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Laboratory of Nuclear Problems

M.Ya. Balats, L.N. Kondratyev, L.G. Landsberg, P.I. Lebedev, Yu.V. Obukhov
B. Pontecorvo

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RADIATIONLESS TRANSITIONS IN HEAVY μ -MESOATOMS

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RADIATIONLESS TRANSITIONS IN HEAVY μ -MESOATOMS*

* *Reported at the IX International Conference on High Energy Physics (Kiev, 1959). See A.I. Alikhanov's report.*

ANNOTATION

Spectra of meson X-rays, emitted by μ mesoatoms of uranium and lead, have been investigated by means of a scintillation spectrometer. It is shown that the intensity of 2P–1S radiative transitions in mesouranium, normalized to one stopped muon, is considerably less than in mesolead. Thus, there was proved experimentally the existence of a new mechanism of mesoatom transitions, in which the relevant energy is directly transferred to the nucleus.

I. INTRODUCTION

In Wheeler's paper/1/ two types of fission by μ -mesons in heavy nuclei had been predicted: 'internal' fission, when the energy necessary for fission is released in the nuclear capture of the muon from the lower mesoatom level, and 'external' fission, in which the muon does not disappear, the energy necessary for fission being released in a nonradiative mesoatom transition.

Zaretsky/2/ has calculated the probability of radiationless transitions in mesoatoms of heavy nuclei, more exactly, the probability that the 2P–1S transition energy is not released in the form of mesonic X-rays but is directly transferred to the nucleus.

In the experiment of Belovitsky and others/3/, in which photoplates were used, the conclusion was drawn that muons stopping in U^{238} cause only 'internal' fission with a probability of 0.07 (nonradiative fission was not observed by those authors and has a probability less than 1%). The research of Diaz* et al./4/, carried out by means of electronic methods, shows that radiationless fission, if any, must be rare.

With the exception of those experiments which gave negative results, the radiationless mechanism proposed by Zaretsky for the 2P–1S transitions had not been investigated experimentally. Thus, up to now only two mechanisms for the 2P–1S mesonic transitions were known: 1) mesonic X-ray emission and 2) Auger effect, which in heavy nuclei does not practically play any role.

In the present paper it is shown experimentally that mesonic 2P–1S radiationless transitions really take place in heavy mesoatoms.

The investigation of such phenomenon not only is of interest in itself but could also give valuable information on heavy nuclei properties.

Zaretsky/2/ indicated that the probability of radiationless transitions in a μ -mesoatom of uranium, where the density of nuclear levels is large, must be appreciable. In a μ -mesoatom of lead, where the density of nuclear levels is small, this probability is practically equal to zero. According to this, the fraction of 2P–1S radiationless transitions in mesouranium was determined by measuring the difference of the yield of the corresponding radiative X-ray mesonic transitions in U^{238} and Pb. The fact that the

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* We are grateful to Dr. Moyer for communicating to us the results of this investigation during the Kiev Conference.

transition energies in mesouranium and mesolead are close ($\sim$ 6 MeV) made the task of comparing photon yields easier, since there was practically no need to introduce corrections to the spectra obtained experimentally.

II. EXPERIMENTAL PROCEDURE

Use was made of the 270 MeV/c pion beam from the Joint Nuclear Research Institute synchrocyclotron. The experimental arrangement is given in Fig. 1. The rate of muons stopping in the target was registered by a three scintillation counters telescope in coincidence as $1+2-3$ (coincidence of counters 1, 2 in anticoincidence with counter 3) The absorption curve obtained in an experiment with a thin (4 gr/cm^2) target is given in Fig. 2. Radiation spectra of mesonic X-ray photons were measured with thicker targets, the uranium target (100 x 100 mm^2 x 10.7 gr/cm^2 and the lead one (100 x 100 mm^2 x x 10.3 gr/cm^2) being equivalent as far as ionisation loss is concerned.

Scintillation counter 4, consisting of a NaJ(Tl) crystal 30 mm in diameter and 35 mm in height connected to a photomultiplier served as a detector of γ quanta. The γ -counter output was connected to a 64-channel amplitude analyser which was triggered by a signal of the type $(1+2-3)$ $(2+4)$. The accidental coincidence backrgound was about 1/20 of the total count.

A Na^{24} source giving photons with energies of 1.38 MeV and 2.76 MeV was used in order to calibrate the energy scale and to check the linearity of the whole system. The uranium and lead targets were alternated periodically during the measurements. All the spectra had the same form and did not show appreciable shift with respect to each other.

III. RESULTS AND CONCLUSIONS

Photon spectra of mesouranium and mesolead in the energy range from 3 MeV to 8 MeV are shown in Fig. 3. The spectra are normalized to an equal number of muons stopped in the target. In the Pb spectrum there appears a clear peak at $\sim$5.3 MeV. Owing to the relatively small size of the NaJ(Tl) crystal, this peak is related to three values of the energy lost by photons in the crystal: 1) E_γ, 2) E_γ - – 0.51 MeV, 3) E_γ – 1.02 MeV, where $E_\gamma \approx 6.02$ MeV/5/ is the 2P–IS transition energy in mesolead. The number of counts in uranium is smaller than in lead in the 5 – 5.5 MeV region, while in regions far enough from 5.5 MeV the counts in U^{238} and Pb are practically equal. The mean peak energy corresponding to the 2P–IS transition energy in uranium is approximately 200 KeV higher than in lead.

The difference in the intensity of 6 MeV photons in mesouranium and mesolead under conditions of similar geometry and close radiation energies demonstrates the existence of radiationless transitions of μ - mesons to the 1S - state of mesonuranium. A quantitative estimation of the probability of this phenomenon appears to be difficult. In order to determine the ratio of the intensities of the radiative 2P–1S state transitions in mesouranium and mesolead, it is necessary to know the number of counts in each analyser channel which is really due to 2P–1S photons. In other words it is necessary to know the contribution of the background counting rate, i.e. of the rate which is not connected with 2P–1S transitions. Background counts are due to other mesoatom transitions and also to the presence of electrons in the primary beam.

The determination of the background is rather a complicated problem which is under study now. At present we can only indicate rough limits within which the background must lie. From measurements carried out with a gas Cerenkov counter it became clear that the background count for photon energies $E > 4$ MeV both in the case of uranium and lead is mostly due to electrons. This background practically does not depend upon the target material and the analyser channel number. It is clear that the counting rates in uranium and lead for energies close to 8 MeV are lower limits of the background levels in uranium and lead in the energy region of interest around 5 MeV (Fig.3). On the other hand the upper limit of the background (Fig. 3) will correspond to the line obtained by a smooth interpolation of uranium and lead spectra between the regions with $E \ll 5$ MeV and $E \gg 5$ MeV.

Assuming that the probability of radiationless transitions W_{exc} in lead is negligibly small in comparison with the probability of photon emission $W_{h\nu}$, $(W_{exc}/W_{h\nu})_{Pb} = 0$ and taking into account the above background limits we obtain:

$$0.1 < \left(\frac{W_{exc}}{W_{h\nu}}\right)_{U^{238}} < 1 \qquad (1)$$

Another rough estimate of the background can be made from the condition that the uranium and lead peak widths must be about equal. From this estimate we obtain $(W_{exc}/W_{h\nu})_{U^{238}} \sim 0.2$, i.e., a value close to the lower limits of (1).

Thus one can conclude that the probabilities of radiative and nonradiative transitions in U^{238} are comparable*, the radiative transitions apparently predominating.

Preliminary experiments show that nonradiative transitions take place in Th^{232}

In Zaretsky's paper a magnitude 5–20 was predicted for the ratio $(W_{exc}/W_{h\nu})_{U^{238}}$. This result does not agree with the value (1). It is necessary to point out, however, that in the original Zaretsky's estimate it was assumed that in a nucleus of uranium $\rho\,\Gamma_{nuc} \gg 1$, where ρ is the mean density of the uranium levels excitable by the 2P–1S mesonic transition and Γ_{nuc} is their mean nuclear width. Under such assumption we can neglect the processes in which the excited nucleus with a muon in the 1S–state undergoes a transition into the ground state of the nucleus, the muon going back to the 2P-state. As Zaretsky

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* In our preliminary communication at the Kiev Conference (1959) it was stated that the probabilities of the 2P–1S nonradiative and radiative transitions in U^{238} are approximately equal. This was an overstatement.

pointed out while discussing our results, the hypothesis $\rho \Gamma_{nuc} \gg 1$ is not really justifiable a priori. If $\rho \Gamma_{nuc} \ll 1$, the processes of muon oscillation between the 2P and 1S states with simultaneous oscillation of the nucleus between the excited and the ground states are no more negligible, so that the ratio $(W_{exc}/W_{k\nu})$ greatly decreases/6/.

At present more accurate measurements of the ratio $(W_{exc}/W_{k\nu})$ in different mesoatoms are being carried out.

The authors are sincerely grateful to A.I. Alikhanov for his constant interest and to D.F. Zaretsky for illuminating discussions.

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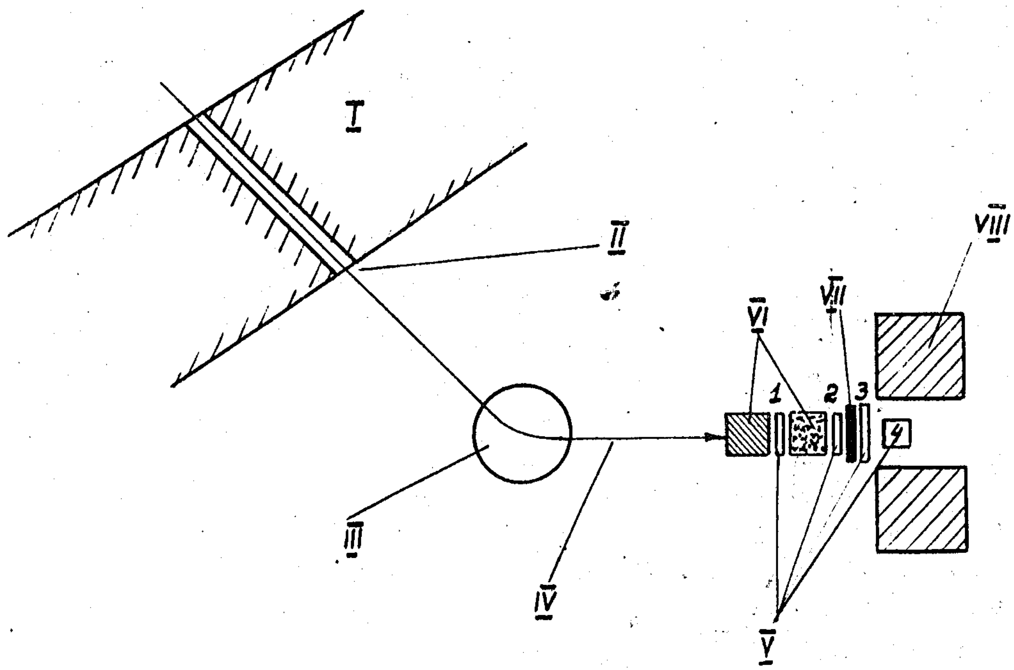

Fig. 1. Experimental arrangement. I – Concrete shielding. II – Collimator (Ø 100 mm). III – Deflecting magnet. IV – π^--meson beam. V. – Scintillation counters: 1,2 – Plastic counter Ø 100 mm, thickness 10 mm. 3 – Plastic counter Ø 125 mm, thickness 12 mm. 4. – Crystal NaJ (Tl) Ø 30 mm, thickness 35 mm. IV – Filter (75 gr/cm^2 Cu + 32 gr/cm^2 B_4C). VII – Target. VIII – Shielding of counter 4 (20 cm Pb).

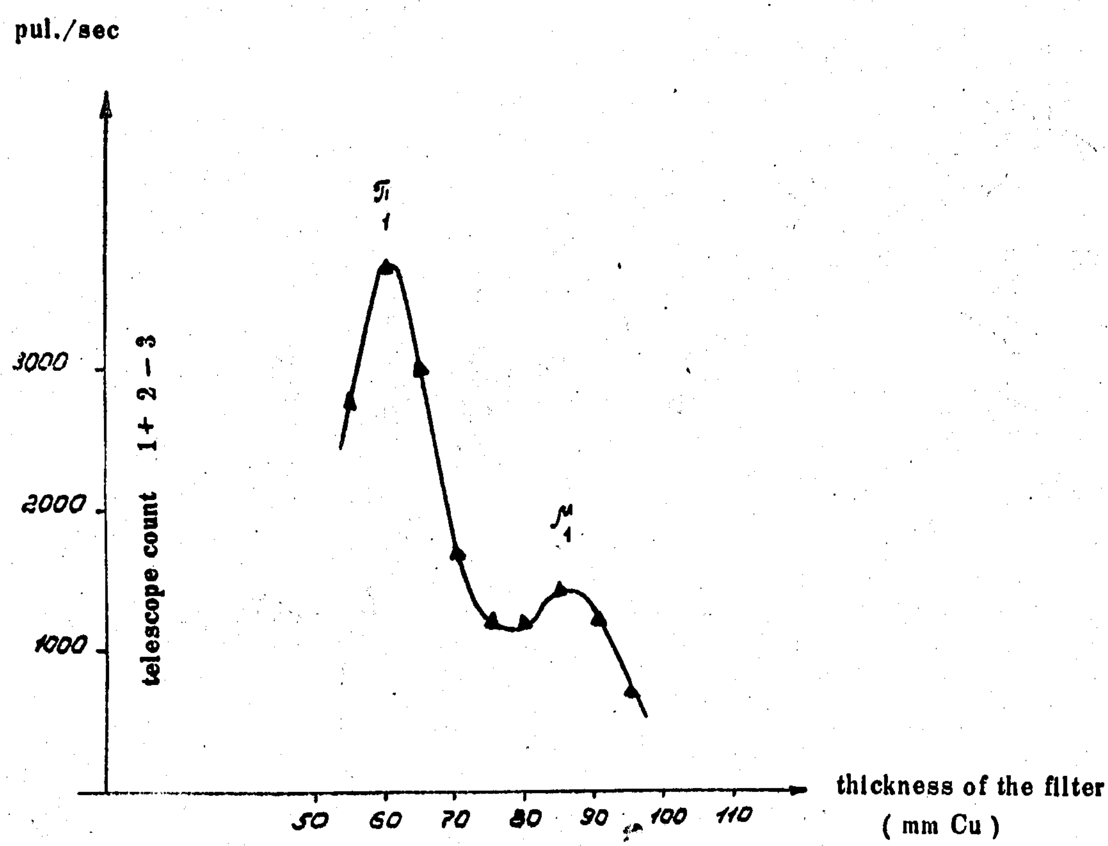

Fig. 2. Absorption curve.

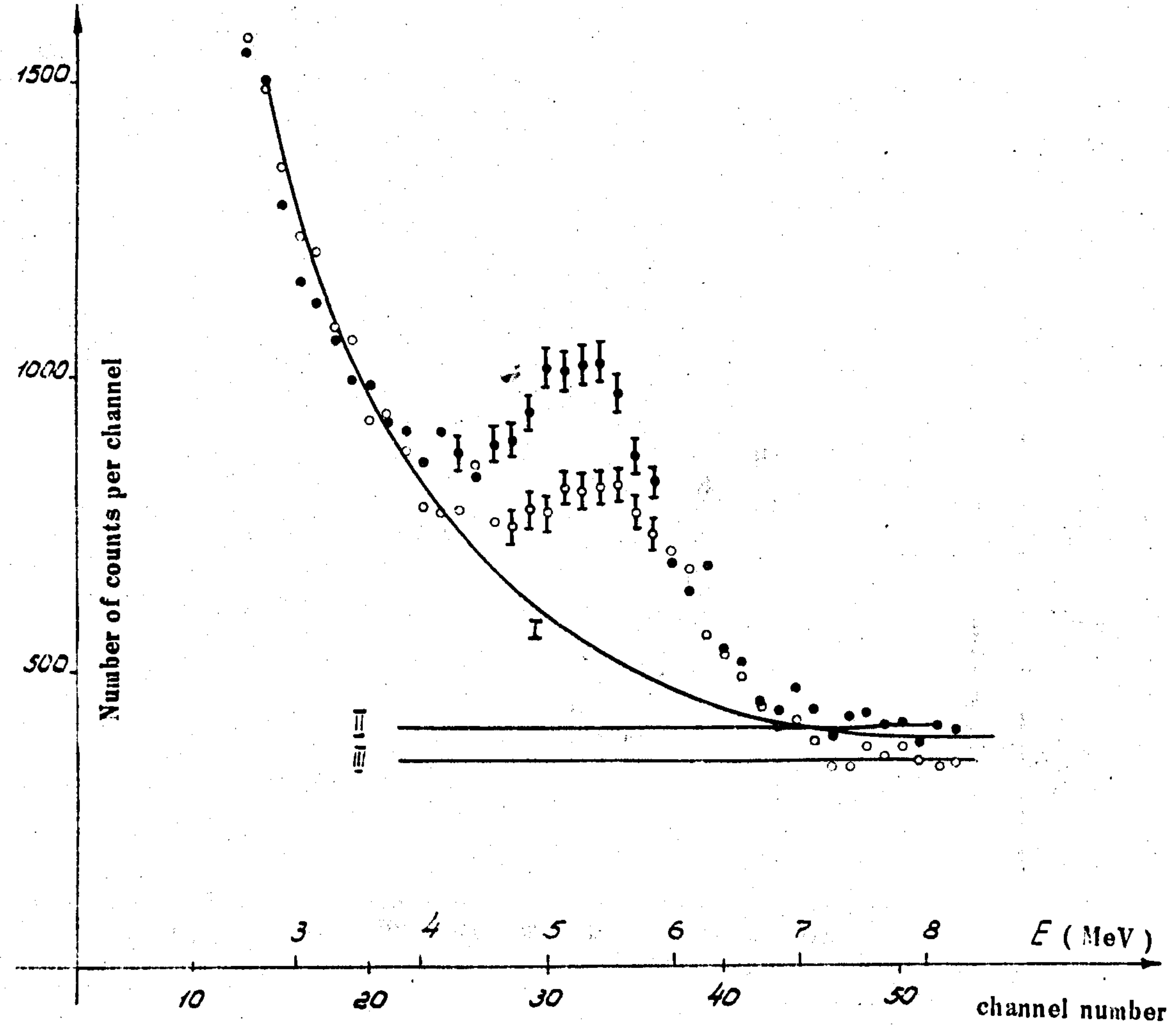

Fig. 3. Photon spectra from mesouranium and mesolead. – Pb, – U.
I – The upper limit of the background. II. – The lower limit of the background in lead.
III – The lower limit of the background in uranium.