ANALYSIS OF CHARACTERISTICS OF THE PHOTONUCLEAR REACTIONS WITH CHARGED PARTICLES IN OUTPUT CHANNEL USING EMPIRE II AND TALYS CODES

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Contribution of various photonuclear reaction channels for deriving Giant Dipole Resonance (GDR) parameters is considered. It is shown that output channels with emission of charged particles are very important for some nuclei. GDR parameters for nuclei ^{60}Ni, ^{63}Cu, ^{64}Zn are evaluated taking into account all photonuclear reaction output channels. EMPIRE II and TALYS codes have been used for calculations.

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1. INTRODUCTION

Photo-induced reaction cross section data are of great importance for study the structure of nucleus and mechanisms of nuclear reactions. Also these data are useful for various applications - radiation shielding design, calculations of absorbed dose in the human body during radiotherapy, activation analysis, nuclear waste transmutation, astrophysical nucleosynthesis, physics of fusion and fission reactors.

Photoabsorption cross section is used for characteristics calculation of any photonuclear reaction in the GDR region. Therefore the calculated photoabsorption cross section should be in a good accordance with experimental data to minimize calculation uncertainties of partial cross sections for photonuclear reactions. Semiempirical models [1] with using radiative strength function (RSF) are more preferable for accurate theoretical description of experimental photoabsorption cross sections. GDR parameters of RSF are needed for this calculation. In reality semiempirical methods are parameterization of experimental data and values of GDR parameters are being obtained by fitting of photonuclear reaction cross sections.

2. COMPARISON OF CALCULATED AND EXPERIMENTAL PHOTOABSORPTION CROSS SECTIONS

Nowadays powerful and effective nuclear reaction codes for advanced modeling of nuclear reactions are developed. Such codes as EMPIRE II [2] and TALYS [3] have open source status and allow to calculate in details the cross sections and other characteristics of nuclear reactions. We used EMPIRE II code to test level of accordance with experimental data for theoretical calculation of (γ, xn) and (γ, sn) reaction cross sections. Nearly 100 nuclei were studied. In Fig.1 one can see examples of such rather good theoretical description for (γ, xn) reactions.

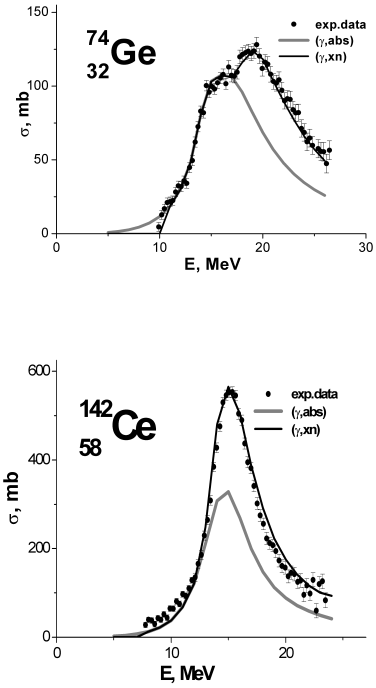

Fig.1. *Examples of good theoretical description of experimental data. (γ, abs) - calculated photoabsorption cross section, filled circles - experimental data [4],[5] for (γ, xn) reaction from EXFOR data base, (γ, xn) - calculated (γ, xn) cross section*

The evaluated values of GDR parameters from library RIPL-2 [6], EXFOR [7] experimental data, MLO model [1] for RSF and other default parameters of EMPIRE II code were used during testing. Good accordance between experimental and calculation data was obtained only for part of nuclei (nearly 70% of all considered nuclei). For other nuclei there are visible (nearly 10-15%) systematic deviations (nearly 20% of all studied nuclei). Also we obtained very large discrepancy for some nuclei. In Fig.2 one can see examples of inadequate theoretical description for (γ, xn) reactions.

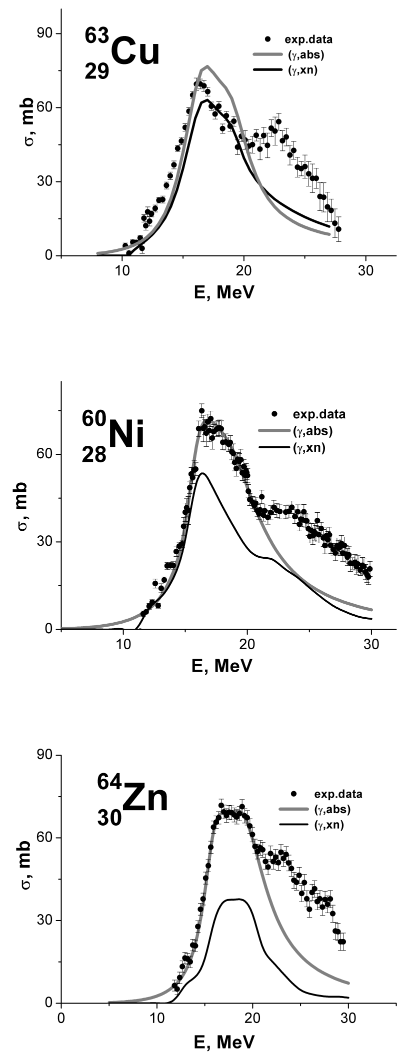

Fig.2. *Examples with large discrepancy between calculated and experimental data.* (γ, abs) *- calculated photoabsorption cross section, filled circles - experimental data [8],[9],[4] for* (γ, xn) *reaction from EXFOR data base,* (γ, xn) *- calculated* (γ, xn) *cross section*

3. METHODS OF EXPERIMENTAL EVALUATION OF GDR PARAMETERS

We considered causes of such large deviations. Fitting the experimental photoabsorption cross sections is the most consistent method to obtain values of GDR parameters. Unfortunately due to experimental difficulties such cross sections are measured only for few nuclei. Therefore photoneutron cross sections are used, based on assumption of negligibly small contribution from emission of charged particles [10]. In the region of excitation energies under threshold of second neutron emission only (γ, n) reaction contributes to GDR peak. For larger energies (nearly after GDR peak maximum) multiple neutron escape is possible. Also one has to take into account that a competition between neutron emission and escape of charged particles (mainly protons and sometimes alpha particles) should exists. Hence complex theoretical calculations with incorporated detailed mechanism of multiple escape of neutrons and protons are needed for accurate analysis.

4. EMISSION OF CHARGED PARTICLES IN PHOTONUCLEAR REACTIONS

During analysis of experimental data and theoretical calculation we came to conclusion that it is necessary to add a contribution of charged particles emission for some nuclei (such as ^{60}Ni, ^{63}Cu, ^{64}Zn) due to large values of photoproton cross sections. One can see in Fig.3 the calculated photonuclear reaction cross sections with emission of charged particles in a good accordance with measured values.

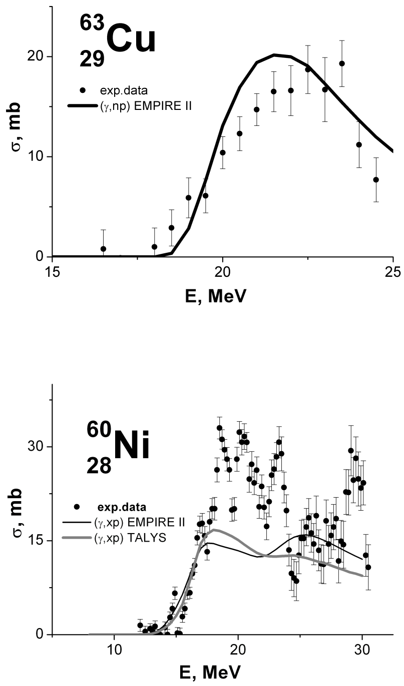

Fig.3. *Examples of calculated values and experimental data [11],[12] of* (γ, np)*,* (γ, xp) *reaction, filled circles - experimental data from EXFOR data base*

These values are not negligible. One can explain irregular discrepancies between theoretical and experimental data for nucleus ^{60}Ni by contribution of nonstatistical processes. Unfortunately the number of experimental data for photonuclear reactions with emission of charged particles is very limited. Using codes like EMPIRE II and TALYS one can perform a fitting of GDR parameters for that nuclei where experimental data about emission of charged particles are absent at all.

5. UPDATING OF GDR PARAMETERS FOR NUCLEI ^{60}Ni, ^{63}Cu, ^{64}Zn

MLO model for RSF, Gilbert-Cameron approach for level densities and other default parameters of code EMPIRE II were used during fitting. Calculated GDR parameters can depend from level density and transmission coefficients of neutrons and protons. But variation of these values is limited by experimental cross-sections data. Calculated photoabsorption and partial cross sections after such fitting of GDR parameters in comparison with experimental data are shown for nuclei ^{60}Ni, ^{63}Cu, ^{64}Zn. One can see sufficiently good results (see Fig.4) in comparison with calculations using values of GDR parameters from RIPL-2 library (see Fig.2).

Values of updated GDR parameters for nuclei ^{60}Ni, ^{63}Cu, ^{64}Zn

Nucleus	E_1, MeV	σ_1, mb	Γ_1, MeV	E_2, MeV	σ_2, mb	Γ_2, MeV	χ^2_n	Reference
^{64}Zn	16,23	41,40	3,27	19,19	56,10	5,98	61,1	RIPL-2 [1, 10]
	16,67	95,10	3,11	19,49	121,10	8,15	1,3	this work
^{63}Cu	16,72	66,10	4,19	19,10	30,10	3,56	29,3	RIPL-2 [1, 10]
	16,52	81,10	4,79	21,50	28,50	5,76	1,7	this work
^{60}Ni	16,30	34,10	2,44	18,51	55,20	6,37	27,9	RIPL-2 [1, 10]
	17,00	51,10	3,45	19,40	54,20	8,90	1,4	this work

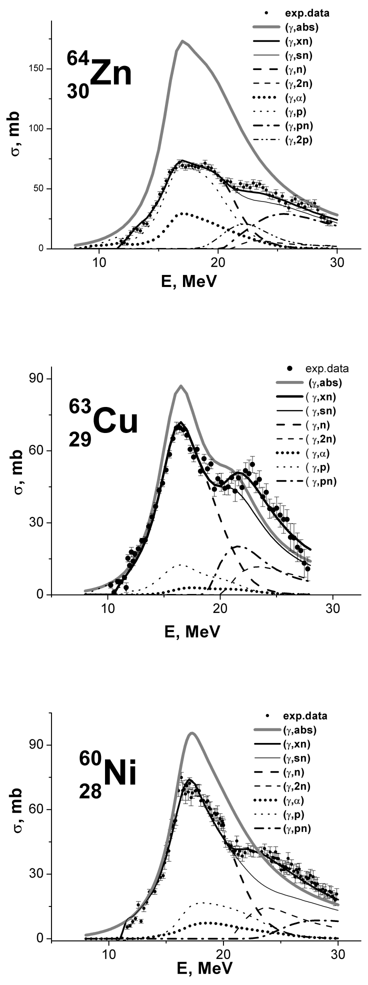

Fig.4. *Calculated photoabsorption and partial cross sections with corrected GDR parameters, filed circles - experimental data [4],[8],[9] for (γ, xn) reaction from EXFOR data base*

Values of updated GDR parameters for nuclei ^{60}Ni, ^{63}Cu, ^{64}Zn are presented in table. $\Gamma_1(\Gamma_2)$, $E_1(E_2)$, $\sigma_1(\sigma_2)$ - width, energy, amplitude of first (second) GDR peak.

The normalized chi-square (column χ^2_n) in the fitting interval 13-30 MeV (13-28 MeV for nucleus ^{63}Cu) is presented for GDR parameters set of RIPL-2 library (line RIPL-2) and for GDR parameters fitted with taking into account emission of charged particles (line this work).

One can see a good accordance of calculation results for codes TALYS and EMPIRE II (see Fig.5) notwithstanding different models for RSF (we used SLO [1] model for TALYS).

Such calculations also can help to analyse fine structure of concurrence dependence between emision neutrons, protons and gamma-quanta in photonuclear reactions.

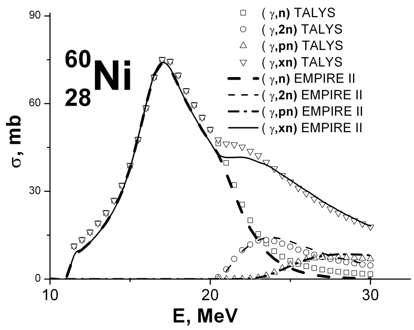

Fig.5. *Comparison of calculations using codes TALYS and EMPIRE II*

6. CONCLUSIONS

Giant Dipole Resonance (GDR) parameters are being calculated usually using only experimental data from photoneutron reactions. Comparison of theoretical calculations with experimental data is complicated in the energy region where multiple neutron escape is possible, but this information is essential to get correct values of GDR parameters. Also one has to take into account that a competition between neutron emission and escape of charged particles (mainly protons and sometimes alpha particles) exists and complex theoretical calculations with incorporated detailed mechanism of multiple escape of neutrons and protons are needed.

In this paper we used code EMPIRE II to evaluate GDR parameters for some medium mass nuclei (^{60}Ni, ^{63}Cu, ^{64}Zn) with all photonuclear reaction output channels considered. This information is useful for extending databases with input parameters for theoretical calculations of nuclear reactions characteristics.

REFERENCES

1. M. Herman, V.A. Plujko. Gamma-ray strength functions // *Reference Input Parameter Library RIPL-2. Handbook for calculations of nuclear reaction data.* IAEA-TECDOC, 2002, (http://www-nds.iaea.or.at/ripl2/).

2. M. Herman , P. Oblozinsky , R. Capote et al. Recent Development of the Nuclear Reaction Model Code Empire // *Proc. of International Conf. on Nuclear Data for Sci. and Technology "ND2004".* Sept. 26-Oct. 1, 2004, Santa Fe (USA). - N.-Y., 2005. - AIP Conf. Proc. v.769, p.1184-1187; http://www.nndc.bnl.gov/ empire219/index.html.

3. A.J. Koning , S. Hilaire , M.C. Duijvestijn. TALYS: Comprehensive nuclear reaction modeling // *Proc. of International Conf. on Nuclear Data for Sci. and Technology "ND2004".* Sept. 26-Oct. 1, 2004, Santa Fe (USA), - N.-Y., 2005, AIP Conf. Proc. v.769, p.1154-1159; http://www.talys.eu/ .

4. P.Carlos, H.Beil, R.Bergere et al. A study of the photoneutron contribution to the giant dipole resonance of nuclei in the 64$\leq$ A $\leq$86 mass region // *Nuclear Physics A*, Feb 1976, v.258, N2, p.365-387.

5. A.Lepretre, H.Beil, R.Bergere, P.Carlos, J.Fagot et all. A study of the giant dipole resonance in doubly even tellurium and cerium isotopes // *Nuclear Physics A*, Feb 1976, v.258, N2, p.350-364.

6. http://www-nds.iaea.org/RIPL-2/

7. http://www-nds.iaea.org/exfor/exfor00.htm

8. S.C.Fultz, R.L.Bramlett, J.T.Caldwell, R.R.Harvey. Photoneutron cross sections for natural Cu, ^{63}Cu and ^{65}Cu // *Phys. Rev. B.* 1964, v.133, N5B, p.1149 - 1154.

9. S.C.Fultz, R.A.Alvarez, B.L.Berman, P.Meyer. Photoneutron cross sections of ^{58}Ni and ^{60}Ni // *Phys. Rev. C.* 1974, v.10, N5, p.608 - 619.

10. S.S. Dietrich, B.L. Berman. Atlas of photoneutron cross section obtained with monoenergetic photons // *Atomic Data and Nuclear Data Tables.* 1988, v.38, p.199-338.

11. V.V.Varlamov, N.G.Efimkin, B.S.Ishkhanov et all. The ^{63,65}CU, NAT (G,NP) reaction cross sections in the Giant Dipole Resonance region // *Vopr. Atom. Nauki i Tekhn. Ser.: Yadernye Konstanty.* 1994, N2, p.3.

12. B.S.Ishkhanov, I.M.Kapitonov, I.M.Piskarev, V.G.Shevchenko. Photoproton cross sections for nuclei with (1F-2P) shell // *JYF.* 1970, N11, (3), p.485.

СРАВНИТЕЛЬНЫЙ АНАЛИЗ РАСЧЕТОВ ХАРАКТЕРИСТИК ФОТОЯДЕРНЫХ РЕАКЦИЙ С ВЫЛЕТОМ ЗАРЯЖЕННЫХ ЧАСТИЦ С ИСПОЛЬЗОВАНИЕМ КОДОВ EMPIRE II И TALYS

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Рассматривается вклад различных каналов фотоядерных реакций для получения параметров гигантского дипольного резонанса (ГДР). Отмечается, что канал с излучением заряженных частиц является очень важным для некоторых ядер. Параметры ГДР для ядер ^{60}Ni, ^{63}Cu, ^{64}Zn оцениваются с учетом всех выходных каналов фотоядерных реакций. Для теоретических расчетов используются коды EMPIRE II и TALYS.

ПОРІВНЯЛЬНИЙ АНАЛІЗ РОЗРАХУНКІВ ХАРАКТЕРИСТИК ФОТОЯДЕРНИХ РЕАКЦІЙ З ВИЛЬОТОМ ЗАРЯДЖЕНИХ ЧАСТИНОК З ВИКОРИСТАННЯМ КОДІВ EMPIRE II И TALYS

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Розглядається вклад різних каналів фотоядерних реакцій для отримання параметрів гігантського дипольного резонансу (ГДР). Відзначається, що канали із випромінюванням заряджених частинок є дуже важливими для деяких ядер. Параметри ГДР для ядер ^{60}Ni, ^{63}Cu, ^{64}Zn оцінюються із урахуванням усіх вихідних каналів фотоядерних реакцій. Для теоретичних розрахунків використовуються коди EMPIRE II і TALYS.