GIANT RESONANCE IN PHOTODISINTEGRATION OF THE Zr^{90} NUCLEUS

K. V. SHITIKOVA

Institute of Nuclear Physics, Moscow State University

Submitted to JETP editor October 10, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 868-870 (March, 1962)

The position and parameters of the giant resonance in the photoabsorption cross section for the Zr^{90} nucleus are calculated within the framework of the shell model by taking residual interaction into account. The results are in good agreement with the experiments.

MANY recent papers [1] have emphasized the important role of residual interaction in the formation of collective dipole excitations of atomic nuclei. Detailed calculations carried for the light nuclei O^{16} and Ca^{40} and for the heavy nucleus Pb^{208}, within the framework of the shell model, have yielded a detailed description of the character of dipole absorption of γ quanta by these nuclei in the giant resonance region. The medium nuclei have, however, not been investigated to date. In particular, it is uncertain whether residual interactions can be used to explain the fact that in medium nuclei, as in heavy ones, the photoabsorption maximum lies at energies that are one-and-a-half or two times greater than those given by the single-particle model.

We consider in the present paper the effect of residual interaction on the properties of dipole excitation of medium nuclei, with Zr^{90} as an example. The giant resonance photoabsorption characteristics are calculated within the framework of the generator model of dipole nuclear states, proposed by Balashov.[2]

The wave function Ψ_{dip}, which describes the collective dipole excitation of the nucleus, is constructed by having the electric dipole moment operator $\hat{D}$ act on the ground-state function

$$\Psi_{dip} = (\hat{D}\Psi_0) / N(\Psi_0). \tag{1}$$

The function Ψ_{dip} is not an eigenfunction of the nuclear Hamiltonian, so that the dipole state is not monoenergetic and the giant resonance has a finite width. The ground state function Ψ_0 is chosen in accord with the shell model. The Zr^{90} nucleus is characterized by filled proton (1f, 2p) and neutron (1f, 2p, 1g) shells.

The total nuclear Hamiltonian H is represented as the sum of the single-particle Hamiltonian H_0 and the potential V of the residual pair interaction between the nucleons

$$H = H_0 + V,$$
$$H_0 = \sum_{i=1}^{A} H_i = \sum_{i=1}^{A}\left(\frac{p_i^2}{2M} + V_i\right), \qquad V = \sum_{i<j} V_{ij}. \tag{2}$$

Following Balashov[2] we can expand Ψ_{dip} in independent configurations of the hole-particle type, and directly reduce the problem of determining the single-particle level energy to that of obtaining experimental data on the levels of the neighboring nuclei. Unfortunately, there is no information at present on all the single-particle and hole levels of the nuclei A = 91 and A = 89 needed for the calculations. The lacking information was taken from Schröder's theoretical paper [3].

The "zeroth approximation" levels are listed in Table I.

Table I

Configuration	Excitation energy for neutrons	Excitation energy for protons	Configuration	Excitation energy for neutrons	Excitation energy for protons
$1f_{7/2}^{-1}\,1g_{9/2}$	10.2	8.1	$1f_{5/2}^{-1}\,2d_{5/2}$	8.9	8.4
$1f_{7/2}^{-1}\,1g_{7/2}$	16.1	15.0	$1f_{5/2}^{-1}\,2d_{3/2}$	11.7	11.0
$1f_{7/2}^{-1}\,2d_{5/2}$	14.7	13.0	$2p_{1/2}^{-1}\,2d_{3/2}$	9.4	8.6
$2p_{3/2}^{-1}\,2d_{5/2}$	8.3	7.6	$2p_{1/2}^{-1}\,3s_{1/2}$	9.0	8.6
$2p_{3/2}^{-1}\,2d_{3/2}$	11.1	10.2	$1g_{9/2}^{-1}\,1h_{11/2}$	8.1	
$2p_{3/2}^{-1}\,3s_{1/2}$	10,7	10.2	$1g_{9/2}^{-1}\,1h_{9/2}$	14.6	
$1f_{5/2}^{-1}\,1g_{7/2}$	10.3	10.4	$1g_{9/2}^{-1}\,2f_{7/2}$	11.5	

Table II

	Theoretical results					Experimental results		
	$V_0 = 0$	$V_0 = 3.5$		$V_0 = 7$		[4]	[5]	[6]
		$\alpha=0$	$\alpha=0.15$	$\alpha=0$	$\alpha=0.15$	—	—	—
E_{dip}, MeV	9.39	9.26	13.35	9.57	17.54	16	18	16.8
Γ, MeV	3.19	3.0	3.45	5.46	5.77	4.1	5.7	2.9

The residual pair interaction between nucleons was described by δ-forces

$$V_{12} = -g\,[(1-\alpha) + \alpha\sigma_1\sigma_2]\,\delta(\mathbf{r}_1 - \mathbf{r}_2), \tag{3}$$

where the coefficient α characterizes the spin dependence of the interaction. In the calculations we used oscillator functions with

$$r_0 = \sqrt{\hbar/M\omega} = 1.98\cdot 10^{-13}\ \text{cm}.$$

The energy of the dipole state E_{dip} and the quantity Δ characterizing its energy spread were calculated in accordance with[2]

$$E_{dip} = \langle\Psi_{dip}|(H-E_0)^2|\Psi_{dip}\rangle / \langle\Psi_{dip}|(H-E_0)|\Psi_{dip}\rangle, \tag{4}$$

$$\Delta^2 = \langle\Psi_{dip}|(H-E_0)^3|\Psi_{dip}\rangle / \langle\Psi_{dip}|(H-E_0)|\Psi_{dip}\rangle - E_{dip}^2, \tag{5}$$

where $E_0 = \langle\Psi_0|H|\Psi_0\rangle$.

The results of the calculations for different values of α and $V_0 = 9/4\pi^{3/2}r_0^3$ are listed in Table II and shown in Figs. 1a, b. The solid curve in Fig. 2 shows the absorption cross section corresponding to g = 1210 MeV-F and $\alpha = 0.15$. The cross section was calculated from the formula

$$\sigma(E) = \frac{\int\sigma dE}{\sqrt{2\pi}\Delta}\exp\left\{-\frac{(E-E_{dip})^2}{2\Delta^2}\right\},$$

with

$$\int\sigma dE = 1800\ \text{mb}\cdot\text{MeV},$$

$$V_0 = 7,\quad \Gamma_{theor} = 2.4\,\Delta.$$

For comparison, the dashed curve represents the experimental results[5] of the (γ, n) reaction. The (γ, p) reaction on Zr^{90} has not yet been investigated.

Thus, the generator model of dipole nuclei is in good agreement with the character of the dipole photoabsorption curve of medium nuclei. The residual interactions between nucleons play qualitatively the same role in medium nuclei as in heavy ones, and cause the giant resonance energy to increase to nearly double the value obtained with the single-particle model.

In conclusion, the author is deeply grateful to V. V. Balashov for suggesting the subject and for continuous help, and also to Yu. F. Smirnov and N. P. Yudin for useful advice and discussions.

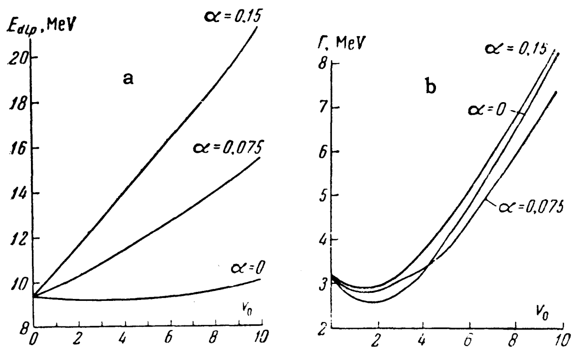

FIG. 1

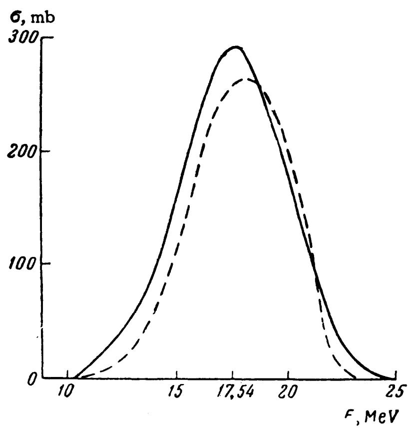

FIG. 2

[1] J. P. Elliot and B. H. Flowers, Proc. Roy. Soc. A242, 57 (1957). Neudachin, Shevchenko, and Yudin, JETP **39**, 108 (1960), Soviet Phys. JETP **12**, 79 (1961); G. Brown and M. Bolsterli, Phys. Rev. Lett. 3, 472 (1959). Balashov, Shevchenko, and Yudin, JETP **41**, 1929 (1961), Soviet Phys. JETP **14**, 1371 (1962); Nucl. Phys. 27, 323 (1961).

[2] V. V. Balashov, JETP, in press.

[3] A. Schröder, Nuovo Cim. 7, 461 (1958).

[4] R. Nathans and P. Yergin, Phys. Rev. **98**, 1296 (1955).

[5] Katz, Baker, and Montalbetti. Canad. J. Phys. **31**, 250 (1953).

[6] M. Naoshi and O. Yuju, J. Phys. Soc. Japan **14**, 1649 (1959).

Translated by J. G. Adashko
138