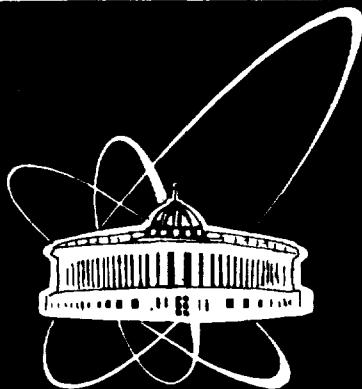




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STUDIES OF α -SPECTRA
IN ^{221}Fr , ^{217}At , ^{213}Bi AND ^{213}Po DECAYS

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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 presence 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 $E_{\alpha} = 5018$ keV and $J_{\alpha} = 0.03$ %, should be observed in the α -spectrum of ^{213}Bi .
- Chuumin et al. [7], studying ($\alpha - \gamma$)-coincidence in the decay of ^{225}Ac

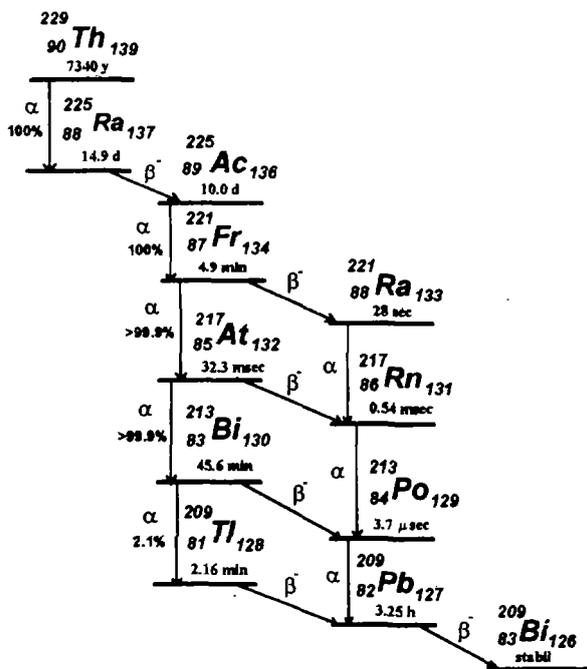


Fig. 1. Decay chain of ^{229}Th to ^{209}Bi

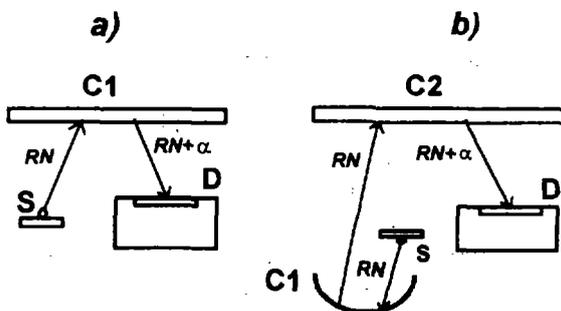


Fig. 2. Block diagram of the experiments for α -spectra investigation using an α -recoil: once (a) and twice (b).

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 $(11\pm 5)\cdot 10^{-5}$ decays. It is of interest to confirm this result in direct α -spectrum measurements.

- Chumín et al. [8] found the ^{217}At α -decay to the ^{213}Bi 759 keV level. The α -line $E_{\alpha 759} (^{217}\text{At})=6322$ keV, $J_{\alpha 759} = 5\cdot 10^{-3}$ % is close to the ^{221}Fr α -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 $5 \cdot 10^{-4}$ J $_{\alpha 0}$ ^{217}At . Thus the investigations, whose results are displaced 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 $5 \cdot 10^{-4}$. To evaluate the ^{225}Ac impurity is more difficult because the α -lines ($E_{\alpha 0}(^{225}\text{Ac}) = 5830$ keV and $E_{\alpha 0}(^{213}\text{Bi}) = 5870$ keV) are too close in energy. But it can be said with confidence that the intensity of the $E_{\alpha 0}(^{225}\text{Ac})$ line in these spectra is below $5 \cdot 10^{-3}$.

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

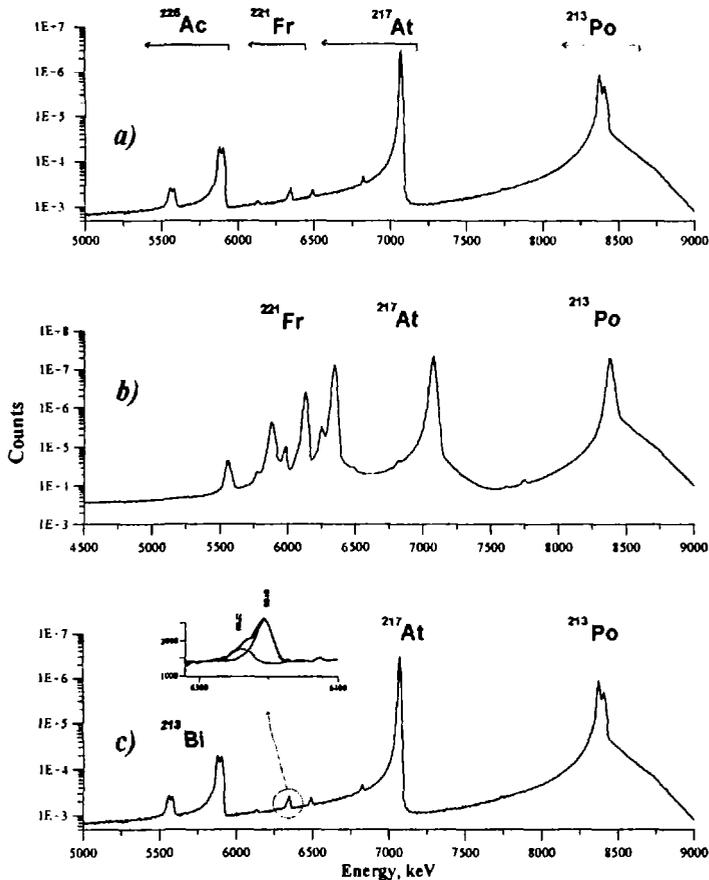


Fig. 3. Alpha spectra of:

- 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: $E_0(^{221}\text{Fr}) = 6341$ keV and $E_{\alpha 759}(^{217}\text{At}) = 6322$ 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
$^{217}\text{At} \rightarrow ^{213}\text{Bi}$			
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]
$^{213}\text{Bi} \rightarrow ^{209}\text{Tl}$			
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]
$^{213}\text{Po} \rightarrow ^{209}\text{Pb}$			
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 $J_{\alpha 759} = (12 \pm 6) \cdot 10^{-3} \%$ and agrees with [8]. The intensity evaluation of the $E_{\alpha} = 6037$ 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 $E_{\alpha 0} (^{213}\text{Bi}) = 5870$ keV and $E_{\alpha 324} (^{213}\text{Bi}) = 5549$ 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 $^{213}\text{Bi} \rightarrow ^{209}\text{Po}$ 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 $E_{\alpha 778}(^{213}\text{Po})$ 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	$(4.8 \pm 1.5) \cdot 10^{-5}$	$(11 \pm 5) \cdot 10^{-5}$ [7]
^{217}At	$(6.7 \pm 2.4) \cdot 10^{-5}$	$(12 \pm 6) \cdot 10^{-5}$ [1] < $5 \cdot 10^{-5}$ [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 $(4.8 \pm 1.5) \cdot 10^{-3}$ % in agreement with the result of [7]: $(11 \pm 5) \cdot 10^{-3}$ %. 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 $(6.7 \pm 2.4) \cdot 10^{-5}$ 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):

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

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 .

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E6-97-189

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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