SOME QUESTIONS OF THE NUCLEAR PROPERTIES EVIDENCE IN SIMPLE PHOTONUCLEAR REACTIONS*

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The results of the study of photonuclear reactions at energies of accelerated electrons ranging up to 40 MeV are presented. Under study were simple (γ,n) and (γ,p) reaction processing via the excitation of the metastable longlived nuclear states. The data of the isomeric ratio measurements and comparison with results of calculations made in the framework of the statistical models allow one to investigate some characteristics of the excited intermediate nuclei.

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1. Introduction

The study of nuclear reactions at low energies is one of the main sources of information about the properties and structure of excited nuclear states [1–3]. The calculation of relative cross-sections for population of separated nuclear levels in some simple reactions in this energy range can be made by using the concept of the compound nucleus in the framework of statistical model [2,3]. The comparison of calculated and experimental data allows to obtain the information about the properties of excited nuclei.

The applicability of different representations of the nuclear level density have been also tested (as Fermi gas model, pairing and superconductor models).

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2. Experimental methods

The experimental determination of the reaction yields included the measurements of an induced activity and identification of residual nuclei. The targets in the mass range $A = 85$–179 a.e.m. were irradiated with a beam of bremsstrahlung photons from electrons of the electron linac — the injector of the Yerevan Electron Synchrotron, accelerated up to 40 MeV. The induced activity was measured with the help of HPGe detector. The spectroscopic data for identification of the residual nuclei were taken from [4] and from newly published data. The experimental results are presented in Table.

TABLE

Isomeric Ratios

Target	Product	20 MeV	30 MeV	40 MeV
^{85}Rb ($^5\!/_2{}^-$)	^{84}Rb $m(6^+)$, $g(2^+)$	0.31 ± 0.04 0.21 HV	0.34 ± 0.06 0.23 HV	0.44 ± 0.08 0.25 HV
^{90}Zr (0^+)	^{89}Zr $m(^1\!/_2{}^-)$, $g(^9\!/_2{}^+)$			0.85 ± 0.04 0.84 FM
^{107}Ag ($^1\!/_2{}^-$)	^{106}Ag $m(6^+)$, $g(1^+)$	0.015 ± 0.0045 0.016 PM	0.01 ± 0.002 0.0097 PM	
^{113}In ($^9\!/_2{}^+$)	^{112}In $m(4^+)$, $g(1^+)$		2.21 ± 0.2 2.33 FM	
^{116}Cd (0^+)	^{115}Cd $m(^{11}\!/_2)$, $g(^1\!/_2{}^+)$	0.148 ± 0.02 0.148 PM		
^{124}Sn (0^+)	^{123}Sn $m(^3\!/_2{}^+)$, $g(^{11}\!/_2{}^-)$		0.33 ± 01 0.408 FM	
^{130}Te(0^+)	^{129}Te $m(^{11}\!/_2{}^-)$, $g(^3\!/_2{}^+)$	0.43 ± 0.06 0.3 HV	0.48 ± 0.02 0.38 HV	0.55 ± 0.11 0.4 HV
^{180}W(0^+)	^{179}W $m(^1\!/_2{}^-)$, $g(^7\!/_2{}^-)$		1.93 ± 0.2 1.82 FM	
^{112}Sn(0^+)	^{111}In $m(^1\!/_2{}^-)$, $g(^9\!/_2{}^+)$		≤ 2 1.21 FM	
^{118}Sn(0^+)	^{117}In $m(^1\!/_2{}^-)$, $g(^9\!/_2{}^+)$		0.66 ± 0.07 0.646 PM	0.85 ± 0.08 0.741 PM
^{120}Sn(0^+)	^{117}In $m(^1\!/_2{}^-)$, $g(^9\!/_2{}^+)$	0.53 ± 0.05 0.47 FM	0.68 ± 0.07 0.65 FM	0.68 ± 0.07 0.673 FM
^{179}Hf($^9\!/_2{}^+$)	^{178}Lu $m(9^-)$, $g(1^+)$	0.365 ± 0.04 0.364 FM		

HV — Huizenga and Vanderbosh model [5]; FM — Fermi-gas model [2]; PM — pairing model [2]

3. The excitation of isomeric states in simple photonuclear reactions

One may use the nuclei with isomeric and an unstable ground states for measurement of relative population of these two states in nuclear reactions and to get information on the properties of an excited nucleus. The so-called isomeric cross-sections ratio is defined as relation high–to–low spin nuclear states. Huizenga and Vandenbosch have developed a statistical model procedure to calculate the isomeric ratio [2,5]. At low energies the photonuclear reactions under study proceeded via compound nucleus and can be described in the framework of any statistical model. The representation of these reactions as the ones, in which the escape of one or two nucleons is followed by a γ-quanta cascade allows to calculate the probability of the population of different nuclear states. In the formalism proposed in [5] the main element of calculations is the density of the distribution of nuclear levels. By fitting the calculated isomeric rations to the experimental ones one can obtain information on the spin dependence of nuclear level density, in particular, on spin cut-off parameter σ, the parameter a of the level density and can determine the moment of inertia I of the nucleus in the intermediate state. The main disadvantage of this formalism is the presence of some free parameters, such as a number of γ-quanta in cascade and the spin cut-off parameter. We attempt to avoid these uncertainties by making some additional assumptions about reaction mechanism. The calculation scheme was as follows.

1. Excitation energy of a nucleus was determined from the photoabsorption cross-section in the vicinity of giant resonance and the photon spectra of bremsstrahlung in Shiff's form. We have used the Lorentzian form of the absorption cross-sections [3].

2. Since the quadrupole photoabsorption is approximately 10% in this energy range, the spin state of the compound nucleus was determined at the assumption of dipole photoabsorption. There are nuclear states with spin projections $+1$ and -1 for the even–even target nuclei and $J_0, J_0 \pm 1$ for the initial nucleus spin J_0 [5].

3. The escaping neutrons with $l = 0$ have the mean energy $E_n = 2T$ [5,6], where T is the nuclear temperature to be determined as $1/T \approx (a/E^*)^{1/2} - 3/4E^*$, where E^* is the excitation energy, a is the level density parameter. In calculations we have used two values of a-parameter: $a = A/8$ and $a = A/9$.

4. The excitation energy of the residual nucleus was estimated as difference $E = E^* - B - E_n$, where B the energy threshold of the reaction,

E^* is the mean excitation energy. In cases of proton evaporation one must also take into consideration the repulse Coulomb energy.

5. The γ-quanta in the cascade are assumed to have dipole nature and mean energies $E_\gamma = 4(E^*/a - 5/a^2)^{1/2}$ [6].

6. The density distribution function of nuclear levels has the from [5]:

$$\rho(J,E) = \rho(E)\rho(J)\,,$$

   where $\rho(J)$ is the spin part of the density distribution, that play the main role in the process of production residual nuclear states:

$$\rho(J) = (2J+1)\exp[-(J+1/2)^2/2\sigma^2]\,,$$

   where σ is the cut-off parameter the depends on inertia momentum of nucleus as rigid body ($I = 2MAR^2/5$, where J is the spin, M is the nucleon mass, A is the nucleus mass number, R is the nuclear radius. This dependence has different form in the considered model representations, above mentioned).

7. The calculations were made up to excitation energy level 1–2 MeV. The γ-transitions lead to the population of metastable or ground states. The probability of the latter transition was estimated by using the spin selection rule and strength functions [6,7].

The calculation data are given in Table in comparison with experimental results. The most adequate description are the ones obtained by using Fermi-gas and pairing model approximations and a parameter values are $A/8$ and $A/9$. The calculated effective moment of inertia of the intermediate nucleus taken as a rigid body is lass then 1 (0.75–0.8), that seems to be probable for excitation energies expected in this type reactions.

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