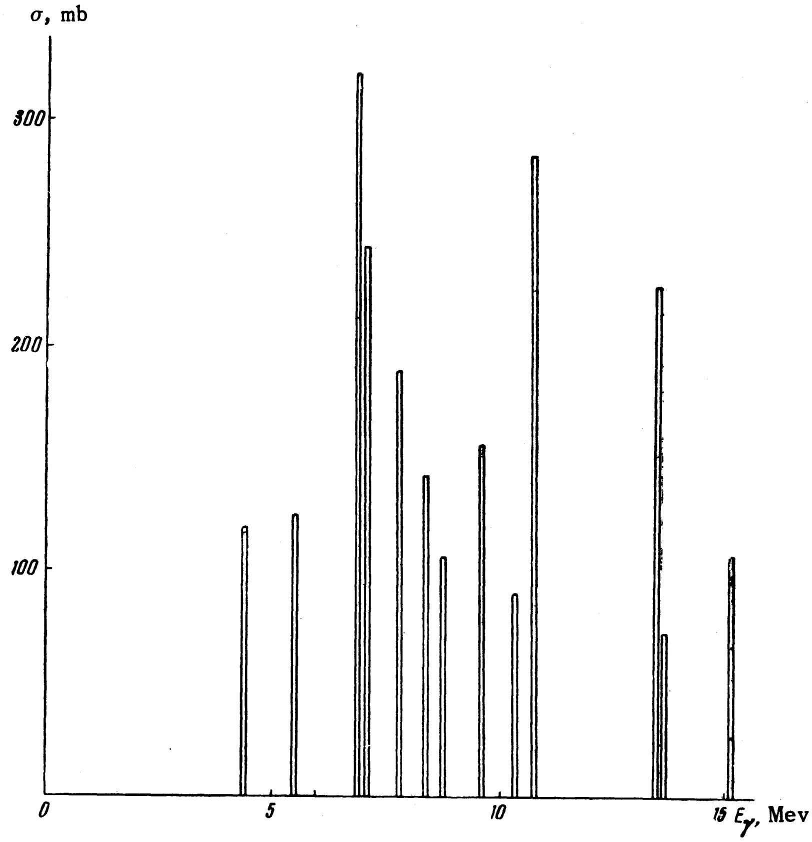

FIG. 3. Histogram of main dipole transitions for Wigner forces in Pb^{208}.

ferent nondiagonal matrix elements for the interaction between a particle and a hole, as determined by the properties of the residual nucleon-nucleon interaction.

Shell-model calculations of photonuclear reactions have by now been performed for all nuclei. The most detailed calculations have been carried out for the magic nuclei O^{16}, Ca^{40}, and Pb^{208}, and show that the principal features of giant resonance in photodisintegration are successfully accounted for by the shell model including configurational mixing. One might expect the principal conclusions derived from these calculations to be applicable to all nuclei. However, technical difficulties arise which make it doubtful that similar calculations can actually be performed for non-magic nuclei, with the exception of some special cases. The problem appears to consist in the construction of a simpler model of nuclear dipole states not requiring the diagonalization procedure and based on a microscopic (shell) interpretation of collective dipole excitation.

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Translated by I. Emin
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