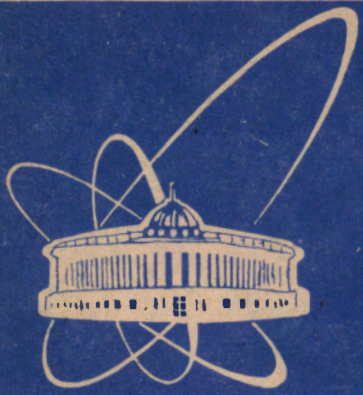

ОБЪЕДИНЕННЫЙ
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Дубна

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STUDIES OF α-SPECTRA IN ^{221}Fr, ^{217}At, ^{213}Bi AND ^{213}Po DECAYS

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1. Introduction

In the last ten years several investigations on the decays of nuclides from the ^{225}Ac equilibrium decay chain (Fig. 1) have been published. New data on the structure of the ^{217}At, ^{213}Bi, ^{213}Po and ^{209}Pb nuclei close to double magic ^{208}Pb have been gained. It is expected that the ^{225}Ac α-decay studies can reveal some new information on the presense of the static octupole deformation in the ^{221}Fr nucleus.

To study nuclear radiations of the above nuclei, ^{225}Ac is separated from ^{229}Th. The daughter nuclides are rapidly accumulated in the prepared source. Complex α-, β- and γ-radiation spectra and relatively short half-lives of the daughter nuclei hinder the identification of specific transitions with the decay of appropriate nuclei from the ^{225}Ac chain.

The fine structure lines in the ^{221}Fr α-decay were identified by Liang [1] as he investigated the ^{225}Ac α-recoil nuclei α-spectrum with the magnetic spectrograph. Ardisson et al. [2,3] developed and used fast radiochemical methods for separation of ^{213}Bi, ^{209}Tl and ^{221}Fr nuclei and investigation of their γ-spectra. Sheline et al. [4] and Gromov et al. [5-8] confirmed the belonging of γ-transitions to the ^{225}Ac, ^{221}Fr and ^{217}At decay in $(\alpha-\gamma)$-coincidence experiments.

But some problems still require careful studies of the weak components of the ^{221}Fr, ^{217}At and ^{213}Bi α-spectra. For example,

- Liang [1], when studying the α-spectrum of recoil nuclei from the ^{225}Ac source, observed a weak line with $E_\alpha = 6037$ keV, $J_\alpha = 0.003$ % per decay. An excited ^{217}At level with energy 310 keV and $I^\pi = (13/2^+)$ is introduced on this basis [1,4,6]. Unlike the case with other levels introduced on the basis of the ^{221}Fr fine structure α-lines [1], no γ-transitions from the 310 keV level are observed. It is not impossible that the 6037 keV line is not associated with the ^{221}Fr α-decay, but with the α-decay of the daughter ^{217}At nucleus to the 1050 keV level of ^{213}Bi and, therefore, this line can be found in the α-spectrum of ^{217}At.

- Ardisson et al. [2] assumed that the 868 keV ^{209}Tl level is excited in the ^{213}Bi α-decay. The sum intensity of the 868 and 545 keV γ- rays from this level was determined to be 0.03 % per decay. Accordingly, the fine structure α-line, with E_α=5018 keV and J_α=0.03 %, should be observed in the α-spectrum of ^{213}Bi.

- Chumin et al. [7], studying $(\alpha-\gamma)$-coincidence in the decay of ^{225}Ac

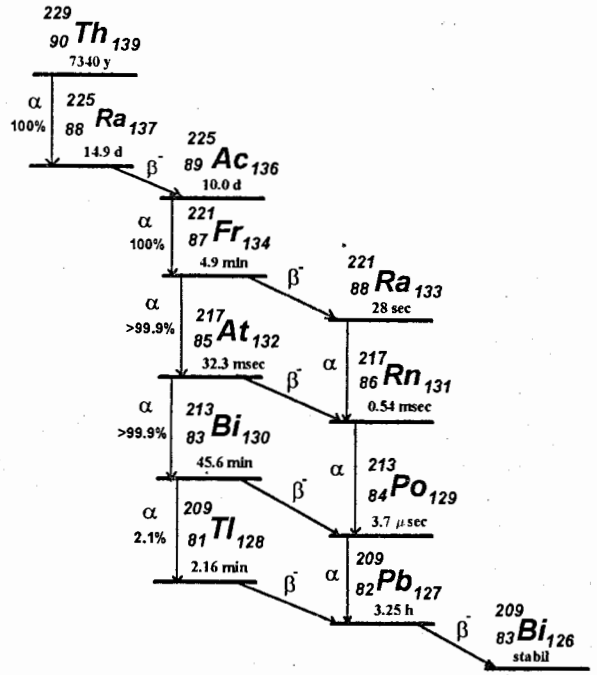

Fig. 1. Decay chain of ^{229}Th to ^{209}Bi

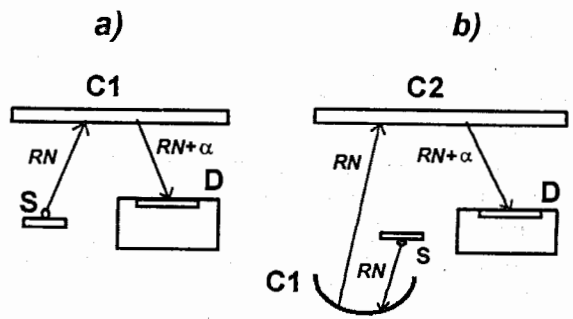

Fig. 2. Block diagram of the experiments for α-spectra investigation using an α-recoil: once (a) and twice (b).

S - ^{225}Ac source, C1 and C2 - collectors of recoil nuclei, D - α-particle detector, RN - recoil nuclei

and its daughters, observed the coincidences of 150 keV γ-rays with $E_{\alpha 150}$=6612 keV α-particles of ^{221}Ra, resulting from the β-decay of ^{221}Fr [1]. Thus, the observation of the ^{221}Fr β-decay [1] was confirmed. Its intensity was redetermined as $(11\pm5)\cdot10^{-5}$ decays. It is of interest to confirm this result in direct α-spectrum measurements.

- Chumin et al. [8] found the ^{217}At α-decay to the ^{213}Bi 759 keV level. The α-line $E_{\alpha 759}$ (^{217}At)=6322 keV, $J_{\alpha 759} = 5\cdot10^{-3}$ % is close to the ^{221}Fr α_0-line ($E_{\alpha 0} = 6341$ keV, $J_{\alpha 0} = 85$ %) and was observed only in $(\alpha-\gamma)$-coincidences. It is worthwhile to confirm these data in direct α-spectrum measurements.

In the present paper the weak components of the ^{221}Fr, ^{217}At, and ^{213}Bi α-spectra are studied. The phenomenon of recoil in α-decay is used to eliminate the contribution to these spectra from the α-radiation of mother nuclei.

2. Experimental set-up

The main source of α-radiation was ^{225}Ac separated from ^{229}Th by the technique "The isotope generator of ^{225}Ac" [9]. The ^{225}Ac source activity was about 20 mCi. The ^{225}Ac activity was electrolytically deposited on a tantalum foil and then vacuum evaporated on an aluminum foil. Small thickness of the resulting sources provided a considerable (up to 30 %) yield of recoil nuclei. To study α-spectra of the recoil nuclei, the ^{225}Ac source was placed in a vacuum chamber so that the detector, situated in the chamber, could not detect α-particles from the source (Fig. 2). The recoil nuclei from the α-decay of ^{225}Ac and daughter nuclei were gathered on a collector (C1 in Fig. 2). The detector recorded α-particles from the decay of the recoil nuclei gathered on the collector. Thus the α-spectrum of the ^{221}Fr and daughter nuclei free of the contribution from α-particles of ^{225}Ac was provided (from here on it is called the ^{221}Fr α-spectrum).

To have the ^{217}At α-spectrum the α-recoil phenomenon was used twice. The detector was placed in the chamber in a position where it could not "see" both the ^{225}Ac source and the first collector. The recoil nuclei from the α-decay on the first collector were gathered on the second collector. The detector recorded α-particles from the decay of nuclei on the second collector (Fig. 2(b)).

A Canberra Si(Au) detector (diameter 10 mm, FWHM 15 keV) was used to measure α-spectra. The ^{221}Fr and ^{217}At decay spectra shown in Figs.

3(b,c), are compared with the α-spectrum of the ^{225}Ac and daughter nuclei (Fig. 3(a)). Note that the widths and forms of the α-lines from the decay of different nuclides are different. This is because part of the nuclei resulting from the α-decay penetrate into the collector material, which broadens the α-lines of these nuclei. That is why the narrowest in spectrum Fig. 3(a) lines belong to the ^{225}Ac decay, in Fig. 3(b) to the ^{221}Fr decay, and in Fig. 3(c) to the ^{217}At decay. Note also that since the recoil nuclei leave the ^{225}Ac source or the collectors with a relatively high yield, the number of decays recorded per time unit will be not constant for different members of the ^{225}Ac decay chain. It decreases with increasing number of α-decays leading to formation of the nucleus in question from ^{225}Ac. Therefore, the relative intensities of α-lines from the decay of nuclei with the same mass numbers were used in the analysis of the result given in Tables 1 and 2. The relative intensities of α-lines were taken to be proportional to their areas, i.e. the efficiency of the detector was taken to be constant in the energy interval $E_\alpha = 5.0 \div 8.5$ MeV.

3. Experimental Results

The comparison of the ^{221}Fr and ^{217}At spectra (Figs. 3(b,c)) with the spectrum of the ^{225}Ac and daughter nuclei (Fig. 3(a)) allows one to estimate the degree of their purity from α-radiation of mother nuclei. In the ^{217}At α-spectrum the $E_{\alpha 0}$=6341 keV ^{221}Fr line is observed. Its intensity is $5\cdot10^{-4}$ J_{α_0} ^{217}At. Thus the investigations, whose results are displaed in Fig. 3(c), are equivalent to the investigations with the mass-separated source of ^{217}At (32 ms) with the ^{221}Fr impurity of the order of $5\cdot10^{-4}$. To evaluate the ^{225}Ac impurity is more difficult because the α-lines ($E_{\alpha 0}$(^{225}Ac)=5830 keV and $E_{\alpha 0}$(^{213}Bi) =5870 keV) are too close in energy. But it can be said with confidence that the intensity of the $E_{\alpha 0}$(^{225}Ac) line in these spectra is below $5\cdot10^{-3}$.

Table 1 gives the results of the analysis of the spectra from Figs. 3(b) and (c).

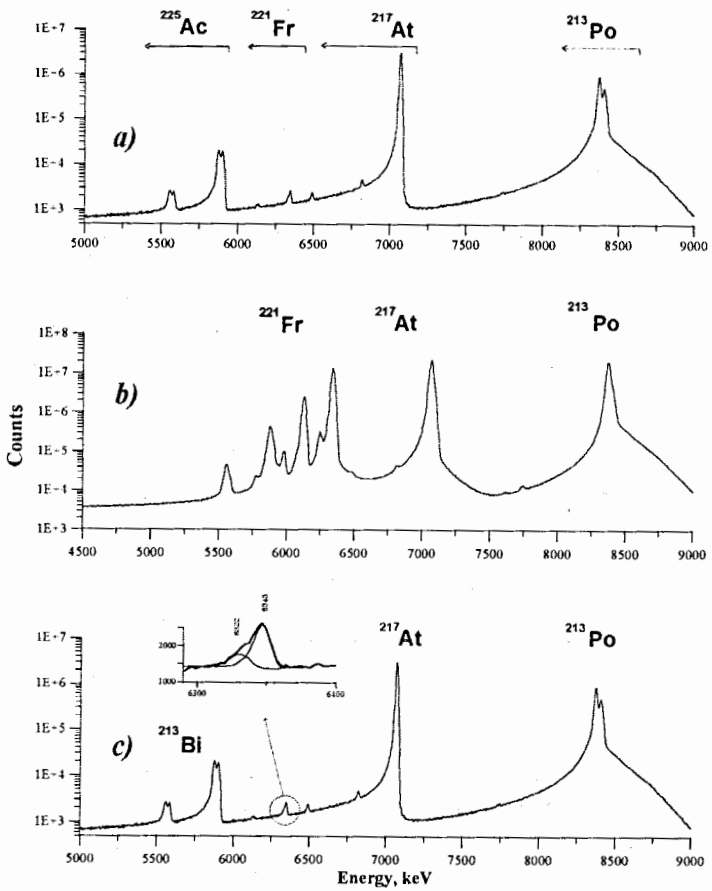

Fig. 3. Alpha spectra of:
a) ^{225}Ac and daughter nuclei (exposition 108 h);
b) ^{221}Fr and daughter nuclei (once recoil nuclei, exposition 270 h);
c) ^{217}At and daughter nuclei (twice recoil nuclei,exposition 182 h).
Complex line: $E_0(^{221}\mathrm{Fr}) = 6341$ keV and $E_{\alpha 759}(^{217}\mathrm{At}) = 6322$ keV is shown in the insert

Table 1. Intensities of the α-lines of the ^{217}At, ^{213}Bi, and ^{213}Po decay

Energy, keV		Intensity per cent	
Levels	α-particles	Present paper	Other publications
$^{217}\mathrm{At} \rightarrow {}^{213}\mathrm{Bi}$			
0	7067	>99.9	>99.9
258	6814	0.038(4)	0.036(3) [8]
(465)	6609	-	0.010(5) [10]
593	6485	0.022(2)	0.021(2) [8]
759	6322	0.012(6)	0.005(1) [8]
(1050)	6037	<0.002	(0.003) [1,10]
$^{213}\mathrm{Bi} \rightarrow {}^{209}\mathrm{Tl}$			
0	5869	2.05(3)	1.94(11) [10]
324	5549	0.153(3)	0.16(3) [10]
(868)	(5018)	$<10^{-4}$	(0.03) [2,10]
$^{213}\mathrm{Po} \rightarrow {}^{209}\mathrm{Pb}$			
0	8376	97.76(3)	97.91(3) [10]
779	7614	0.0030(2)	0.0047(5) [10]

Note: Energies of alpha-particles and levels are from references [1,2,8,10].

- **The ^{217}At α-spectrum:** Intensities of the $E_{\alpha 258} = 6814$ keV and $E_{\alpha 593}$=6485 keV lines are in good agreement with the results of the $(\alpha - \gamma)$-coincidence experiments [8]. The $E_\alpha = 6341$ keV line (Fig. 3(c)), whose main part we attribute to the ^{221}Fr decay (see above), is a complex one. Its decomposition, shown in the insert in Fig. 3(c), allowed us to determine the intensity of the new $E_{\alpha 759} = 6322$ keV line (α-decay of ^{217}At in the 759 keV level of ^{213}Bi). It is $J_{\alpha 759} = (12\pm6)\cdot10^{-3}$ % and agrees with [8]. The intensity evaluation of the E_α=6037 keV line does not exclude the possibility of assigning this α-line to the ^{217}At decay.

- **The ^{213}Bi α-spectrum:** The measured intensities of the $E_{\alpha 0}$ (^{213}Bi)= 5870 keV and $E_{\alpha 324}$ (^{213}Bi)=5549 keV lines agree with the known ones [10]. The measured upper limit for the intensity of the $E_{\alpha 868}$=5018 keV line appeared to be 100 times smaller than expected from [2]. Thus, the assumption that the ^{209}Tl 868 keV level is excited in the ^{213}Bi α-decay is not confirmed. Note that in their later paper [3] the authors of [2] attributed the 868 keV γ-transition to the $^{213}\mathrm{Bi} \rightarrow {}^{209}$Po β-decay, but did not abandon the earlier assumption that the 868 keV

level is excited in ^{209}Tl. Accordingly, in the 1996 Table of Isotopes [10] the 868 keV level in ^{209}Tl is preserved.

- **The ^{213}Po α-spectrum:** The measured intensity of the $E_{\alpha 778}(^{213}Po)$ line agrees with the known data [10].

Table 2 gives the results concerning the β^--decay of ^{221}Fr, ^{217}At and ^{213}Bi.

Table 2. Intensities of the ^{221}Fr, ^{217}At, and ^{213}Bi β^--decay

Nuclei	β-decay	
	Present paper	Other publications
^{221}Fr	$(4.8\pm1.5)\cdot10^{-5}$	$(11\pm5)\cdot10^{-5}$ [7]
^{217}At	$(6.7\pm2.4)\cdot10^{-5}$	$(12\pm6)\cdot10^{-5}$ [1]
		$<5\cdot10^{-5}$ [7]
^{213}Bi	(0.9776(3)	0.9791(3)[10]

- **^{221}Fr:** In the ^{221}Fr α-spectrum very weak lines of ^{221}Ra are observed. The $E_{\alpha 150}$= 6612 keV line is the most distinct. This line was earlier attributed in the ^{225}Ac decay chain to the ^{217}At decay [10]. Its belonging to the ^{221}Ra decay was proved in [7] by observation of coincidences of this line with the 150 keV γ-ray, and is confirmed in the present study by the fact that ^{221}Ra α-lines are displayed in the ^{221}Fr spectrum and are not observed in the ^{217}At spectrum. In the ^{225}Ac decay chain ^{221}Ra results from the β-decay of ^{221}Fr. There is not another explanation of the ^{221}Ra presence in the ^{225}Ac decay chain. Using the 6612 keV α-line intensity we determined the intensity of the ^{221}Fr β-decay branch to be $(4.8\pm 1.5)\cdot10^{-3}$ % in agreement with the result of [7]: $(11\pm5)\cdot10^{-3}$ %. Now that the 6612 keV α-line is ascribed to the ^{221}Ra α-decay, there are not experimental data for introduction of the ^{213}Bi 450 keV level in the decay of ^{217}At [10].

- **^{217}At:** In the ^{217}At α-spectrum, (Fig. 3(c)) the $E_{\alpha 0}$=7741 keV, $J_{\alpha 0}$=100 % α_0-line of ^{217}Rn ($T_{1/2}$=0.54 ms) is observed. This ^{217}Ra is formed both in the ^{221}Ra α-decay and in the β-decay of ^{217}At. The intensity of the ^{217}At β-decay branch was calculated as a difference between the $E_{\alpha 0}$=7741 keV line intensity in the spectrum of Fig. 3(c) and the ^{221}Fr β-decay branch intensity found above. The

value $(6.7\pm2.4)\cdot10^{-5}$ per decay does not contradict the upper limit determined in [7] and earlier investigations.

- **^{213}Bi:** The intensity of the ^{213}Bi α-decay determined from the ratio of the α-line areas in the spectrum of Fig. 3(c):

$$\frac{S_{\alpha 0}(^{213}Po)}{S_{\alpha 0}(^{213}Po)+S_{\alpha 0}(^{213}Bi)+S_{\alpha 324}(^{213}Bi)}=0.9776(10).$$

is in agreement with the known value [10].

4. Conclusion

The use of the α-recoil phenomenon to study α-spectra in the ^{225}Ac equilibrium decay chain has allowed us to free spectra investigated from the α-radiation of mother nuclei and to gain new or more reliable experimental data on the intensity of weak components of these spectra.

The research of the ^{217}At α-spectrum confirms the results [8] about the excitation of the 759 keV level in ^{213}Bi and yields more correct data on the intensity of the ^{217}At α-decay to the 258 and 593 keV levels in ^{213}Bi. It is established that the 6612 keV α-line, previously attributed to the ^{217}At α-decay, arises from the ^{221}Ra α-decay and thus there is no experimental basis for the introduction of the 450 keV level in ^{213}Bi.

It is shown that the assumed [2] excitation of the ^{209}Tl 868 keV level in the ^{213}Bi α-decay contradicts the results of the present ^{213}Bi α-spectrum investigation.

Identification of the ^{221}Ra and ^{217}Rn α-lines in α- spectra of the nuclei from the ^{225}Ac decay chain and measurement of their intensity has allowed us to repeat determination of the β-decay intensity for ^{221}Fr, ^{217}At, and ^{213}Bi.

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Исследование α-спектров при распаде ^{221}Fr, ^{217}At, ^{213}Bi и ^{213}Po

Для получения информации об интенсивности слабых компонентов α-спектров нуклидов из цепочки распадов ^{225}Ac использовано явление отдачи при α-распаде. Показано, что нет экспериментальных оснований для введения уровней 450 кэВ ^{213}Bi при распаде ^{217}At и 868 кэВ ^{209}Tl при распаде ^{213}Bi. Подтверждается возбуждение уровня 759 кэВ ^{213}Bi при распаде ^{217}At. Измерены интенсивности β^--распада ^{221}Fr, ^{217}At и ^{213}Bi.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Studies of α-Spectra in ^{221}Fr, ^{217}At, ^{213}Bi and ^{213}Po Decays

The alpha-recoil phenomenon is used to gain data on the weak components of the α-spectra of the nuclides from the ^{225}Ac equilibrium chain. It is established that there is no experimental basis for introducing the 450 keV level of ^{213}Bi in the ^{217}At decay and the 868 keV level of ^{209}Tl in the ^{213}Bi decay. Excitation of the 759 keV level in the ^{217}At decay is confirmed. The intensities of the ^{221}Fr, ^{217}At and ^{213}Bi β^--decay are measured.

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

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