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ISOMERIC TARGETS AND BEAMS

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Introduction

During the last few years there has been taking place an intensive development of radioactive beam facilities for the investigation of nuclear reactions and properties of radioactive nuclei by "in-beam" nuclear spectroscopic methods. At the same time, the radioactive target technique in many cases has certain advantages connected with a possibility to use traditional methods as well as earlier built accelerators and experimental arrays.

Nuclear reactions with high-spin partners are in the focus of attention of modern physics. During the decades only $^{180}Ta^{m}(9^-)$ and $^{176}Lu(7^-)$ practically stable isotopes were available as high-spin targets. Their level schemes, neutron resonance parameters as well as high-spin levels in neighbouring nuclei were studied [1-6] using these targets. Recently, a more exotic 16^+ four-quasiparticle isomer of $^{178}Hf^{m_2}$ ($T_{1/2}$=31 years) was added to the group of the high-spin targets [7] and the first nuclear reactions on it were successfully observed [8,9]. The interest to nuclear reactions with high-spin isomers has been enhanced by the theoretical consideration of the K-mixing in excited nuclei and a search for an efficient pumping process in an actual γ-laser problem [10].

A wide international collaboration of research groups from France, Germany, USA and Russia was organized [11] to study electromagnetic and nuclear interactions of the $^{178}Hf^{m_2}$ isomer since it could give important information on shell structure manifestations in interactions with the impact radiation. This talk contains a current review of collaborative work, carried out after the previous report [12]. The progress in reactions with $^{178}Hf^{m_2}$ isomer, some new ideas of future experiments as well as possibilities for the isomeric beam formation are also described. Well known results from literature obtained earlier in reactions with ^{176}Lu and $^{180}Ta^{m}$ targets are not included to save space.

I. Creation of the $^{178}Hf^{m_2}$ target

The $^{178}Hf^{m_2}$ isomer has an excitation energy (E^*=2.446 MeV) below the yrast-line and thus is an yrast-trap with the longest known lifetime. Its shell model configuration and high value K=16 make it an intriguing object for studies both of the nuclear structure and of nuclear reactions. Methods of the $^{178}Hf^{m_2}$ production and of target preparation are described here in brief.

For the production of the isomer it is necessary to choose a producing reaction which is optimum with respect to both the absolute yield and the isomeric-to-ground state ratio as well as to arrange intensive long irradiations. After a series of experiments on different beams from γ-rays up to ^{12}C ions we have chosen the producing reaction $^{176}Yb(^4He,2n)^{178}Hf^{m_2}$. The measured cross-section and excitation function of this reaction are presented in fig.1. The stable isotopes $^{178,177,176}Hf$ excitation functions were calculated using the statistical model code. So, the isomer-to-ground state ratio σ_{m_2}/σ_g could be determined as a function of ^4He-ion energy. The known values of σ_{m_2}/σ_g for the $^{178}Hf^{m_2}$ production are presented in fig.2 and their systematical dependence from the maximum angular momentum of a projectile is seen. In the case of an α-induced reaction the σ_{m_2}/σ_g value reaches 3–6%, meanwhile, the cross-section is about 5–9 mbarns in an optimum energy range near 28–36 MeV. For 36 MeV ^4He ions we can estimate, taking into account the energy losses, that the $^{176}Yb_2O_3$ target thickness of about 90 mg/cm^2 is the optimum one.

The absolute production yield of about $3 \cdot 10^8$ isomeric atoms per second was achieved in the irradiations on the external beam of the U-200 cyclotron at FLNR JINR. The maximum intensity of a 36 MeV $^4He^{++}$ beam was restricted by the level of 100 μA due to the target instability. A special design of the Yb_2O_3 target on a cooled substrate was worked out to solve the problem of long expositions to a powerful beam. The effective beam time used for the production of the $^{178}Hf^{m_2}$ isomer in the course of three years totals to about 2500 h. There have been produced more than $1.5 \cdot 10^{15}$ atoms of the isomer, i.e. about 0.5 μg.

A very important question is the purification of the produced isomeric material both from ballast activities and weight contaminations by widely spread elements. A high enriched isotope ^{176}Yb (99,998%) was produced on the mass-separator at Orsay specially to eliminate the activities of ^{172}Hf and ^{175}Hf in the hafnium fraction. Clean backing materials and chemically purified $^{176}Yb_2O_3$ oxide were used for the cyclotron target preparation.

The long-lived activities induced in the cyclotron target after irradiation due to reactions on admixtures are listed in table 1. In the chemical processing for the hafnium fraction isolation all these activities were washed out. It means that the chemical methods worked out [12] specially for hafnium isolation provide a complete purification from ballast activities and also from many weight contaminants with different chemical properties.

Finally, the prepared $^{178}Hf^{m_2}$ sources and targets were deposited onto Be, C, Al or quartz substrates. The purity of the backings is also very important. So they were controlled by means of neutron and proton induced activation analysis. For example, typical activities induced in a Be foil after bremsstrahlung (E_m=23 MeV) irradiation are listed in table 2. Quantitative information on impurities was used to choose the purest backing materials. Small diameter (down to 3 mm), uniform layer deposition on thin foils were achieved using delicate chemical methods such as electrospraying of hafnium acetate. Chemical manipulations with $^{178}Hf^{m_2}$ activities can lead to the new build-up of contaminations because high purity reagents are not available in all the cases. The $^{178}Hf^{m_2}$ targets on thin carbon foils were finally prepared for the studies of charged particles induced reactions and they were

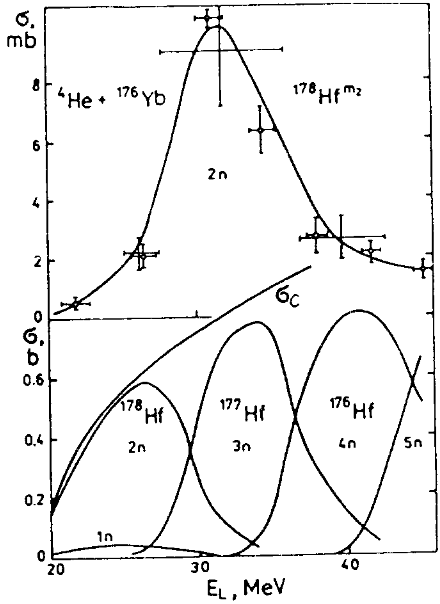

Fig.1. Excitation functions for the $^{178}Hf^{m2}$ isomer (measured) and $^{178,177,176}Hf$ stable nuclei (calculated) produced in the nuclear reactions $^{176}Yb(^{4}He, xn)$.

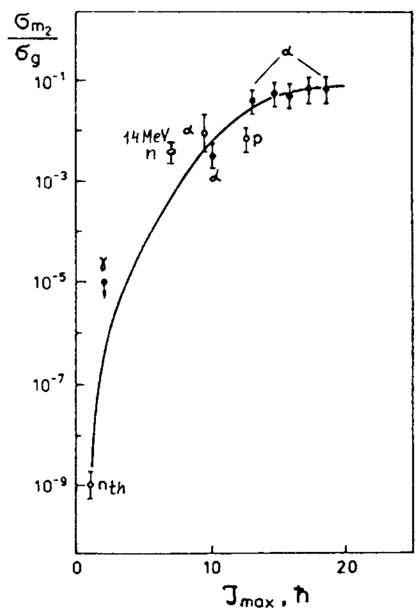

Fig.2. Isomeric to ground state ratio σ_{m_2}/σ_g as a function of the incident particle maximum angular momentum J_{max}. Closed circles show the measured values, opened ones are taken from literature.

Table 1. Radioactive nuclides presented in the ^{4}He ion exposed $^{176}Yb_2O_3$ target

Nuclide	$T_{1/2}$	E_γ, keV	Admixture
^{7}Be	53 d	478	Al-backing
^{22}Na	2.6 y	1275	Al-backing
^{46}Sc	84 d	889	Sc
		1121	
^{51}Cr	28 d	320	Cr
^{54}Mn	312 d	835	Mn
^{56}Co	77 d	847	Mn, Fe
		1238	
^{57}Co	272 d	122	Mn, Fe, Co
		136	
^{58}Co	71 d	811	Fe, Co
^{65}Zn	244 d	1116	Cu, Zn
^{88}Y	107 d	898	Sr, Y
		1836	
^{88}Zr	85 d	393	Sr, Y
^{134}Cs	2.1 y	605	Cs, Ba
		796	
^{139}Ce	138 d	166	Ba, La

Table 2. Photon induced analysis of the ^{178}Hf target on a Be backing

Radioactive nuclide	$T_{1/2}$	E_γ, keV	Admisture
^{34m}Cl	32 min	1176	Cl
^{44}Sc	3.9 h	1157	Sc
^{47}Sc	3.3 d	159	Ti
^{49}Cr	42 min	153	Cr
^{53}Fe	8.5 min	378	Fe
^{56}Mn	2.6 h	847	Fe
^{57}Ni	36 h	1378	Ni
^{63}Zn	38 min	670	Zn
^{64}Cu	12.7 h	1346	Cu
^{68}Ga	68 min	1077	Ga
$^{85}Sr^{m}$	68 min	232	Sr
$^{87}Sr^{m}$	2.8 h	388	Sr
^{89}Zr	3.3 d	909	Zr

analyzed using the X-ray fluorescence technique. The results are given in table 3. One can see that the first target contains Br, Zr and Pt while two other targets, prepared using special measures against contaminations, do not contain these elements. The absolute quantity of the total Hf weight was determined too and the result was not much different from that predicted using fig.1 data.

II. Experimental studies of nuclear reactions with ^{178}Hf^{m_2}

The ^{178}Hf^{m_2} isomeric state has a shell model configuration ($\pi 7/2^+, \pi 9/2^-, \nu 7/2^-, \nu 9/2^+$). Fortunately, there are similar long-lived enough isomeric states in the neighbouring nuclei: ^{177}Hf^{m_2} (J^π=37/2$^-$, $T_{1/2}$=51.4 min, ($\pi 7/2^+, \pi 9/2^-, \nu 5/2^-, \nu 7/2^-, \nu 9/2^+$)) and ^{179}Hf^{m_2} ($J^\pi$=25/2$^-$, $T_{1/2}$=25.1 d, ($\pi 7/2^+, \pi 9/2^-, \nu 9/2^+$)). One can expect that these states will be populated with a high cross section in the (γ,n) and (n,γ) reactions on a ^{178}Hf^{m_2} target because of similar shell-model configurations of the target and of the residue states.

In principle, it is not a very hard task to search for the activities of ^{177}Hf^{m_2} or ^{179}Hf^{m_2} induced in the ^{178}Hf^{m_2} target by exposing it to a γ- or n- flux. The γ-decay properties of these three isomers are given in table 4, and one can see many specific γ-lines with a high quantum yield emitted at the decay of each isomer. So, the idea to study the (γ,n) and (n,γ) reactions on the exotic ^{178}Hf^{m_2} isomer by the activation technique was formulated as early as four years ago [14]. These experiments have been realized [8,15,16] and the results are described below.

Another group of experiments has as the main objective the study of reactions induced by charged particles on a ^{178}Hf^{m_2} target by the "in-beam" nuclear spectroscopy methods. The (d,d') inelastic scattering, (p,t)-reaction and the Coulomb excitation by ^{208}Pb-ions on a ^{178}Hf^{m_2} target were observed successfully [9,17,18] as described below.

2.1. Resonance neutron capture reaction on a ^{178}Hf^{m_2} nucleus

The interest to studying the neutron capture reaction on the isomeric ^{178}Hf^{m_2} nucleus is motivated by a possibility to get information on high-spin neutron resonances and to touch on the question of spin dependence of the level density as well as to follow the γ-cascades and levels feeding in the deexcitation process. In Dubna experiment on the reactor IBR-2 [8] thermal cross-section and resonance integral values were estimated for the first time for the reaction ^{178}Hf^{m_2} (n,γ)^{179}Hf^{m_2}:

$$\sigma_{th} = (50 \pm 10) \text{ barns};$$

$$I_\gamma = (800 \pm 130) \text{ barns}.$$

It means that the ^{178}Hf^{m_2} nucleus has strong neutron resonances in the eV energy region. The major population of the m_2 state in residue nucleus ^{179}Hf can be deduced, otherwise the total resonance integral becomes too high. This result permits to formulate an experiment for measurements of neutron resonance parameters of the ^{178}Hf^{m_2} target.

The estimation of the neutron resonance position by the method of selective neutron filters was performed [19] in Orsay with using the Saclay "Osiris" reactor for the targets activation. When the activated sample is surrounded by the filter layer, the neutron spectrum is modified in a predictable way. So, a strong resonance energy position can be estimated because the filter changes the activation yield only in the case of a resonance presence at the position of the filter absorption band. The ^{10}B (81% enriched), Er_2O_3 and Rh layers in

Table 3. Results of X-ray fluorescent analysis of the $^{178}Hf^{m_2}$ targets on thin carbon backings

Number of the target	X-ray counts*), 10^3/s		
	Br	Zr	Pt
1	0.18	0.30	0.033
2	0.099	0.0188	0.0018
3	-0.0006	0.0202	-0.0034

*) Background subtracted count. rate

Table 4. Major γ-lines of the $^{177}Hf^{m_2}$, $^{178}Hf^{m_2}$ and $^{179}Hf^{m_2}$ isomers decay

$^{177}Hf^{m_2}$		$^{178}Hf^{m_2}$		$^{179}Hf^{m_2}$	
E_γ, keV	I_γ, %	E_γ, keV	I_γ, %	E_γ, keV	I_γ, %
113.0	27.0	88.9	62.0	122.7	28.0
128.5	20.2	93.2	17.3	146.[illegible]	27.3
153.3	21.8	213.4	80.9	169.8	19.6
208.4	73.0	216.7	63.7	192.8	21.8
214.0	40.9	237.4	8.8	217.0	9.1
228.5	48.0	257.6	16.6	236.6	19.0
277.3	75.8	277.4	1.5	268.9	11.4
295.1	69.0	296.8	9.8	316.0	20.5
311.5	58.8	325.6	93.9	362.6	40.1
326.7	65.4	426.4	96.9	409.8	21.7
327.7	23.7	454.0	16.3	453.7	68.6
378.5	39.3	495.0	68.7		
418.5	28.1	535.0	8.9		
638.2	20.1	574.2	83.6		

addition to the Cd screen were used as filters. Total neutron cross-sections are given in fig.3 for the filter materials and for gold used as a control sample. Rhodium is a typical example of a resonance filter since it absorbs neutrons only in a narrow region near the resonance energy E_r=1.3 eV. The ^{10}B material is a filter of another type, because its total cross-section shows, on the contrary, a uniform decrease at a low $\sim E^{-1/2}$. The boundary energy of strong absorption is dependent in a regular way on the ^{10}B layer thickness. The $^{178}Hf^{m_2}$ samples for the neutron irradiation were prepared on pure Al foil substrates. About 10^{12} atoms of $^{178}Hf^{m_2}$ were placed on each sample.

For the neutron irradiation there was used a pneumotransport channel of the "Osiris" reactor at Saclay. A standard size container was transported to the position near the reactor active zone where the neutron flux reached $2 \cdot 10^{14}$ n/cm^{2}s. The construction of the irradiation device is shown schematically in fig.4. The container wall has a 1 mm Cd layer between two Al shells. So, a thermal neutron flux was damped perfectly while resonance neutrons, $E_n \gtrsim 0.5$ eV, were slightly absorbed. The filter layers were pressed down into a thin wall (0.5 mm) Al cup. A couple of such filters with the sample between them were placed in the transverse hole of the Al cylinder which was inserted in an Al-Cd container. Four $^{178}Hf^{m_2}$ samples were exposed simultaneously. After the end of 65 hour exposure the container was delivered in a shielded box, where it was shaken out by the manipulator and all elements fell down separately being not fixed in.

The activated targets were taken out and were studied on a HP Ge γ-spectrometer after a 3 day cooling. The enormous background of the ^{24}Na ($T_{1/2}$=15 h) activity produced in the (n,α)-reaction on Al foils was decaying, spectra were cleaned up and the searched activity of $^{179}Hf^{m_2}$ was detected successfully in all $^{178}Hf^{m_2}$ targets exposed with different filters.

The typical spectrum of the neutron exposed $^{178}Hf^{m_2}$ sample is presented in table 5. All lines of $^{179}Hf^{m_2}$ have correct intensity ratios. The areas of the $^{179}Hf^{m_2}$ peaks are determined with a statistical accuracy better than 1%. The number of $^{178}Hf^{m_2}$ and $^{179}Hf^{m_2}$ atoms and their ratio $N_{at}^{179m_2}/N_{at}^{178m_2}$ were determined after the processing of γ-spectra. The statistical accuracy of much better than 1% was reached due to averaging of the figures determined by all lines in many spectra measured during two weeks. An eventual inaccuracy of the Ge detector efficiency (calibrated by absolute sources) do not influence strongly the final result, $N_{at}^{179m_2}/N_{at}^{178m_2}$, because both of the numbers are determined basing on the same efficiency function. However, the γ-quanta yield per decay is given in the literature compilation with a limited accuracy and it is accumulated in the error of the final result.

The activation yield of the residue nucleus $N_{at}^{res}/N_{at}^{targ}$ is connected with the neutron fluence Φ and the resonance integral value I_γ by the following equation:

$$N_{at}^{res}/N_{at}^{targ} = \sigma_{th}\Phi_{th} + I_\gamma c \Phi_{res},$$

where c is the spectrum normalizing constant. The first term of this equation is negligible due to full absorption of thermal neutrons when the irradiation is done with a Cd screen. The activation yield measured without any filter (in addition to Cd) gives a possibility to deduce the I_γ values for the $^{178}Hf^{m_2}$ (n,γ)$^{179}Hf^{m_2}$ reaction:

$$I_\gamma = (1060 \pm 60) \text{ barns},$$

which does not deviated strongly from the previous estimation [8]. The fluence absolutization is based on the gold activation yield measured. The tabular resonance integral value I_γ=(1560±40) barns for the ^{198}Au yield was used. For the $^{179}Hf^{m_2}$ yield the standard de-

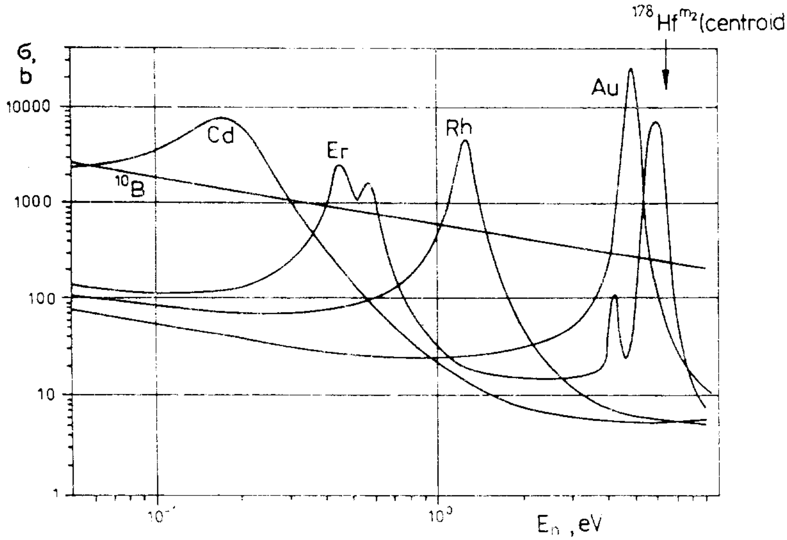

Fig.3. Energy dependencies of the total neutron cross-sections for ^{10}B, Rh, Cd, Er and Au nuclei.

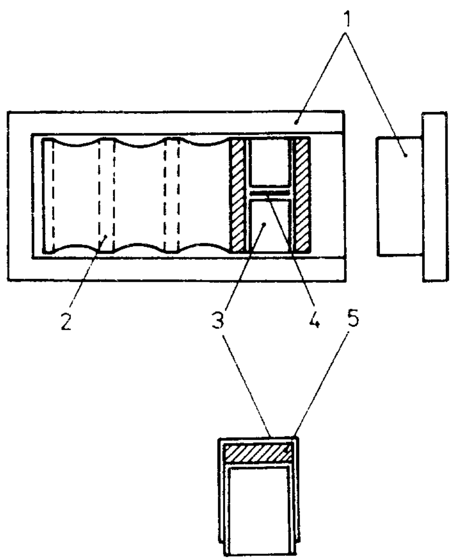

Fig.4. Schematic picture of a device for the neutron irradiation:
1 – container, 2 – insert cylinder, 3 - filter cup, 4 – sample, 5 – filter material.

Table 5. Typical γ-spectrum of the neutron exposed $^{178}Hf^{m_2}$ target

* — lines of the $^{179}Hf^{m_2}$

E_γ, keV	Area, counts	Error, counts	
122.7	46172	593	*
146	45348	558	*
169.8	32294	433	*
192.8	35734	412	*
213.4+ 217	431338	1031	
237	50672	475	
257.6	46396	490	
268.9	13757	320	*
316.0	18999	298	*
325.6	192174	513	
362.6	32706	280	*
426.4	159018	447	
454	72910	315	
495.0	104917	360	
535.0	12277	176	
574.2	115535	380	

Table 6. Yields of the radioactive isotopes $^{179}Hf^{m_2}$ and ^{198}Au induced in the epicadmium neutron irradiation of the $^{178}Hf^{m_2}$ and ^{197}Au targets as a function of the filter species.

Filter material		$^{nat}Er_2O_3$	^{nat}Rh	^{10}B (81%)
Average thicknesss, g/cm^2		0.56	0.33	0.077
Absorption band, eV		0.37-0.63 5.25-6.45	1.02-1.55	$\leq$5.2
$N_{at}^{179m_2}/N_{at}^{178m_2}$	$1.20\cdot10^{-3}$	$1.02\cdot10^{-3}$	$1.06\cdot10^{-3}$	$0.596\cdot10^{-3}$
Reduction factor	1.0	0.85	0.88	0.497±0.005
$N_{at}^{198}/N_{at}^{197}$	$1.77\cdot10^{-3}$			$0.783\cdot10^{-3}$
Reduction factor	1.0			0.442±0.003

viation of the I_γ value includes random errors and systematical errors of all tabular data used.

The variation of the activation yield as a function of filter species is presented in table 6 for the Hf and control Au samples. The 4π averaged filter thickness was calculated taking into account a 0.5 mm air gap between the sample and the filter cup, see fig.4. Using that and the cross-section functions shown in fig.3 one can calculate for each filter the band of the flux absorption down to $\leq e^{-1}$ level. The absorption band intervals are also given in table 6. As one can see in table 6 such filters as Er and Rh influence slightly the yield while the ^{10}B filter suppresses the yield significantly. It means that no major resonances of the studied reaction are found at an energy range 0.3-2 eV. The ^{10}B filter damps the ^{198}Au yield a little more drastically than the one for the ^{179m}Hf. Since the ^{197}Au (n,γ) reaction has a single powerful resonance at E_r=4.91 eV, we can conclude that in the reaction $^{178}Hf^{m2}$ (n,γ) the centroid of the resonance strength is placed near a 6 eV neutron energy. If one assumes a single resonance in the latter reaction, the result taken with the ^{10}B filter will contradict the one with the Er filter which has a resonance just at an energy of 5.9 eV. So, one can make a conclusion about the presence of at least two resonances at energies of perhaps 4-5 and 7-8 eVs.

This conclusion is in a good agreement with the statistical theory estimations which give the mean interresonance distance of about 4 eV for the $^{178}Hf^{m2}$ target. So the model predictions for the spin dependence of the level density are confirmed now experimentally. The second conclusion can be done: the high value of the resonance integral value for the $^{179}Hf^{m2}$ yield indicates perhaps the preferential population of the high-K isomer in the residue nucleus when the target nucleus is also a high-K isomer.

2.2. Test for the ^{178}Hf^{m2} $(\gamma,n)^{177}$Hf^{m2} reaction yield

Photonuclear reactions with a high-spin isomeric nucleus is a real challenge in the study of giant resonances built on high-K states as well as of the K-mixing at high excitation [19]. The idea of the presence of special K-mixed levels at some excitation energy (2-4 MeV) was suggested after the experimental observation of the threshold behaviour of the isomer feeding in photonuclear reaction as a function of the bremsstrahlung boundary energy E_m. It was supported [20] after revealing some short lived high-K isomers which are decaying on the low-K levels without any significant hindrance factor. The excitation energy of the $^{178}Hf^{m2}$ isomeric state should be eventually not far from the first K-mixed level and one can expect the allowed depopulation of high-K structure in all nuclear reactions such as (γ,γ'), (γ,n), (n,γ) on this isomer. The result taken in the $^{178}Hf^{m2}$ $(n,\gamma)^{179}Hf^{m2}$-reaction supports rather the stability of the high-K structure. So, it is most interesting to study the (γ,n)-reaction on $^{178}Hf^{m2}$ nucleus.

The $^{178}Hf^{m2}$ $(\gamma,n)^{177}Hf^{m2}$ reaction is a unique case when the reaction on a four-quasiparticle K^π=16^+ isomeric target leading to another exotic five-quasiparticle K^π=$37/2^-$ isomer could be detected experimentally. This is because the $^{177}Hf^{m2}$ isomer ($T_{1/2}$=51.4 min) has decay properties convenient for the observation by the activation technique (see table 4). However, the background conditions due to bremsstrahlung induced activation of all elements were rather hard because a low enough absolute level of the $^{177}Hf^{m2}$ activity is expected. Be foil was chosen as a target backing material since it is activated slightly by the bremsstrahlung, the yield of the ^7Be activity is small enough.

A $^{178}Hf^{m2}$ target of $3\cdot10^{13}$ atoms on a Be substrate was prepared using precision radiochemical methods. A lot of care was taken to find the purest Be foil as well as to purify

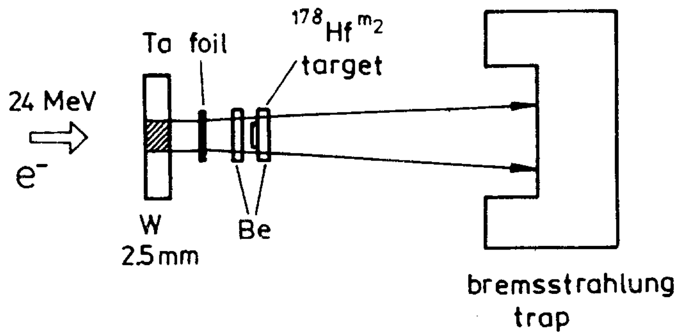

Fig.5. Scheme of the experiment on bremsstrahlung induced activation of the $^{178}Hf^{m2}$ target.

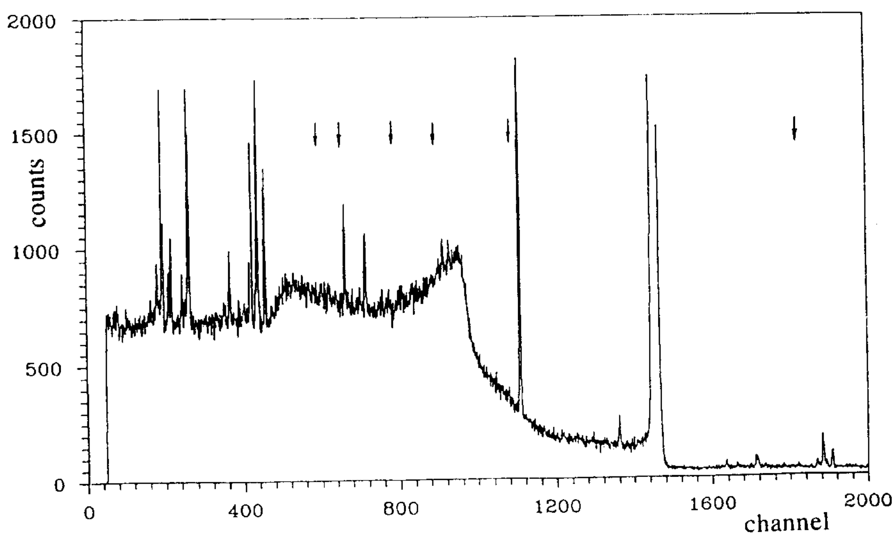

Fig.6. γ-spectrum of the catcher after 24 MeV bremsstrahlung irradiation of the $^{178}Hf^{m2}$ target.

the hafnium fraction from both ballast activities and weight contaminants. This target was exposed to the bremsstrahlung with maximum energy of 24 MeV on the electron beam with an intensity of 15 μA of the MT-25 microtron at Dubna. The irradiation scheme was optimized to reach the maximum sensitivity, it is shown in fig.5.

The activated samples were placed just after the 2.5 mm W converter. The Ta foil was used as a control sample for the absolutization of the standard photoneutron yield using the reaction ^{181}Ta(γ,n)^{180}Ta^{g}. The ^{178}Hf^{m_2} target was covered with a Be catcher to collect the ^{177}Hf^{m_2} atoms recoiled eventually from the thin target layer. Almost isotropic neutron emission in the (γ,n) reaction leads to about 50% efficiency of the activity collection by the catcher.

After the irradiation the activities of both the target and the catcher were measured on the high-resolution "Ortec" and "Canberra" HP Ge γ-detectors as well as on a Si spectrometer of conversion electrons with a magnetic guide line. The experimental condition such as the geometry and time intervals of the irradiation and measurement were optimized, however, the searched for ^{177}Hf^{m_2} activity was not manifesting itself in the spectra. The γ-spectrum of the catcher taken 15 min after a 100 min irradiation is shown in fig.6. The intensive lines should be attributed to the activities listed in table 2 which are generated in the reactions on contaminants in the Be foil. Only the upper limit of the ^{177}Hf^{m_2} activity yield can be estimated by the spectrum shown in fig.6. The activated ^{178}Hf^{m_2} target itself was also studied, but the sensitivity was not better due to a high enough self activity of the ^{178}Hf^{m_2} isomer.

Finally after a series of irradiations and measurements using γ and e$^-$ spectrometers the yield of the ^{178}Hf^{m_2} (γ,n)^{177}Hf^{m_2} reaction was limited to about 20% of the ^{181}Ta(γ,n)^{180}Ta^{g} reaction yield:

$$Y(^{177}Hf^{m_2})/Y(^{180}Ta^{g}) \leq 0.2.$$

This unexpectedly low feeding probability for the ^{177}Hf^{m_2} isomeric state in the evaporation residue of the (γ,n)-reaction seems to be a significant result for physical interpretation. Proceeding from the earlier observed [6,8] high probability of the ^{178}Hf^{m_2} (n,γ)^{179}Hf^{m_2} and ^{180}Ta^{m}(γ,2n)^{178}Ta^{m} reactions, one can predict for the ^{177}Hf^{m_2} state the feeding intensity of about 50% of the total reaction yield. The experimental result deviating from this prediction can be interpreted by efficient trapping of the deexcitation cascade intensity on some levels connected with the ground state band by enhanced transitions. It is also necessary to study theoretically whether the regular statistical code is capable of explaining the observed feeding intensity of ^{177}Hf^{m_2}. In such calculations the deexcitation cascade is considered normally in the coordinates of excitation energy E^* and spin J, no selection by the K-quantum number is assumed. So this could be a real confirmation of the K-mixing if the statistical calculation reproduces the experimental results on isomeric levels population in reactions with high spin isomeric targets.

2.3. Charged particles induced reactions on the ^{178}Hf^{m_2} target

In the framework of the international "Hafnium collaboration" a few experiments were performed to study the nuclear properties of the ^{178}Hf^{m_2} isomeric state using the "in-beam" nuclear spectroscopic technique. A high quality beams of European accelerators and precision spectrographs created earlier were used successfully in these experiments [9,17,18]. The spectra of the inelastically scattered deuterons and protons were measured in the Muenchen experiment with the first ^{178}Hf^{m_2} target prepared on a thin C backing at Orsay from the material produced at Dubna. The quantity of the ^{178}Hf^{m_2} isomer was 2.1×10^{14} atoms in a spot of 5 mm in diameter. The Q3D spectrograph of nuclear reaction products on the Muenchen Tandem beam has an energy resolution of about 4 keV including the beam resolution [21], and it determines the quality of charged particle spectroscopic measurements. As already discussed in refs.[12,17,22] the excitation of the first level (17^+) of the rotational band built on the 16^+ isomeric state was probably observed in the spectra of the (p,p') and (d,d')-reactions. Such an attribution of the peak placed at an excitation energy E^*=353 keV looks reliable because its position and amplitude are in accordance with preliminary theoretical estimations. However, the evidence strength is not an absolute one. So it was important to confirm the position of the 17^+ level by another method.

The Coulomb excitation of the $^{178}Hf^{m2}$ isomeric target was studied recently on the ^{208}Pb ion beam with an energy of 980 MeV and intensity of about 3 electrical nA on the "Unilac" accelerator at Darmstadt. The precision "Coulex" array was worked out earlier for the measurement of the absolute probability of the Coulomb excitation as a function of the impact parameter in heavy-ion collisions [18]. It consists of a 4π gas filled position-sensitive avalanche counter system for the detection of scattered nuclei and eight HP Ge γ-detectors switched on coincidences. The γ-spectra were processed by a special computer code in order to introduce the Doppler-shift correction. During a one week run on the ^{208}Pb beam the spectra taken on the isomeric $^{178}Hf^{m2}$ targets as well as on the targets prepared by the same method from stable enriched hafnium isotopes were recorded. The spectra of the isomeric and stable ^{177}Hf targets are compared in fig.7. The stable isotopes composition of both targets was qualitatively similar, and one can see that almost all peaks are observed in identical positions in both spectra. So, the only evident additional peak at E_γ=354 keV in the spectrum of the isomeric target can be attributed to the $^{178}Hf^{m2}$ nucleus. The energy of this peak is just near the position which was observed earlier in the (d,d') spectrum and it is most probable that an energy of the $17^+ \rightarrow 16^+$ transition in the rotational band built on the isomeric state is really about 354 keV. The moment of inertia $\mathcal{J}$ of this rotational band can be deduced immediately using the equation:

$$E_I = \frac{\hbar^2}{2\mathcal{J}}[J(J+1) - J_0(J_0+1)]\,,$$

where J_0 is the spin value of the basic level of the band. In table 7 the moments of inertia deduced in the same way from the energy position of the first levels in the K=0 g.s.b. ($J^\pi = 2^+$), in the K=8 band ($J^\pi = 9^-$) and in the K=16 band ($J^\pi = 17^+$) are compared. The strong increase of $\mathcal{J}$ value is evident when decoupling of quasiparticles takes place. This result is not unexpected, however, it is interesting for the theoretical interpretation in terms of the superfluidity reduction with the decoupling of nucleon pairs. The quantitative treatment of the absolute counting rate for the 17^+ peak in the Coulomb excitation and (d,d') spectra will lead to the determination of the B(E2) value, static quadrupole moment Q_0 and quadrupole deformation parameter β_2 for the isomeric 16^+ state ^{178}Hf.

One can anticipate the observation of the second level 18^+ of the K=16 band in addition to the 17^+ level, however the statistics in the spectrum shown in fig.7 is not sufficient to observe the transition $18^+ \rightarrow 16^+$ at an energy near 700 keV. The schematical pattern of the Coulomb excitation process is presented in fig.8. Taking into account the excitation probability, the deexcitation branching and the detector efficiency variation one can estimate that the peak intensity of the $18^+ \rightarrow 16^+$ transition should be about 20 times lower than the $17^+ \rightarrow 16^+$ peak in the spectrum. The statistics should be increased by about 10 times in order to observe the second level of the K=16^+ band. A lead beam intensity 10 times higher

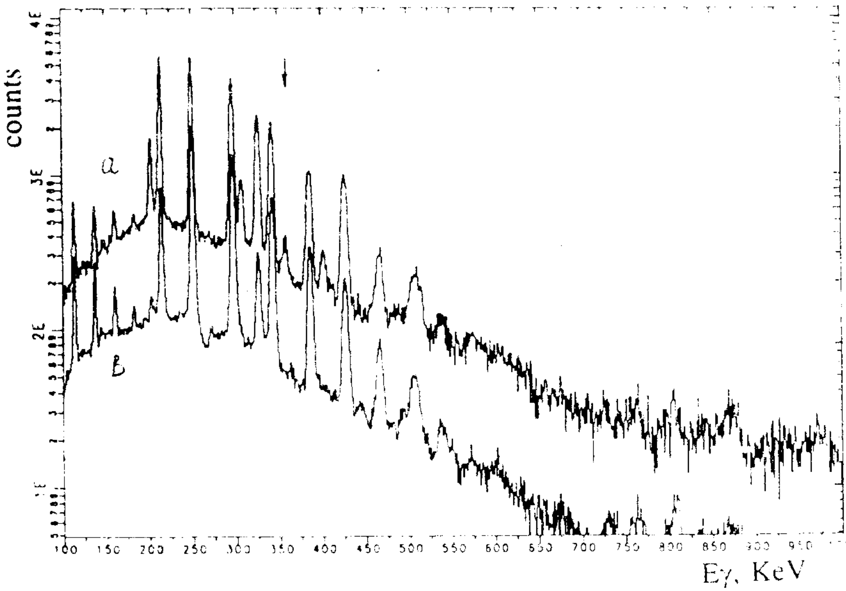

Fig.7. γ-spectra of the Coulomb excitation of the isomeric $^{178}Hf^{m2}$ (**a**) and enriched ^{177}Hf (**b**) targets taken on the beam of ^{208}Pb ions with an energy of 980 MeV.

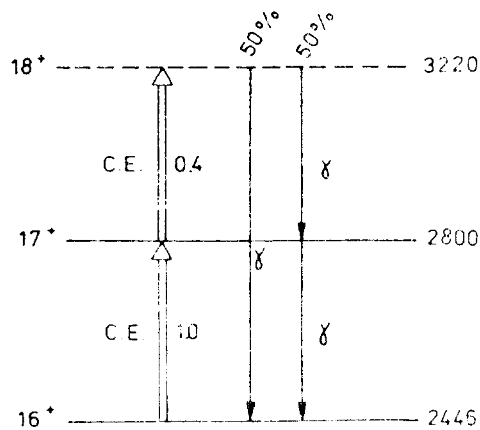

Fig.8. Schematic diagram of the Coulomb excitation of the rotational band built on the 16^+ isomeric state in the ^{178}Hf.

Table 7. Moments of inertia deduced from the first level energy of the bands in ^{178}**Hf**

K	Transition	Energy, keV	$\mathcal{J}$, MeV^{-1}
0	$2^+ \to 0^+$	93	32
8	$9^- \to 8^-$	217	41
16	$17^+ \to 16^+$	353	48
	Rigid rotor:		77

than the one used was available. However, it was limited by the target instability under the lead beam. During the run described the target was covered by additional carbon foils for the mechanical fixation. It disturbs the Doppler-shift correction processing and one can see in the spectra that line widths are increasing with energy E_γ. So, there are plans to continue the Coulomb excitation experiment in better conditions, eventually using the "Eurogam" facility.

Another experiment was performed in the frame of the Hafnium collaboration to test the influence of decoupled neutrons on the pick-up reaction cross-section. The (p,t)-reaction is known to be a probe of pair correlation [23]. The $^{178}Hf^{m_2}$ target allows to measure the effect of blocking the aligned quasineutron orbitals on the neutron pair transfer. The $J,K^\pi=16,16^+$ state with the same configuration as in ^{178}Hf is placed in ^{176}Hf at an excitation energy of 3226 keV. So the triton kinetic energy for the $16^+ \rightarrow 16^+$ transition can be calculated exactly. The target of $^{178}Hf^{m_2}$ was exposed to a proton beam with an energy of 19 MeV of the Tandem at Orsay and triton spectra and angular distribution were measured using a splite-pole spectrograph with a position-sensitive drift chamber as a focal detector. The overall energy resolution was 15 keV full width at half maximum. The peak was observed at the expected location of $16^+ \rightarrow 16^+$ transition, no elements presented in the target can generate this peak. The angular distribution of the $16^+ \rightarrow 16^+$ transition was well reproduced by the typical shape for L=0 transitions measured for the case of other hafnium isotopes. However, the cross-section shows strong deviation from the measured one for even-even hafnium isotopes. As seen in fig.9 the differential cross-section of the (p,t) reactions is reduced in case of odd isotopes of Hf as a result of the blocking by the unpaired neutron orbital. And for the $^{178}Hf^{m_2}$ target the reduction is quadratically drastic. So the evidences are obtained for the first time, that decoupled neutrons in the even-even isotope ^{178}Hf both play the role of odd particles. This new result perhaps will be treated by theoreticians.

III. Laser spectroscopy of the $^{178}Hf^{m_2}$ atom

An in-beam laser experiment [24] was performed on the "Paris" mass-separator at Orsay where hafnium atoms with a 40 keV kinetic energy were excited by a single mode dye laser in a contralinear geometry. The hafnium tetrachloride vapor is flowed from a heated sample into the ion source chamber, in which it is decomposed and ionized. The elemental ions are extracted and accelerated by a 40 keV potential and finally mass-separated. The selected mass is delivered into the collinear array, where ions are neutralized in the sodium vapor of a charge exchange cell and interact with a fixed frequency laser beam. The frequency scanning was done by the ion beam velocity tuning in the charge exchange cell. The fluorescence light after passing through the filters was detected by a photomultiplier. The hyperfine splitting and isomer shift were measured for ions with a mass number A=178. A complete multuplet of hyperfine structure was detected and it is a reliable evidence for the attribution of these atomic levels to the atom of 16^+ $^{178}Hf^{m_2}$ nuclear state. A powerful peak of the ^{178}Hf ground state was observed too. The frequency spectrum of the resonance fluorescence is presented in fig. 10. From these experimental results after quantitative processing the dipole magnetic moment μ_I, static quadrupole moment Q_o and mean square radius change were deduced for the $^{178}Hf^{m_2}$ nucleus:

$$\mu_I = 8.16(4) n.m.;$$

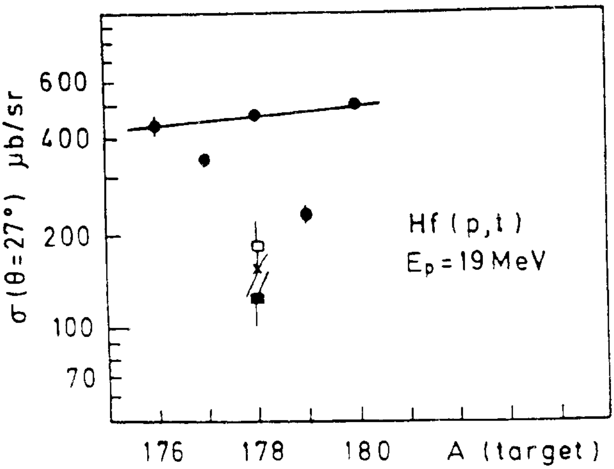

Fig.9. Cross-section systematics for the (p,t)-reaction on hafnium nuclei. Black circles - stable isotopes, others $^{178}Hf^{m2}$ target (× theory, ■ and ❑ - experimental limits).

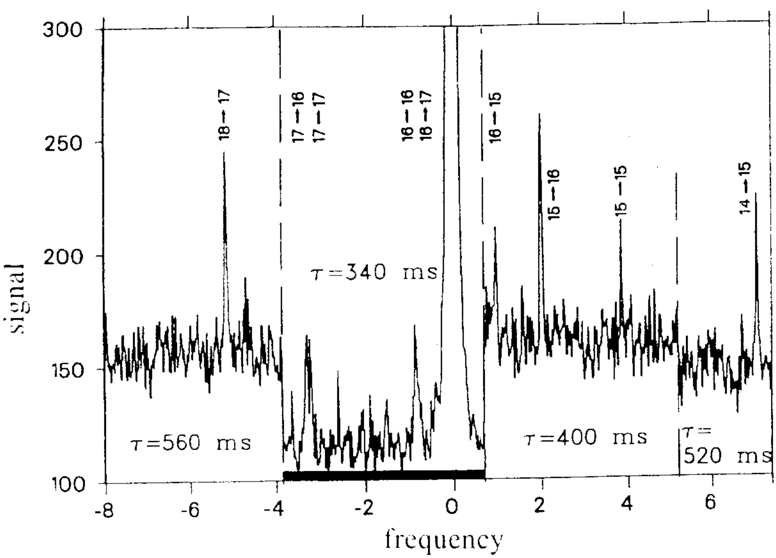

Fig.10. Resonance photoabsorption spectrum of an atomic beam of the $^{178}Hf^{m2+g}$.

$Q_o = 7.2(1)\ b \quad (6.96(4)\ b \quad \text{for the g.s.})$:

$$\delta\langle r^2\rangle^{g,m_2} = -0.059(9) fm^2.$$

This experiment demonstrates perfect possibilities of nuclear properties measurements by the method of atomic levels hyperfine structure spectroscopy. Also a beam of $^{178}Hf^{m_2}$ isomer ions was produced for the first time, and the high enough efficiency reached opens additional perspectives for the isomeric ions acceleration, separation from ground state nuclei and so on. The numerical results given above are important for the theoretical description of the isomeric state nuclear structure.

IV. Future experiments with the $^{178}Hf^{m_2}$ target

The experiments already fulfilled with $^{178}Hf^{m_2}$ isomeric targets have demonstrated enormous difficulties due to backgrounds generated by stable hafnium isotopes present in the isomeric target as well as by the weight quantities of the backing material and microadmixtures in that. So, it is very important to create isomeric targets of the second generation with higher concentration of the $^{178}Hf^{m_2}$ nuclei in the target layer. There are good possibilities to produce the separation of the ^{178}Hf isotope on the mass-separator "Paris" at Orsay, where as high as 25% efficiency has been achieved recently for the hafnium separation /25/. Also a possibility was discussed to work out a method of separation of isomeric and ground state ^{178}Hf nuclei using their mass difference, $\Delta M/M = 1.5 \cdot 10^{-5}$, on a special cyclotron resonance analyzer developed by the French group (M. Sant-Simon et.al) and installed now at CERN. These methodical progress together with the production of an additional quantity of the $^{178}Hf^{m_2}$ material will determine in future the success of new experiments. Now we would like to discuss some new proposals of experiments which are most interesting from a physical point of view.

4.1. $^{178}Hf^{m_2}$ (γ, γ')-reaction

As has been already mentioned above, a giant cross-section for the $^{180}Ta^m(\gamma, \gamma')$ -reaction with transition from K=9 to K=1 state was observed in ref /19/. After that the idea about K-mixing for excited states was suggested. So it is important to continue studies of the feeding of states with different K-values in the (γ, γ') reaction on a high-K target. The $^{178}Hf^{m_2}$ isomeric target is very interesting for this experiment because one can expect a high cross-section for the population by bremsstrahlung in (γ, γ')- reaction for the level with J, $K^\pi = 14,14^-$, $E^* = 2.574$ MeV and $T_{1/2} = 68$ μs as well as for the level with J, $K^\pi = 6,6^+$, $E^* = 1.544$ MeV and $T_{1/2} = 78$ ns. The fragment of the ^{178}Hf level scheme is presented in fig. 11. One can see that the output transitions from these levels are not the same as cascade transitions in the radioactive decay of the $^{178}Hf^{m_2}$ state. So, the population of the K=14 and K=6 levels in the (γ, γ')-reaction on a K=16 target of $^{178}Hf^{m_2}$ can be studied experimentally with using the detection of the delayed γ-radiation after the pulsed excitation of the target by the bremsstrahlung. However, the difficulties with the γ-ray background make this experiment difficult.

4.2. Threshold K-mixing behaviour in the $^{178}Hf^{m_2}$ $(p, p'\gamma)$-reaction

One can suggest another variant of studying the K-mixing threshold behaviour using the proton induced reaction which is preferable in the sense of better background conditions.

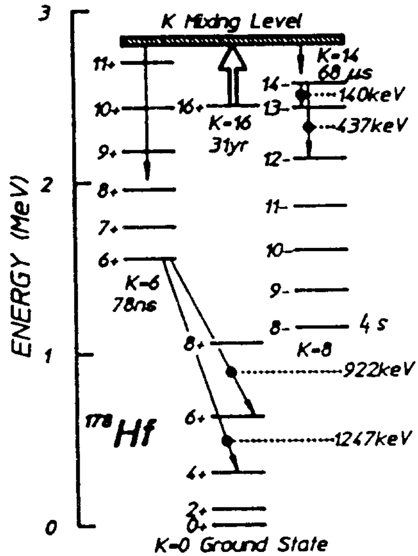

Fig.11. Scheme of the bremsstahlung induced population of short-lived isomeric levels with the $^{178}Hf^{m2}$ target.

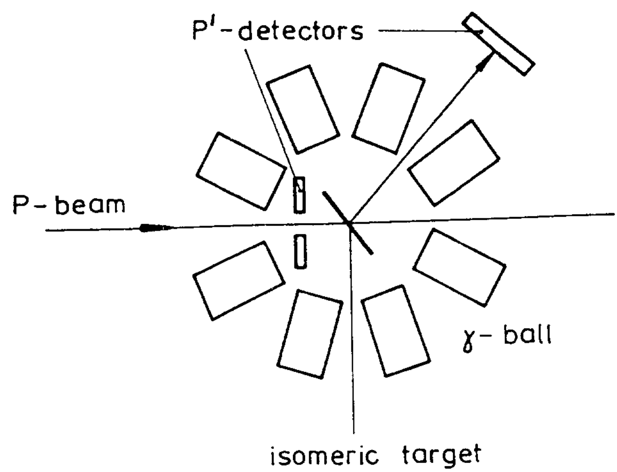

Fig.12. Experimental scheme of the study of the (p,p'γ)-reaction on the $^{178}Hf^{m2}$ target.

As it is seen in fig. 11 the hypothetical K-mixed level is located at an excitation energy of about 3 MeV, e.g. not far from the 16^+ isomeric state. So it should be excited in the (p,p') scattering with a high enough probability, because the K-hindrance is invalid for mixed level. Being excited it can decay to the ground state band and a high multiplicity γ-cascade should arise as a result of spin conservation. So, the detection of inelastically scattered protons in the coincidence with a high γ-multiplicity cascade, $M_\gamma \approx 8$, will indicate the excitation of the K-mixed level. A regular inelastic scattering with an excitation of rotational bands of stable Hf nuclei gives multiplicities not higher then M_γ=2-4, and does not create a dangerous background.

A proposed scheme of such an experiment is presented in fig. 12. The proton beam with an energy about 20-30 MeV from a tandem accelerator hits an isomeric target. The 4π granular γ-detector provides high efficiency of the detection of high γ-multiplicity events in coincidences with inelastically scattered protons detected by the annular detector in backward direction for the solid angle increase. The measured concidence rate as a function of the detected proton energy has to show a step increase at an excitation energy of the target $^{178}Hf^{m_2}$ nucleus of about 0.5-1.0 MeV. This energy corresponds to the expected position of the K-mixed level. Such an observation being realized will mean a direct discovery of a special K-mixed level which plays a very important role in the process of levels population with a strong change of the K-value.

4.3. Giant resonances built on four-quasiparticle state

As it was demonstrated by the IPN Orsay group a few years ago [26] heavy-ion inelastic scattering is a powerful instrument for the excitation and studying of many giant resonances of different nature. The spectra of inelastically scattered ions were measured in a forward direction on a beam with an energy of about 50 MeV/a.m.u. Up to now giant resonances built on isomeric states are not studied. This idea can be realized on the U-400 cyclotron at Dubna using an isomeric $^{178}Hf^{m_2}$ target in a heavy-ion inelastic scattering experiment. The most difficult methodical problem is to separate the scattering events on an isomeric nucleus from those on stable Hf nuclei presented in the target. To solve this problem we suggest to use the method of high γ-multiplicity filter in coincidence with scattered ions. As shown in fig. 13 ions scattered at an angle near 0° are detected by a magnetic spectrograph with a focal detector switched on coincidences with a 4π granular γ-multiplicity filter. For additional selection of events one can use the time-of-flight parameter. At the forward-angle inelastic scattering on stable nuclei high-spin states are populated with a negligible probablity but not in the case of scattering on the 16^+ isomeric nucleus. So, the detection of a high γ-multiplicity events in coincidence with scattered ions provides reliable selection of the reactions with an isomeric nucleus. So, the giant resonances of the isomeric nucleus could be studied by this method.

4.4. Transition mass-density distribution of the $^{178}Hf^{m_2}$ nucleus

The charge radius of the $^{178}Hf^{m_2}$ nucleus was measured recently [24] in the framework of the "Hafnium collaboration" by the method of the collinear laser-spectroscopy. It is interesting to measure also the mass-radius and compare it with the charge radius. As known for decades, the diffraction proton-scattering angular distribution brings information on the mass-density distribution in a nucleus. One can cite the systematical measurments of the elastic scattering on the 1 GeV proton beam at Gatchina and developed methods of the data treatment using Glauber-Sitenko approach [27]. It is difficult to measure the angular distribution of the elastic scattering on the $^{178}Hf^{m_2}$ nucleus because of the impossibility

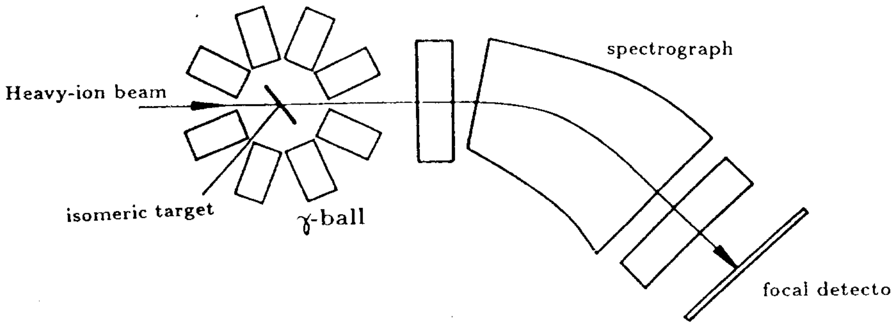

Fig.13. Scheme of the giant resonances study in the heavy-ion inelastic scattering on the $^{178}Hf^{m2}$ target.

Table 8. Properties of some high-excited isomeric states

Isomer	$^{24}Na^m$	$^{38}Cl^m$	$^{42}Sc^m$	$^{90}Zr^m$	$^{93}Mo^m$	$^{177}Hf^{m_2}$	$^{178}Hf^{m_2}$	$^{212}Po^m$
$T_{1/2}$	0.02s	0.72s	62s	0.81s	6.9h	0.85h	31y	45s
I^π	1^+	5^-	7^+	5^-	$21/2^+$	$37/2^-$	16^+	18^+
$\Delta M/M_g$, 10^{-5}	2.1	1.9	1.6	2.8	2.8	1.7	1.5	1.5

to separate that from the elastic scattering on stable Hf nuclei. However, in the case of the inelastic scattering it is possible when using the same scheme as before (see fig. 13). The mobile spectrograph should measure the angular distribution of inelastically scattered protons in coincidences with a γ-multiplicity filter. The estimations of the absolute counting rate confirm the possibility to realize such an experiment on the proton beam with an energy of 0.5-1.0 GeV. A big mobile spectrograph on the Ring cyclotron at Osaka [28] is a favorable facility for this type of studies. When the elastic scattering is studied, one can deduce the mass-density distribution for the target nucleus. In the discussed case the scattering with the excitation of some level is proposed to be measured, so the transition mass-density distribution will be deduced, which characterizes the individual transition. This information is valuable from the theoretical point of view.

5. Isomeric beams

Relatively long-lived nuclear isomeric states are in abundance through the nuclides chart in a wide range of mass numbers. They are systematized in fig.14, and one can see that the highest spin isomers are located in the region of A=180-210. Properties of few interesting isomeric states are presented also in table 8, their excitation energy is given in ratio to the mass of the nucleus.

Isomeric ions as projectiles were discussed earlier by Kutschera in ref.[29] on the $^{178}Hf^{m_2}$ as well as by Armbruster and Polikanov [30] in the GSI proposal on production of secondary beam of spontaneously fissioning isomer. Recently the first successful experiments on the production of the $^{26}Al^m$, $^{38}K^m$ and $^{42}Sc^m$ isomeric beams were performed on the Michigan and French tandem-cyclotron facilities at East-Lansing and Caen [31,32]. In the cited and future works for the isomeric beams production one has to overcome the following difficulties:

1. The physical limitations on the production rate of isomeric atoms demands for high efficiency of acceleration, or high efficiency of isomeric ions consumption when working on a secondary beam.

2. Short lifetimes of many isomers limit the total processing time from the production to consumption of the isomer nucleus.

3. Not high isomeric-to-ground state ratio in the producing reaction creates enormous difficulties for the formation of a purely isomeric beam.

In this talk some general problems such as atom ionization, acceleration, stripping, storage and extraction are not discussed in detail because they happen to be already solved when any heavy-ion beam is produced. Only special problems of isomeric beams are considered in a schematical approach and some concrete advantageous variants for the production of beams of individual isomers are suggested.

5.1. Direct acceleration of $^{180}Ta^m$ isomeric ions

The $^{180}Ta^m$ is the only isomer abundant in nature ($1.2 \cdot 10^{-2}\%$) due to its record long lifetime $\geq 1.2 \cdot 10^{15}$y. Two odd nucleons being aligned produce this 75 keV, $J^\pi = 9^-$ excited state while the ground state 1^+ has a short lifetime, 8.15h. The weight quantities of $^{180}Ta^m$ are already available for acceleration. In addition, in this case the presence of ground state nuclei is excluded which is an important advantage. The enriched $^{180}Ta^m$ material is very expensive, hence the most effective acceleration should be achieved using a cyclotron in

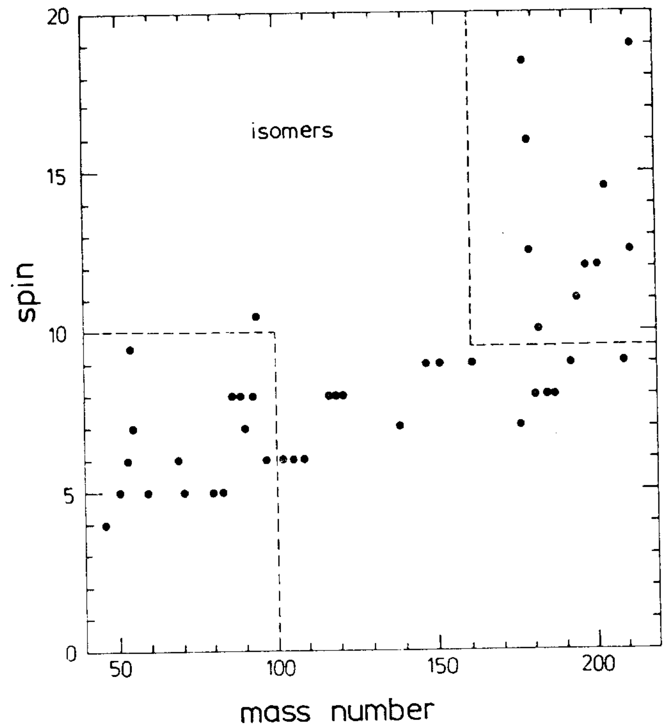

Fig.14. Systematics of the isomeric nuclear states.

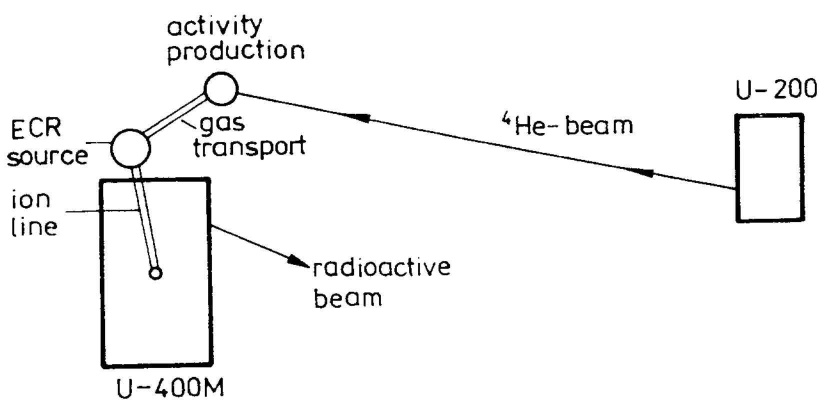

Fig.15. Scheme of the acceleration of the exotic $^{212}Po^m$ isomeric nuclei.

combination with an ECR ion-source [33]. Moderately high (non-record) efficiency values are about 0.1 for the ionization in an ECR source and about 0.1 for the acceleration in a cyclotron according to literature. The total efficiency of about 10^{-2} can be reached for the production of a $^{180}Ta^m$ ion beam by this method. When a Ta material enriched to 1% of the $^{180}Ta^m$ content is used, one can expect the beam intensity on the level of 10^{10}/s of the $^{180}Ta^m$ ions. So the accelerator will consume $^{180}Ta^m$ at a rate of 30 μg/day. Such expenditures of the material are not high both from the technical and economical points of view. The project can be realized at Dubna on the cyclotron U-400M when an ECR source is mounted. An ion energy of about 6 MeV/amu is expected for 18^+ charged Ta ions, which is sufficient for nuclear physics studies.

5.2. Acceleration of $^{178}Hf^{m_2}$ nuclei

The maximum production rate of $^{178}Hf^{m_2}$ reached on the U-200 cyclotron at Dubna is about 10^{15} atoms per month of effective irradiation time. Based on the presented above acceleration efficiency value one can estimate that 10^{15} atoms is sufficient for one day of work at the $^{178}Hf^{m_2}$ ion beam intensity as low as 10^8/s. It means, enormous expenses for the $^{178}Hf^{m_2}$ material production are required. A more efficient way to use this material is the preparation of $^{178}Hf^{m_2}$ targets as described above. In addition, the fact, that the isomeric-to-ground state ratio is not higher than 5% for the $^{178}Hf^{m_2}$ production, leads to serious difficulties in the pure isomeric beam creation. It is clear that another way to produce a $^{178}Hf^{m_2}$ ion beam should be considered.

Let us assume that a heavy ion storage facility similar to the Darmstadt one is available. There are plans to construct in a few years a heavy-ion storage ring complex K4-K10 at Dubna [34]. The Darmstadt facility is an assembly of the Unilac accelerator, the SIS synchrotron, the FRS fragment separator and the ESR cooler storage ring. Radioactive isotopes are produced with a high enough yield at the SIS energies, they can be selected by the FRS and stored at the ESR. This scheme is acceptable for the $^{178}Hf^{m_2}$ secondary beam creation One can expect a good enough yield for the $^{178}Hf^{m_2}$ isomer production in the fragmentation reaction on the 1 GeV/amu ^{181}Ta (for instance) ion beam. So, efforts to produce a $^{178}Hf^m$ ion beam are not much greater than those for any radioactive secondary beam.

High momentum resolution of the beam in the storage ring reached after the electron cooling gives a possibility to select a pure $^{178}Hf^{m_2}$ beam with a deep reduction of the $^{178}Hf^g$ ion beam. The mass difference of g and m_2 states in ^{178}Hf is 2.45 MeV, or $1.5 \cdot 10^{-5}$ in relative units. This is sufficient for the separation in the ESR cooler, because its momentum resolution is on the level of 10^{-6}. Hundreds of MeV per amu ion beam of $^{178}Hf^{m_2}$ is a promising one for nuclear reactions with high-spin partners studies, for instance, for investigation of multiphonon giant resonances built on a high-spin quasiparticle isomer and so on.

The same way is acceptable to produce beams of other isomers listed in Table 8. High enough ΔM value is promising for efficient separation of the isomeric and ground state beams in the storage ring. Besides, isomers with the highest ΔM values are physically most intriguing as nuclei exotic in structure.

5.3. Secondary beams of the s.f. isomers and $^{212}Po^m$

It is possible to consume secondary radioactive beam on the target just after the fragment separation without storing in the ring. This variant is more advantageous because it avoids losses of radioactive ions during storage and cooling. However, there is no possibility to separate isomeric and ground state nuclei without storage. In the cases of some isomers this a more efficient way is still open. For instance, in ref.[30] it is proposed to study secondary interactions of spontaneously fissioning isomers using the delayed fission as a trigger for the selection of events of the s.f. isomer interaction. Such a selection gives a possibility to study the elastic and inelastic (with a γ-decay deexcitation) scattering of s.f. isomers in spite of a low value, $\sim 10^{-4}$, of the isomeric-to-ground state ratio in the beam.

The $^{212}Po^m$ isomer ($J^\pi = 18^+$) has a long enough lifetime, $T_{1/2}$=45 s, to be stored, however it is much better to use this nucleus just after the separation in the FRS. The fragmentation of ^{232}Th nucleus can be used for the production of the $^{212}Po^m$ nuclei. The ground state of ^{212}Po has $T_{1/2}=3\cdot 10^{-7}$ s and it decays after a short path. So, after FRS one can use a pure $^{212}Po^m$ isomeric beam. Nuclear reactions with an exotic four-quasiparticle $^{212}Po^m$ isomer were never discussed in literature either in experimental or theoretical approach.

5.4. Acceleration of $^{212}Po^m$ nuclei

A few groups in the world are developing [31,32,35] during the decade a method for the production and acceleration of light radioactive beams on a tandem-cyclotron facility. The FLNR JINR has three powerful operating cyclotrons. So we can propose to produce and accelerate exotic nuclei as heavy as $^{212}Po^m$. In this project powerful ^{4}He-ion beam extracted from the U-200 cyclotron will be transported to the area of the ECR-source assembled with the U-400M cyclotron (as schematically shown in fig.15). $^{212}Po^m$ nuclei will be produced in the reaction ^{210}Pb(^{4}He,2n) with a mbarns cross-section. The target material of ^{210}Pb is available at Dubna in the required quantity. There is a technical task to collect the produced $^{212}Po^m$ nuclei and to transport them into the ECR source of the U-400M cyclotron. After that the ionization and acceleration of $^{212}Po^m$ atoms will be produced by the same way as of any other atoms. The production rate of the reaction ^{210}Pb(^{4}He,2n) $^{212}Po^m$ should be about $5\cdot 10^7$/s. The efficiency of the transportation into the ECR source is unknown, however, taking into account good volatility of Po atoms one can expect a not too low efficiency for the penetration through a heated quartz pipe filled with a rare gas at a low pressure. Assuming the known efficiency of ionization and acceleration and somewhat arbitrary transportation efficiency one can anticipate the final intensity of the $^{212}Po^m$ ion beam on the level of 10^5/s.

Summary

The current interest to the reactions with high-spin nuclei is motivated. Recent studies with the exotic $^{178}Hf^{m2}$ isomeric target taken in reactions induced by bremssrahlung, neutrons and charged particles demonstrate a possibility to obtain new information both in the field of nuclear structure and of nuclear reactions. New proposals for the continuation and development of experiments with a $^{178}Hf^{m2}$ target are described. The production of isomeric beams is considered in a schematical approach for some exotic in structure isomers.

Acknowledgement

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Оганесян Ю.Ц., Карамян С.А. E15-94-408

Изомерные мишени и пучки

Исследования экзотических ядер, включая гиперядра, трансфермиевые элементы, протонно- и нейтронно-обогащенные нуклиды вблизи линий ядерной неустойчивости, также как высокоспиновые возбужденные состояния и уровни с аномальной деформацией, являются главными проблемами современной ядерной физики. Изомерия ядер тесно связана с такими явлениями, как выстраивание одночастичных орбиталей, сосуществование разных форм и проявление интрудер-уровней из соседних оболочек. Исследования электромагнитных и ядерных взаимодействий изомеров могут дать важную информацию об их оболочечной структуре и ее роли в механизме ядерных реакций. Для таких экспериментов нужно использовать или изомерные мишени (достаточно долгоживущие) или методы ускорения изомерных ядер. Недавно в микровесовом количестве был получен экзотический 16^+ четырехквазичастичный изомер $^{178}Hf^{m2}$ и наблюдались первые ядерные реакции на этом ядре. Эти эксперименты описаны в докладе, также как некоторые новые идеи по продолжению исследований и приемлемые схемы получения изомерных пучков методами прямого ускорения или вторичных пучков.

Работа выполнена в Лаборатории ядерных реакций им. Г.Н.Флерова ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1994

Oganessian Yu.Ts., Karamian S.A. E15-94-408

Isomeric Targets and Beams

One of the main topics of modern nuclear physics is the investigation of exotic nuclei including hyper-nuclei, transfermium elements, proton and neutron rich isotopes near drip lines as well as high-spin excited states and states with anomalous deformation. The isomerism of nuclei is closely related with such phenomena as the alignment of single-particle orbitals, the coexistence of various deformations and the manifestation of intruder-levels from neighbouring shells. The investigation of electromagnetic and nuclear interactions of isomers could give important information on their shell structure and its role in the mechanism of nuclear reactions. For such experiments one can either make isomeric targets (sufficiently long-lived) or use the methods of acceleration of isomeric nuclei. Recently, an exotic 16^+ four-quasiparticle isomer of $^{178}Hf^{m2}$ was produced in a microweight quantity and the first nuclear reactions on it were successfully observed. The talk describes these experiments as well as new ideas for the continuation of the studies and some advantageous ways for the isomeric beams production by the method of direct acceleration or by the secondary beam method.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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