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1979

Volume 2

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VIENNA, 1980

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PHYSICS AND CHEMISTRY OF FISSION
1979

Volume II

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FISSION FRAGMENT MASS AND ENERGY DISTRIBUTION FOR THE NEUTRON-INDUCED FISSION OF ^{239}Pu AS FUNCTIONS OF THE RESONANCE SPINS
by C.M.C. Wagemans et al.

p.143

The missing footnote to the title should read as follows:

Research sponsored by NFWO, Belgium.

FOREWORD

The Kernforschungsanlage Jülich is among the leading nuclear research centres in the world. It provided a suitable and hospitable meeting-place for the Fourth International Symposium on the Physics and Chemistry of Fission, held from 14 to 18 May 1979.

Previous symposia in this series (Salzburg 1965, Vienna 1969, and Rochester 1973) had set the pace for these IAEA-organized meetings, which summarize the important advances in the field during the last twenty years. From one symposium to the next the scientific emphasis is shifted, new ideas and new experimental approaches being assimilated from year to year, such that it has become difficult to accommodate all the different lines of research under the roof of one meeting. To make the working hours at the Fourth Symposium acceptable, approximately two-thirds of the submitted papers could not be accepted for oral presentation, they were made available at the Symposium in the form of extended summaries. These are included in the Book of Extended Synopses made available to all the participants. Further copies can be obtained from the Physics Section, Department of Research and Laboratories, IAEA.

Many pages in the present Proceedings are taken up with review papers, on the assumption that in this way a more complete and unbiased coverage of many different orientations in fission research could be obtained. The contributed papers have been selected to illustrate or complement the extensive reviews.

The interest in the 1979 Symposium, the number of excellent contributions and the lively discussions during the meeting demonstrate the vitality of fission research. Both theoretical and experimental studies reported at the symposium indicate that fission studies have provided many valuable solutions to problems, but clearly other problems are still open and much work remains to be done.

EDITORIAL NOTE

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MUON-INDUCED FISSION
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Chairman

E. CHEIFETZ
Israel

MUON-INDUCED FISSION

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Abstract

MUON-INDUCED FISSION.

A review of recent experimental results on negative-muon-induced fission, both of ^{238}U and ^{232}Th, is given. Some conclusions drawn by the author are concerned with muonic atoms of fission fragments and muonic atoms of the shape isomer of ^{238}U.

Since the family of elementary particles was discovered, a study of many exotic phenomena appeared to be possible. Some of the elementary particles (μ^-, π^-, K^-, $\bar{p}$, Σ^-, Ξ^-, Ω^-) are stable enough to be slowed down by ionization to the velocity $\sim \alpha c$ and from the continuous spectrum to enter into the discrete one replacing an electron. After that atomic transitions with the emission of Auger electrons and x-rays occur, and finally hydrogen-like atoms are formed. Because of the larger masses in comparison with that for the electron, the atomic orbits for the particles mentioned are placed much closer to the nucleus than electron orbits. But only in the case of a negatively charged muon which we can call a "heavy electron", a rather stable atom is formed living hundreds of nanoseconds. Due to the strong interaction, all other elementary particles are absorbed by nuclei in a short time. For heavy elements they cannot even enter the orbit 1S being captured from orbits with higher n.

In heavy muonic atoms the muon disappears mainly in the process

$$p + \mu^- \rightarrow n + \nu$$

Most of the energy released is taken away by the neutrino. However, the residual nucleus is excited up to an energy of about 20 MeV. As a result, neutron emission or fission will take place. The muon absorption by a nucleus goes through the weak interaction and the typical lifetimes for fissile elements are close to 80 nsec.

It can happen, however, that during the atomic de-excitation the energy of a transition will be transferred into the nucleus without X-ray emission. The possibility of such a radiationless transition was pointed out firstly by Wheeler [1]. The theory was later developed by Zaretsky et al [2]. Until now radiationless transitions are not explored with good accuracy. Balatz et al [3] observed that the probability of a 2P-1S radiationless transition is close to 20% for Th and U.

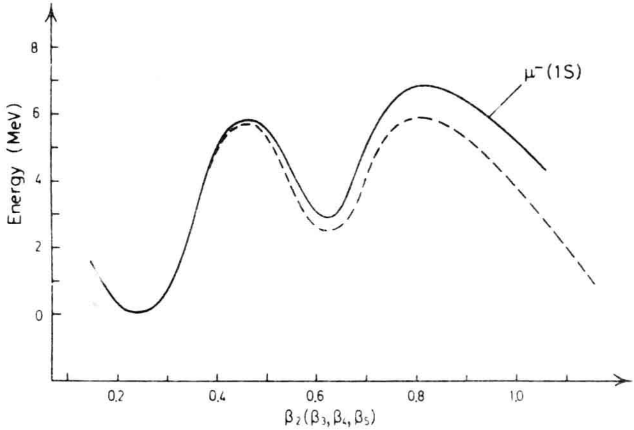

FIG. 1. Fission barrier rise in the presence of a negative muon.

In this work the decrease of the intensity for X-rays was determined by comparison with lead. The energy for the 2P-1S transition is about 6 MeV for fissile nuclei and fission can take place. In fact, we can consider that as photofission in the presence of a negative muon. In the early experiments of Diaz et al [4] fission induced by radiationless transitions was observed.

Since then not too many physicists have been interested in studying muon-induced fission. In the 60's the main attention was paid to the investigation of the effects connected with the two-humped fission barrier [5,6]. Charged particles (p,d,α) beams of high quality available at the electrostatic tandem-generators as well as γ-rays were used in many laboratories. A lot of information was accumulated and the Strutinsky theory was strongly supported by many experimental facts. It is hard now to doubt the role of shell effects at large deformation of nuclei. There are still some groups working in this field and the results obtained so far are concerned with the spectroscopy of the states in the second well.

The improvement of old accelerators as well as the appearance of "mesic factories" with higher intensities of negative muons made it possible to perform some new experiments on muon-induced fission.

In my further considerations I shall follow the lines which were of main interest in the last few years:

1) Muonic shape isomers

2) Muonic fission fragments.

The investigations mentioned stimulated the consideration for the possibility of fission due to nuclear excitation in the β-decay of the muon in the 1S orbit. Rather poor experimental date on these subjects are available now and I would like to start with the Dubna group experiment on the search for muonic

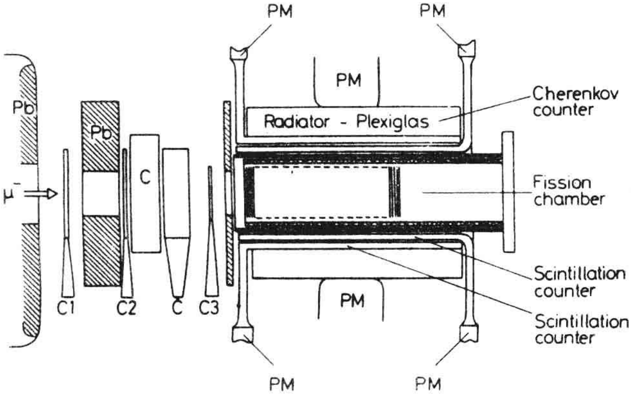

FIG. 2. Simplified scheme of experimental layout.

atoms of ^{238m}U [7]. These experiments were initiated by the work of Bloom [8] who suggested that a muonic shape isomer of ^{238}U can be formed with a rather high probability. The main idea was based on the difference in the measured half-lives for electrons from muon β-decay and fission mode. Later, more precise measurements have shown the difference to be not so large.

Before talking about the experiments it is useful to refer to the theoretical work done by Leander and Möller [9] where the influence of a negative muon sitting in the 1S orbit on the fission barrier was analysed.

Fig. 1 shows how the fission barrier is changed by the presence of a negative muon. It is necessary to remind oneself that the whole change is explained as due to the electromagnetic interaction of the muon with the nucleus. Some conclusions can be drawn from a study of Fig. 1.

First of all the height of the fission barrier is increased. A comparison of the known date on muon-induced fission with those for photofission [10] supports this conclusion. The fission probability is suppressed in the presence of the muon. Especially strong suppression takes place for ^{232}Th. One can understand that because of the large height for the outer barrier in this case.

One can also see that the properties of the shape isomer should be changed enormously in the presence of a muon in the 1S orbit:

1) The isomeric shift is expected to be about 0.5 MeV.
2) The probability for γ-decay will be increased.
3) The probability for spontaneous fission will be decreased.

In the experiments carried out by the Dubna group a target of ^{238}U was irradiated by negative muons. Both X-rays and nuclear

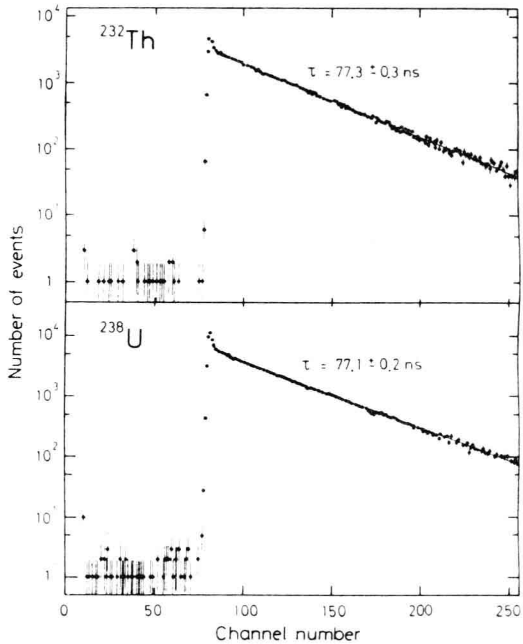

FIG. 3. μ-stop-fission time distribution.

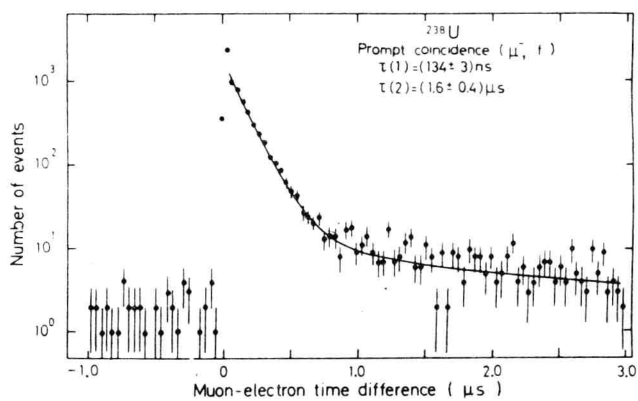

FIG. 4. μ-stop electron time distribution for prompt μ-stop-fission events.

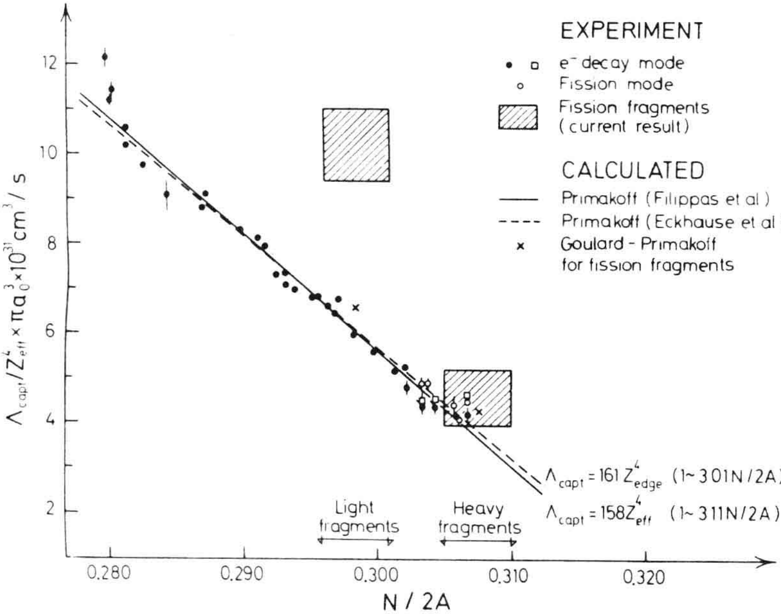

FIG. 5. The Primakoff plot.

γ-rays were registered by a 60 cm^3 Ge-Li detector. The experiments have shown the presence of delayed γ-rays of very low intensity. The half-life was estimated to be about 12 nsec. In similar conditions for ^{232}Th target only γ-rays due to nuclear muon capture were observed. The results obtained gave rise to a suggestion for possible evidence of muonic atom for ^{238}U shape isomer. Because of the extremely poor statistics, that statement is not very strong. The energy of the isomeric level was estimated to be 3.1 MeV. It is about 0,6 MeV higher than that for the well known ^{238}U shape isomer [11]. The half-life measured in the Dubna experiments is 20 times shorter than the one known for ^{238}U. That fits nicely with what one can expect for γ-decay of muonic ^{238}U shape isomer. Similar experiments were done earlier by Kaplan et al [12] but only an upper limit for the effect was established. To some extent confusing is the high probability for the population of the state identified. It is close to 1% per μ^--stop in the target. If the conclusion concerning the existence of a muonic atom for ^{238m}U is right, one has to think about quite a special mechanism for isomeric state population.

A further development of the experiments on muonic atoms of ^{238}U took place at the CERN synchrocyclotron. There some experiments with the equipment produced partially in JINR (Dubna) were done. Fig. 2 shows schematically the last version of the equipment which was used.

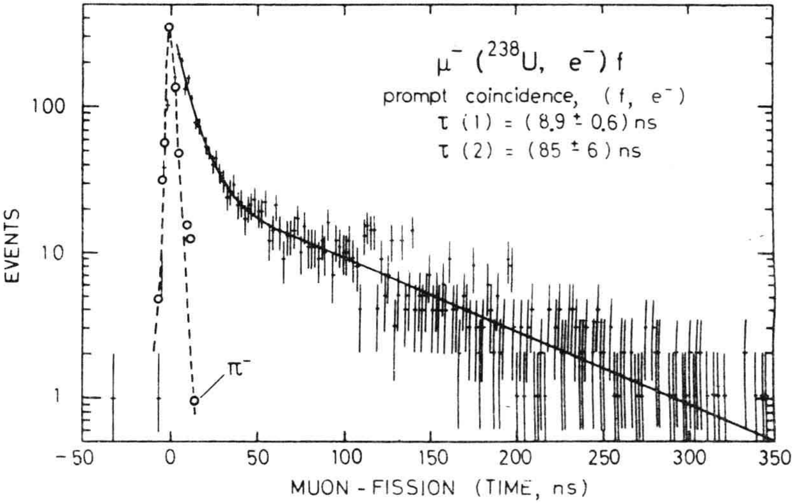

FIG. 6. μ-stop-fission time distribution for prompt fission-electron events.

As a target the multiplate ionisation chamber was used. About 20g of ^{238}U were put on 100 electrodes. The fission fragments were detected by using this chamber. For muon detection a conventional telescope was used. To eliminate the electrons in the muon beam a plexiglas Cerenkov counter was incorporated into the telescope. By a moderator the admixture of pions was minimised. The resolution time (FWHM) was about 4 nsec.

The ionisation chamber was surrounded by two plastic detectors and a plexiglas Cerenkov counter to detect the electrons emitted by the β-decay of a muon.

Fig. 3 shows the μ⁻-stop-fission time distribution measured by the equipment described [13] . One can see clearly both the prompt fission due to radiationless excitation and the exponent due to nuclear capture of a muon.

As a first step of the CERN experiment the β-decay of muonic atoms of fission fragment was studied. One can expect that in the scission process the muon will be transferred to the 1S orbit of one of the fission fragments. Later this muonic atom will decay by nuclear capture or by muon β-decay. In the experiments prompt fission induced by radiationless transitions was detected and the time distribution for the electrons emitted by β-decay of the muon was measured [14] . Both ^{238}U and ^{232}Th targets were used. Fig. 4 shows the time distribution observed. It is necessary to mention here that the amount of material between the targets and Cerenkov counter implied a threshold for electron registration of about 10 MeV. The decay curve presented in Fig. 4 was measured by using one plastic detector in combination with a water Cerenkov counter. By adding a second plastic detector the efficiency for electron detection was decreased by not more than about 10%.