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EXCITATION OF ISOMERIC STATES $1h_{11/2}$ IN (γ, n) REACTIONS

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1. Introduction

Photonuclear reactions (PNR) at low and mean energies of γ-quanta are of important source of information on atomic nuclear structure. One of the directions in researching γ-quanta is measuring the probabilities of nucleus production in separated quantum state. Such investigations will be the most effective if the studied states are in isomeric relation with sufficiently large half-lives so that to separate the irradiation processes and measurements with time.

The goal of the present work is the measurement of isomeric ratios (IR) (the ratios between the reaction cross sections for producing the nuclei in isomeric and ground states) in (γ,n) reactions at excitation energies in the region of the Giant Dipole Resonance for the wide range of nuclei (16 isotopes from ^{107}Pd up to ^{143}Sm) with odd numbers of neutrons. The probability of population of these high spin states at β-decay is very small, therefore the usage of PNR is a very convenient method of their research.

The isomeric state with the same spin and evenness of $11/2^-$ has been chosen for all investigated nuclei, and the isotopes in the reaction involved are the even-odd ones which have spin 1^- upon γ-quantum absorption. Thus, for isomeric state excitation in all studied isotopes there have been chosen the identical conditions - the same type of reaction and excitation energy, the same spins of the primary and residual states. Therefore one can expect that the changes of the measured isomeric ratios when passing from one nucleus to another will be specified by the fact that how the level structure through which isomeric states are populated changes. The obtained experimental data allow one to judge both statistical properties of these levels (the dependence of their density of energy and spin) and their spectroscopical characteristics - spins, evennesses, probabilities of transition of different multipolarity into isomeric state. The information on these nuclear parameters known by now is rather scanty. There are just separated data on IR measured in some isotopes Pd, Cd, Te, Nd, Sm [1-3].

2. Spectroscopic characteristics of nuclei with isomeric states $1h_{11/2}$.

A single-quasiparticle state with $J^{\pi} = 11/2^-$ appears in nuclei with N>50 when neutron shell is filled with $1h_{11/2}$. By now this has been observed in more than 70 nuclei from Zr (Z = 40) up to Yb (Z = 70) [4]. In most cases (more than 50 isotopes) this state is the isomeric one with half-life higher than 1 sec. and many of them can be produced in the reaction (γ, n).

In Table 1 there are presented spectrometric characteristics of the investigated nuclei - spin and evenness of the ground and isomeric states (J^{π}), binding energy of neutron (B_n), half-life ($T_{1/2}$) and energy (E_{is}) of the isomer [5]. It is seen that the energy of the isomeric state is maximum at the beginning and at the end of the studied nuclei region and is minimum at N=71-75 in the isotopes Sn and Te. The state $11/2^-$ is the ground one in the nuclei ^{123}Sn and ^{125}Sn. In the rest nuclei $3s_{1/2}$, $2d_{3/2}$ and $2d_{5/2}$ are the ground states.

Table 1. Nuclear-physical characteristics of investigated nuclides

Nuclde	Z	N	Ground states		Isomeric states	
			J^{π}	B_n, MeV	$T_{1/2}$	E_{is}, кеV
^{107}Pd	46	61	$5/2^+$	6.53	21.30 s	214.9
^{109}Pd	46	63	$5/2^+$	6.15	4.69 m	188.9
^{115}Cd	48	67	$1/2^+$	6.14	44.60 d	181.0
^{117}Sn	50	67	$1/2^+$	6.95	13.60 d	314.6
^{123}Sn	50	73	$11/2^-$	5.95	40.10 m	24.7*
^{119}Te	52	67	$1/2^+$	7.60	4.69 d	261.0
^{121}Te	52	69	$1/2^+$	7.17	154,00 d	294.0
^{123}Te	52	71	$1/2^+$	6.93	119.70 d	247.6
^{129}Te	52	77	$3/2^+$	6.09	33.60 d	105.5
^{133}Ba	56	77	$1/2^+$	7.19	38.90 h	288.3
^{135}Ba	56	79	$3/2^+$	6.97	28.70 m	268.2
^{137}Ba	56	81	$3/2^+$	6.68	2.55 m	661.6
^{137}Ce	58	79	$3/2^+$	7.48	34.40 h	254.3
^{139}Ce	58	81	$3/2^+$	7.47	56.80 s	754.2
^{141}Nd	60	81	$3/2^+$	7.80	62.0 s	756.7
^{143}Sm	62	81	$3/2^+$	8.61	66.00 s	754.0

* Isomeric state have spin $3/2^+$.

Isomeric states are characterized by close values of the magnetic moments (about one half of value is calculated by the Schmidt model [6]) and reduced radiation M4-transition probabilities from the isomeric level into $3/2^+$ state (1-2 single-particle units of Weiskopff). This is a demonstration of small impurities of other configurations and identity of the isomeric level properties in the whole investigated range Z and A. At the same time the spectrum of these excited states essentially differ for different nuclei investigated. Among them there are nuclei with the closed proton shell (SNP isotopes), with one hole in the closed neutron shell (^{135}Xe, ^{137}Ba, ^{139}Ce, ^{141}Nd, ^{143}Sm), transition ones between spherical and deformed (^{109}Pd, ^{133}Ba).

3. Experimental

The yields of the investigated isotopes in the ground and isomeric states were measured on the MT-25 microtron extracted beam of the Flerov Laboratory of Nuclear Reactions, JINR. The description of this microtron and its main characteristics are presented in the work [7]. Electron energy variation was effected in two ways: over a wide range - transition from orbit to orbit, in the energy range up to 1.8 MeV - with changing the magnetic field. The cooled device of tungsten disk 2 mm in thickness behind which there was located the aluminium electron absorber 30 mm in thickness was served as a bremsstrahlung target. The wolfram target serves as a catcher of electrons passing through it in a time of each irradiation and which was measured with the help of the electrical charge integrator. Electron energy was determined by measuring the microtron magnetic field with the method of nuclear magnetic resonance and by measuring the frequency of accelerating electrical field. Instability of electron energy during the experiment didn't exceed 50 keV.

Both pure metals (Pd, Cd, Sn, Te, Nd) and their oxides (BaO, Ce_2O_3, Sm_2O_3) usually from natural isotopic composition were used as samples. In certain cases separated isotopes (^{144}Sm) with a small content of the studied isotope in natural impurity were irradiated. As a rule the samples have ≅100 mg weight and the surface square of ≅ 1cm^2.

The residual activity of the irradiated samples was measured with the help of Ge(Li) detector 60 cm^3 in volume and with the resolution of 3 keV (for the line 1332 keV ^{60}Co. The detector efficiency was determined by a set of standard samples OSGI.

Usually, in the experiments the current of accelerated electrons was ≅20 μA, irradiation time - from some minutes to 5 hours, and measurement time -

until collecting the necessary count statistics (as a rule, of some thousands of pulses in peak of the measured γ-line). Spectra were processed with the help of the ACTIV program [8], which allows to separate a complex γ-spectrum with close γ-lines.

3. Results

Independent yields $Y(E_{\gamma max})$ of isomeric and ground states were measured in the experiment by comparison of photopeak squares. To determine these yields the contribution was taken into account from interfering reactions leading to the same isotopes. Reactions of such types could be (γ,p) with the following β^--decay and (n,2n) on the irradiated isotope, and also (n,γ), (n,n') and (γ,γ') in the impurities of other isotopes which are especially large in using the samples of natural isotopic composition. The yields of these reactions were determined in special experiments (under irradiation of corresponding separated isotopes, in changing the γ-quanta energy or neutron flux). In all cases the contribution of these reactions changed IR not more than by 10%. The measured yields of (γ,n) reactions are connected with the cross sections (differential for the chosen energy of γ-quanta $\sigma(E_\gamma)$ and integral $\sigma_{int}(E_{\gamma max})$ ratio:

$$Y(E_{\gamma max}) = \int_{E_{th}}^{E_{\gamma max}} \sigma(E_\gamma)\, N(E_\gamma, E_{\gamma max})\, dE_\gamma \qquad (1)$$

$$Y(E_{\gamma max}) = \frac{\sigma_{int}(E_{\gamma max})}{E_{\gamma max} - E_{th}} \int_{E_{th}}^{E_{\gamma max}} N(E_\gamma, E_{\gamma max})\, dE_\gamma \qquad (2)$$

where E_{th} - the energy of γ-radiation corresponding to the threshold of the (γ,n) - reaction, which results in isomeric and ground states, $E_{\gamma max}$ - the upper limit of the bremsstrahlung spectrum (it corresponds to the energy of accelerated electrons), $N(E_\gamma, E_{\gamma max})$ - the number of γ-quanta in the bremsstrahlung spectrum with the energy E_γ.

From equations (1) and (2) one can make a conclusion that the ratio of the (γ,n) - reaction yields measured in the experiment with nuclei production in isomeric and ground states corresponds to the ratio of integrated cross sections upon correction insertion per threshold difference of these reactions $\eta(E_{th})$:

$$\frac{Y(E_{\gamma max})_m}{Y(E_{\gamma max})_g} = \frac{\sigma_{int}(E_{\gamma max})_m}{\sigma_{int}(E_{\gamma max})_g}\, \eta(E_{th}) \qquad (3)$$

where indexes m and g are related to isomeric and ground states, respectively. The value of $\eta(E_{th})$ correction was determined by the energy of the isomeric level and accounted from 5% for ^{129}Te nucleus up to 20% for ^{143}Sm.

In Fig.1 there is presented one of the measured γ-spectra produced under the Te sample irradiation of the natural isotopic composition by the bremsstrahlung with the energy limit of 25 MeV. In spectrum one can see the ground and the isomeric states of nuclei ^{119}Te, ^{121}Te, ^{123}Te, and ^{129}Te produced in photonuclear reactions. The many times repeated measurements were performed for experimental determination of half-life of the investigated radionuclides. In most cases the ground state was a radioactive one except the states of ^{107g}Pd, ^{117g}Sn, ^{123g}Te and ^{135,137g}Ba. For ^{123}Te the IR determination with the direct method becomes impossible for lack of the appropriate γ-lines in the ground state. Thus, the yield of ^{123m}Te was

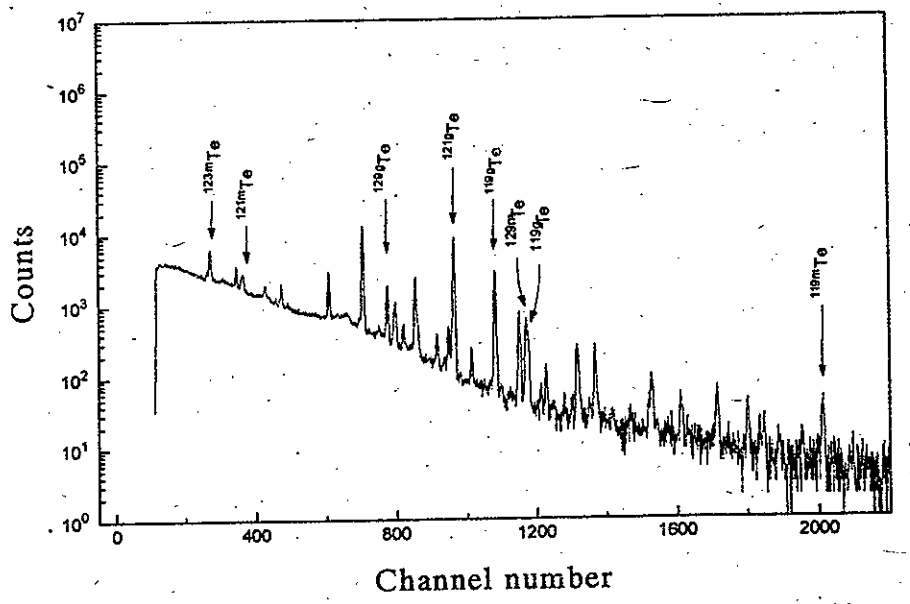

Fig.1. Ta_{nat} γ-spectrum produced upon irradiation by bremsstrahlung $E_{\gamma max}$= 25 MeV. (Irradiation time is 4 hours, cooling time - 23 hours and time of spectrum collecting - 15 minutes)

compared with the yield of neighbouring ^{121m}Te and related to the ground state of ^{121}Te assuming that there was a small difference of the complete (γ,n) cross section for both isotopes.The isotopes ^{117m}Sn and ^{123}Sn have the same decay γ-lines (E_γ = 159.7 keV). Upon determination of the slope of the curve of the corresponding long-lived isomer (^{123m}Sn) subtracting the values of the activity of nuclei ^{123m}Sn from the curve one can define the true curve of nuclei decay of the isomer ^{117m}Sn. Further IR was determined in the same manner as for the Te isotopes.

IR as the ratios of integrated cross sections for 16 nuclei (isotopes Pd, Cd, Sn, Te, Ba, Ce, Nd and Sm) at the energy limit of the bremsstarhlung $E_{\gamma max}$ =25 MeV were obtained by the same procedure. These ratios of IR (σ_m/σ_g) are presented in the last column of Table 2.

Table 2. Integrated values and isomeric ratios of investigated nuclides

Reactions	E_{th} , MeV	σ_{int}, mb·MeV	σ_m/σ_g
^{108}Pd(γ,n)^{107m}Pd	9,43	67(7)	0.054(60
^{110}Pd(γ,n)^{109m}Pd	9.00	77(8)	0.060(7)
^{116}Cd(γ,n)^{115m}Cd	8.87	199(20)	0.18(2)
^{118}Sn(γ,n)^{117m}Sn	9.69	90(18)	0.11(2)
^{124}Sn(γ,n)^{123m}Sn	8.49	285(29)	0.33(3)*
^{120}Te(γ,n)^{119m}Te	10.67	209(22)	0.20(2)
^{122}Te(γ,n)^{121m}Te	10.14	307(28)	0.26(2)
^{124}Te(γ,n)^{123m}Te	9.67	379(30)	0.31(3)
^{130}Te(γ,n)^{129m}Te	8.51	460(45)	0.43(5)
^{134}Ba(γ,n)^{133m}Ba	9.75	256(20)	0.17(1)
^{134}Ba(γ,n)^{133m}Ba	9.38	259(20)	0.15(1)
^{136}Ba(γ,n)^{135m}Ba	9.27	162(12)	0.12(1)
^{138}Ce(γ,n)^{137m}Ce	9.98	157(20)	0.19(2)
^{140}Ce(γ,n)^{139m}Ce	9.95	223(20)	0.14(1)
^{142}Nd(γ,n)^{141m}Nd	10.66	110(15)	0.061(10)
^{144}Sm(γ,n)^{143m}Sm	11.25	91(9)	0.047(4)

* The given values relate to excitation cross-section ratio of the ground state $11/2^-$ and isomeric one $3/2^+$.

The values of integrated cross sections for the isomeric states were obtained by two methods. A number of nuclei are known by complete reaction cross sections (γ,n) - sums of cross-sections for ground and isomeric states [9]. Using the measured IR and the indicated complete cross sections one could determine the values $\sigma^m_{int}(E_{\gamma max})$. When nuclei in the ground states produced in the reactions (γ,n) were stable or with very long half-lives, the relative method of measurement so that to determine $\sigma^m_{int}(E_{\gamma max})$ was applied using the reaction ^{65}Cu(γ,n)^{64}Cu as a standard (the integrated cross section of this reaction at $E_{\gamma max}$ = 23 MeV is 426 mb.MeV [10]. In those cases in order to determine IR the complete integrated cross sections from interpolation of the known data were used [9].

The values $\sigma^m_{int}(E_{\gamma max})$, obtained with such methods and thresholds of the reaction (γ,n) equal the sum of neutron binding energy in the primary nucleus and the energy of isomeric level are given in Table 2. The error of the values σ_{int} and σ_m/σ_g is ≅10% and mainly determined by the error in measuring the yields of γ-radiation emitted at the decay of nuclei produced in the ground and isomeric states.

For a number of nuclei (isotopes Ba and Ce) there were measured differential cross sections and excitation functions of the (γ,n) - reactions, resulting in the ground and isomeric states. These data in the case of Ba isotopes are given in our previous work [11]. It turned out that the IR values obtained from the integrated cross sections are near IR for differential cross sections in the peak of the giant dipole resonance (≅15 MeV). So, the values σ_m/σ_g presented in Table 2 one can consider as IR at excitation energy of primary nucleus of ≅ 15 MeV.

4. Results and discussion

The measured cross sections of the (γ,n)-reactions leading to $11/2^-$ ground and isomeric states in the wide range Z (46-62) and N (63-81) allow one to trace the IR change for the given nuclei and to reveal the influence of nuclear structure upon them.

As seen from Table 2 for the lightest and heaviest nuclei which correspond to the beginning and the end of the isomerism "island" of these states IR and with it the integrated cross sections are the lowest ones. The isotopes Sn and Te which differ almost one order of magnitude in comparison with nuclei being at the edge of the studied region have maximum. In the work [11] one observes the IR dependence of mass number in Ba isotopes. In this case it correlates with a quadrupole deformation parameter. The Ba isotopes are

characterized by increasing both the dynamical quadrupole deformation in the primary even-even nuclei and statistical one in residual odd nucleus with distance from semimagic nucleus ^{138}Ba [12,13].

The IR dependence for the Te isotopes at maximum energy of γ-quanta E_γ=25 MeV is shown in Fig.2. Tellurium nuclei are nearby the Sn nucleus closed in proton number and characterized by a slight change of quadrupole deformation of these isotopes. IR increases with neutron increasing for the Te isotopes. As one can see, the highest IR has ^{129}Te. This ratio is the highest isomeric value among all neutron states $h_{11/2}$ investigated by us. The IR results for the Ba isotopes at γ-quanta energy E_γ = 25 MeV are presented in this figure along with it. For the Ba isotopes the IR dependence has the opposing tendency. As we approach the neutrons semimagic in number (^{138}Ba) IR decreases. This is connected with decreasing the level density as the closed neutron shell N=82 is approached. One should note that IR for the Pd and Sn isotopes has the same tendency as for Te, i.e. it increases with the mass number increase although, on the other hand, it decreases with the mass number increase for the Ce isotopes as for the Ba isotopes.

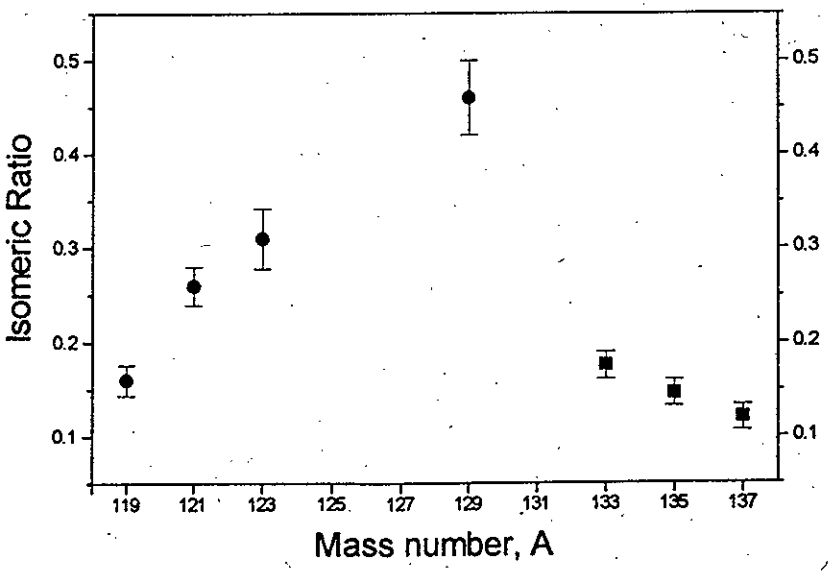

Fig.2. Isomeric ratio of Te • and Ba ■ isotopes.

It is of interest to consider the IR isotone dependence. In this case the isotopes with the closed neutron shells (N=82) as ^{138}Ba, ^{140}Ce, ^{142}Nd and ^{144}Sm are the favourable group. In the (γ,n)-reactions in these nuclei the states with the same spins and evennesses in isomeric and ground states and approximately with the same coefficients of quadrupole deformation in the ground state are excited. Moreover, the isomeric level for the ^{139}Ce, ^{141}Nd and ^{143}Sm isotopes is at 754 keV above the ground state. For ^{137}Ba this level has the energy of 661 keV. Thus, such factors as the difference of isomeric and ground states in spins which, as seen from the Table, is the same for all and equals ΔJ=4 should not appear in IR. So, the same nuclear isomer structure assumes unessential differences in their excitation and decay.

The IR dependence of Z for isotopes with N=82 is shown in Fig.3. The data for ^{136}Xe(γ,n) are taken from the work [3] at maximum gamma-quanta energy of 22 MeV. IR has a peak in the region of ^{140}Ce and ^{138}Ba. This dependence decreases as the "closed" proton shell Z= 64 is approached. Probably the analogous situation will be observed on the left side of this dependence as we approach to the other closed proton shell Z=50.

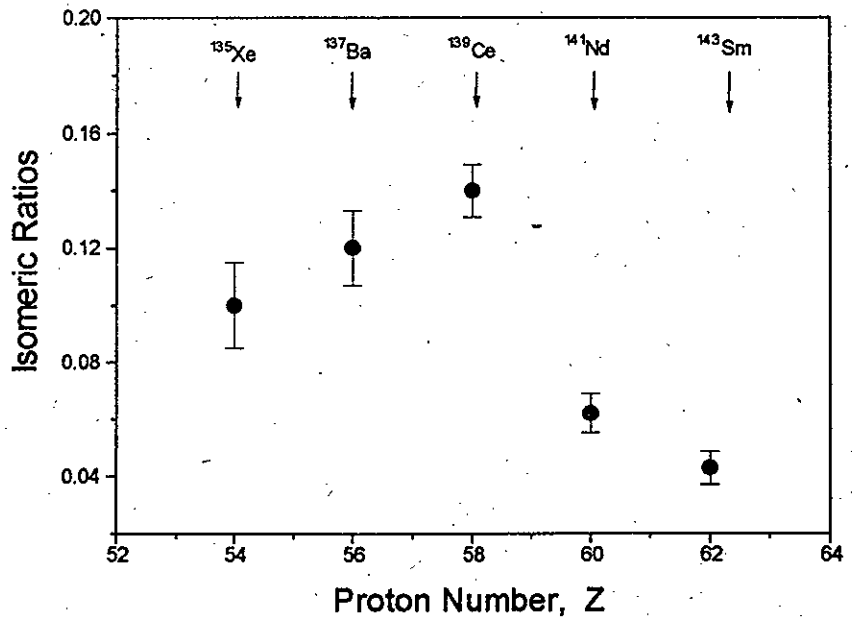

Fig.3. IR versus Z for isotopes with N = 81

Thus, the specific scheme of levels located just over the isomeric state and which is the source of populating the states with spin $J^{\pi} = 11/2^-$ affects IR. The question of disposition of these levels over the energy relatively the isomeric state, their spins and evennesses to a greater extent determine the probability of population of the isomers involved.

5. Statistical calculation of isomeric ratios

The above-mentioned similarity of excitation functions for (γ,n)-reactions resulting in isomeric and ground states allows one to assume the same population scheme of these states - the excitation of the giant dipole resonance and the decay of the compound nucleus with neutron and γ-quanta emission.

In Fig.4 the excitation scheme of these states in PNR with one neutron escape is shown. Upon neutron emission from a state in the primary nucleus with spin and evenness of 1^- (dipole absorption), states in the residual nucleus with spin 1/2, 3/2 and 5/2 are populated. The probability of the direct population of isomeric states $h_{11/2}$ upon neutron emission is small, that's why when they are populated the multicascade process occurs. However, on the way of such cascade γ-decay there must be the levels with spin and evenness $7/2^-$ and $9/2^-$ which populate the isomeric states $h_{11/2}$ with the most probability. With these states the γ-quanta cascade leading either to the ground state or to the isomeric one begins.

With such scheme of isomer population when all studied nuclei are characterized by the same spins at each stage of the reaction mentioned above IR is determined by the following factors:

1. Parameters determining the dependence of the level densities from the energy (a) and (σ).

2. Nucleus excitation energy upon neutron escape whereby the γ-quanta cascade begins. The value of this energy is determined by the equation:

$$E^* = E_{eff} - B_n - \varepsilon_n \qquad (4)$$

where E_{eff} - effective excitation energy, B_n - neutron binding energy, and ε_n- kinetic energy of the neutron escaping from the nucleus.

A peculiarity of PNR with the bremsstrahhlung lies in the fact that in the process of photoexcitation the γ-quanta both with the minimum energy and with the energy equal the maximum electron energy are involved. However, as many experimental results imply IR varies slightly in the (γ,n) - reactions

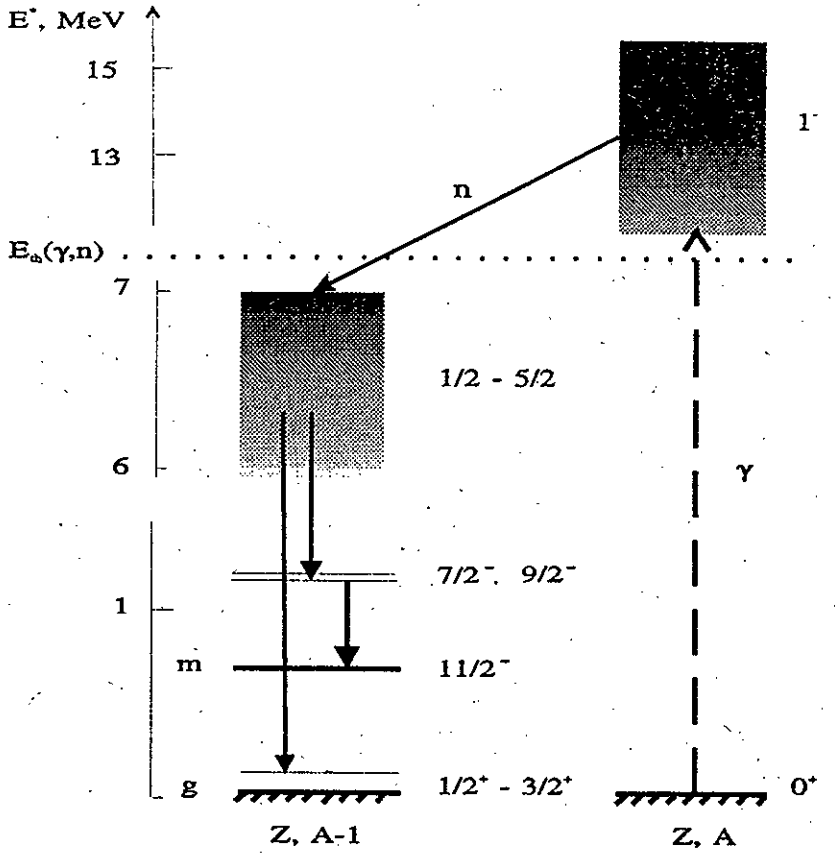

Fig.4. Excitation of isomeric states $11/2^-$ in (γ,n)-reactions

beyond the giant dipole resonance. This suggests that in PNR with one neutron escape the energy center of gravity is in the region of (14-16MeV). It is determined by the ratio:

$$E_{eff} = \frac{\int_{E_{th}}^{E_{\gamma max}} E\,\sigma(E)\,N(E_\gamma, E_{\gamma max})\,dE_\gamma}{\int_{E_{th}}^{E_{\gamma max}} \sigma(E)\,N(E_\gamma, E_{\gamma max})\,dE_\gamma} \qquad (5)$$

where $\sigma(E)$ and $N,(E_\gamma, E_{\gamma max})$ are cross section and bremsstrahlung spectrum, respectively.

Thus, the experimental values of the γ-quanta energy in the maximum excitation cross section were taken as the E_{eff} values [9].

From measuring the neutron spectra in the (γ,n)-reactions in the nuclei region near the studied one it follows that $\varepsilon_n \cong 1$ MeV [14]. With such values E_{eff} and ε_n the value E for different nuclei lies in the range of 3-6 MeV.

3. Specific scheme of the levels connected with isomeric states by radiation transitions. In this scheme the levels with $J^\pi = 7/2^-$ or $9/2^-$ play an important role. With these levels the direct E2-transition into the isomeric state is possible and they are most near the states by their spin value, populated upon neutron emission from the nucleus. Thus, the probability of populating these levels in the γ-quanta cascade and a part of transitions from them into isomeric state finally define the IR value.

Using such a simplified approach the IR values were calculated with the EMPIRE-program [15]. Comprehensive data of these calculations are described in detail in the work [16]. All known descrete levels and relative transitions between them were taken into consideration. Above this energy region the excitation states were described by the Fermi gas equation.

In Fig.5 experimental IR values from the excitation energy of a residual nucleus are presented. In the same Figure there are illustrated the IR minimum and maximum calculated by statistical model upon one neutron emission. The upper straight line (IR_H) is obtained with the values a and σ, 22 and 5, respectively, the lower curve (IR_L) corresponds to the minimum and maximum of $a = 11$ and $\sigma = 3$. The minimum and maximum of a and σ in this region of mass numbers known from neutron resonances correspond to these values [17].

The majority of the IR experimental values is in the region between the both calculated curves. It means that varying the parameters of the level density and the limit parameter by spin one can achieve the agreement between the calculated values and the experimental ones. However, for the isotopes ^{129}Te, ^{123}Te, ^{123}Sn the IR experimental values are beyond the scope of the maximum calculated curve (IR_H).

6. Conclusion

At present there is no full experimental information on the indicated states for all nuclei investigated. Recently in the work [18] at radiation neutron capture on the isotopes ^{122,124}Te there have been detected states with spin

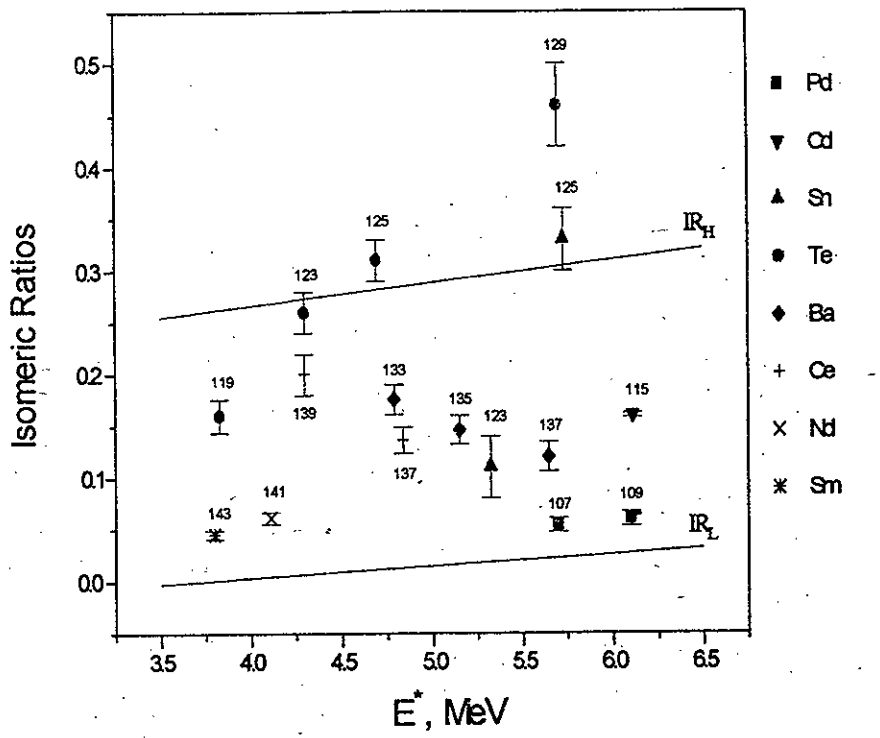

Fig.5. IR versus excitation energy of residual nucleus. Straight lines of IR_L and IR_H correspond to parameters $\alpha = 11$, $\sigma = 3$ and $\alpha = 22$, $\sigma = 5$. The number of each experimental value corresponds to the mass nucleus number.

and negative evenness $7/2^-$ and $9/2^-$ which completely decay at the isomeric level. In this connection a large integrated capture cross section (σ^m =1b) was observed on ^{124}Te isotope [19].

One should note that anomalously large integrated cross section (10 mb.keV) in this region was observed in γ-quanta inelastic scattering reactions on the same isotope as well [20]. A large integrated cross section according to our experimental results is due to a large isomeric ratio which is 0.33 for ^{125}Te .

Thus, from experimental results one can assume that in ^{125}Sn and ^{125,129}Te these activation levels are at more closer distance from the isomeric states

$h_{11/2}$, than e.g. on the isotopes ^{107}Pd and ^{143}Sm. Moreover, the states 7/2$^-$ and 9/2$^-$ in the tellurium and scandium isotopes are the main source of population of the isomeric states $h_{11/2}$.

Therefore, the position of these levels, i.e. the distance from the isomeric state $h_{11/2}$ will affect the intensity of these transitions. The problem of "binding" of these activation levels with isomeric or ground states is essential as well.

Another peculiarity of our results lies in the fact that "heavy" isotopes such as Ce, Nd and Sm have the related IR as for the light ^{107,109}Pd. They are just above the calculated curve (IR_L) with the minimum a and σ. However, from experimental data on neutron capture for nuclei Ce, Nd it follows that the level density parameter and the limit parameter by spin take generally the values more than 15 and 4, respectively [17]. In this connection one can assume that the scheme of levels for heavy isotopes essentially differs from that one for isotopes Te and Sn.

It is likely that further experimental researches connected with the population of the isomeric states $h_{11/2}$ can substantially elucidate the excitation process of these states.

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References

1. T. Deague, E.G. Muirhead and B.M. Spicer, *Nucl.Phys.* A139 (1969) p.501.
2. H.D. Luc, T.D. Thiep, T.T. An, P. An, *Bulg. J. Phys.*, v.14, N2 (1987) p.153.
3. M.G. Davidov, V.G. Magera, A.V. Truhov, *Atomnaj Energija*, v.62, N.4 (1987) p.236.
4. C.M. Lederer, V.S. Shirley, *Tables of Isotopes*. N.Y.: J.Wiley and Sons Inc., 1978.
5. E. Browne and R.B. Firestone, *Table of Radioactive Isotopes*. 1986. edited by Shirley V.S.
6. A. Bohr and B.R. Mottelson, *Nuclear Structure*, v.1, 2 (Benjamin, New York,
7. A.G. Belov, *Workshop on application of microtrons in nuclear physics* 1992. D15-93-80. p.12.
8. V. Zlokazov, *Com. Phys. Comm.* v.28 (1982) p.27.

9. S.S. Dietrich and B.L. Berman, *Atomic Data and Nuclear Data Tables*, v.38 (1988) p.199.
10. S.C. Fultz, R.L. Bramblett, J.T. Caldwel, R.R. Harly, *Phys.Rev* 133, (1964) B1149.
11. A.P. Tonchev, Yu.P. Gangrsky, A.G. Belov et al., *Preprint* JINR E15-95-91, Dubna, 1995.
12. S. Raman, W.C. Nestor, Jr.S. Kahane, and K.H. Bhatt, *Atomic Data and Nuclear Data Tables*. v.42 (1989) p.1.
13. P. Raghavan, *Atomic Data and Nuclear Data Tables.*, v42, (1989) p.189.
14. A.M. Gorjachov, G.N. Zalesny, *Izv. Akad. Nauk* SSSR, Ser.Fiz. 54 (1990) p.2240.
15. M. Herman, A. Marcinkowski and K. Stankiewicz, *Comp. Phys. Comm*, v.33 (1984) p.373.
16. N.P.Balabanov, A.G. Belov, Yu.P. Gangrsky, F.G. Kondev, A.P. Tonchev, H.G.Hristov, *Preprint* JINR (1993) E15-93-370.
17. W. Dilg, H. Schatl, H. Vonach and M. Vhe, *Nucl.Phys.* A217 (1973) p.269.
18. J. Honzatko, K. Konecny, I. Tomandl, *Z.Phys.* A345 (1993) p.429.
19. V.G. Alpatov, A.V. Davidov, G.R.Kartashov et al., *Yad. Fiz.* v.58 (1995) p.15.
20. J.J. Carroll, T.W. Sinor, D.G. Richmond et al., *Phys.Rev.*C. v.43 (1991) p.897.

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