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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Physics III COMMITTEE

SC2

Proposal for a Study of Nuclear Excitation and Isomer Shift in Muonic Atoms

by

H. Backe, R. Engfer, E. Kankeleit and K. Wien

Institut für Technische Kernphysik
der Technischen Hochschule Darmstadt

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I. Results from test experiments.

According to our proposal of January 1967 (PHIII-67/1) on the study of nuclear excitation and isomer shift in muonic atoms experiments were performed at the SC in May and June this year with 12 shifts allocated for first tests. In collaboration with the Karlsruhe-Heidelberg group, data were taken with targets of natural Ta and W which proved the feasibility of these experiments. A report on preliminary results has been presented at a conference in Asilomar (Calif.) and is enclosed in the appendix. The following conclusions can be drawn from these experiments.

1. The CERN muon channel is very well suited for this type of studies. The excitation of the first and second rotational levels has been observed in Ta (see fig. 2 in the appendix). γ-lines from the first rotational levels in ^{182}W, ^{184}W and ^{186}W in a natural tungsten target were observed in an eight hour run.

2. An appreciable excitation probability by stopped pions was detected in the case of Ta. Therefore, low pion contamination is mandatory for these experiments.
3. An isomer shift of (110 ± 60) eV was measured for the 136 keV first rotational level in ^{181}Ta.
4. The tests with tungsten have shown that the use of natural target material is possible. The additional amount of shifts needed for natural targets, in comparison to enriched targets, is partly compensated by the simultaneous collection of data from several isotopes. Also, enriched isotopes are not available in the necessary quantities.
5. An improvement of the counter arrangement (see appendix) has diminished the background from muonic oxygen and carbon by a factor of five.

II. Future program.

1. In future experiments the isomer shift of excited states in the range of heavy elements from Sm to Au will be determined. For some selected nuclei (e.g. ^{181}Ta) the shift of the second rotational level will be studied which is of particular theoretical interest.
2. Different nuclear excitation mechanism due to a resonance effect as predicted by Hüfner$^{1)}$ and as observed by Hargrove et al.$^{2)}$ in Lead will be used for the study of isomer shifts of other than rotational levels.
3. The study of the weak magnetic hyperfine components of the nuclear γ-lines (see appendix) give direct information about the Bohr-Weißkopf-effect. With improved statistics and a reduced background it will be possible to measure this effect with an accuracy better than obtained so far.
4. It will be tried to improve the beam conditions by magnetic devices and different collimations. Ge-detectors with a

new cryostat in combination with an anticoincidence counter are in construction, which should yield a drastic reduction of the compton background of the high energy muonic X-rays.

III. Financial situation.

The financial support of the German Bundesministerium für wissenschaftliche Forschung has been granted for the equipment and travel expenses.

IV. SC-Machine time request.

For testing new beam collimating devices 5 shifts on parasiting beam and 15 shifts with full beam intensity for collecting data will be needed for the end of this year.

80 shifts are asked for the year 1968.

References:

1) J. Hüfner: Nuclear Excitation in Muonic Bismuth, to be published.

2) C.K. Hargrove: Radiationless Transitions in Pb, Int. Conf. on Electromagnetic Sizes of Nuclei, Ottawa May 22. - 24., 1967

<u>Appendix:</u> see following pages.

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Appendix: see following pages.

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MUONIC ISOMER SHIFT IN ^{181}Ta

H. Backe, G. Backenstoss, H. Daniel, R. Engfer, E. Kankeleit,
G. Poelz, H. Schmitt, L. Tauscher and K. Wien

CERN, Geneva, Switzerland

and

Institut für Technische Kernphysik, Technische Hochschule,
Darmstadt, Germany,

and

Max-Planck-Institut für Kernphysik, Heidelberg, Germany,

and

Institut für Experimentelle Kernphysik, Technische Hochschule,
Karlsruhe, Germany.

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CERN, Geneva, Switzerland,

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Institut für Technische Kernphysik, Technische Hochschule,
Darmstadt, Germany,

and

Max-Planck-Institut für Kernphysik, Heidelberg, Germany,

and

Institut für Experimentelle Kernphysik, Technische Hochschule,
Karlsruhe, Germany.

ABSTRACT

Using the CERN muon beam facilities, γ-rays from the muonic excitation of ^{181}Ta have been studied with Ge detectors. γ-lines of 136 keV and 165 keV were observed with a resolution of 1.5 keV, which can be interpreted as the de-excitation of the first and second rotational levels of ^{181}Ta. By comparison with the corresponding γ-line in the radioactive decay of ^{181}W a positive shift of (+110 ± 60) eV of the 136 keV line was found, which can be explained as an increase of the r.m.s. charge radius of the first rotational state with respect to the ground state. Using Fermi type nuclear charge distributions a value of $\Delta \langle r^2 \rangle = (+1.5 \pm 0.8) \times 10^{-3}$ fm^2 can be deduced.

* * *

The excitation of the nucleus by the muon in a muonic atom was described by Wilets[1)] and Jacobsohn[2)] and was first seen in the structure of the muonic X-ray spectra of many isotopes[3,4,5)]. In addition to this nuclear excitation a shift of the transition energy was predicted by Hüfner[6)]. It is due to the Coulomb interaction of the 1s muon with the nucleus in the ground and excited state having different charge distributions. This muonic isomer shift has first been observed in ^{152}Sm by Bernow et al.[7].

In the present paper we describe the measurement of two nuclear γ-rays following the de-excitation of the two lowest rot. levels in ^{181}Ta. A shift of the transition energy is observed for the lower γ-line.

^{181}Ta has a $7/2^+$ ground state and rotational levels with $9/2^+$ at 136.2 keV and with $11/2^+$ at 301.4 keV. Conversion coefficients are $\alpha_T = 1.62$ and $\alpha_T = 0.08$ respectively. The muonic X-ray spectra of ^{181}Ta have been studied recently by De Wit et al.[5]. From the analysis of these data excitation probabilities of 22.6 % and 2.1 % of the $9/2^+$ and $11/2^+$ states, respectively, have been concluded.

In this experiment, performed at the CERN 600 MeV Synchrocyclotron, the muon channel facility was used. In Fig. 1 the conventional set-up is shown consisting of telescope counters 1,2 and 3, the anticoincidence counter 4 - a box made of 3 mm thick plastic scintillator sheets - and the Ge counters outside the muon beam. The anticoincidence counter contains the target of cross shaped Ta metal sheets, 0.5 mm thick. A range curve for muons with 7.7 g/cm^2 half width and 7500 stops per sec in the maximum were obtained with a pion contamination of less than 5 %. The coincidence counting rate was about 10 c $\cdot$ sec^{-1} in the upper Ge detector. Only this detector was used for the analysis up to now because of its better resolution of 1.5 keV fwhm.

The main problem in this type of experiment is the exact determination of the small energy difference between γ-rays from the muonic excitation in the Ta target and the same γ-transition which can be easily provided by a ^{181}W radioactive source. The following calibration method was used. The rather weak ^{181}W source was placed sideways underneath the upper detector. On arrival of a coincident signal $(1,2,3,\bar{4},\mathrm{Ge})$ one subgroup of 1024 channels of a Laben Analyzer accepted the digitized Ge detector pulses. The time resolution, determined by the Ge detector, was 115 nsec. The calibration spectrum from the ^{181}W source was accepted in a second subgroup of the analyzer in a time interval from 2 to 22 µsec after a (1,2) coincidence and anticoincident to a $(1,2,3,\bar{4},\mathrm{Ge})$ pulse, thus leaving priority to the muon spectrum and providing the same time structure for both γ-ray sources. Effectively the second subgroup was opened for about 30 % of the time. Therefore almost only muonic events were recorded in the first subgroup and radiation from the source in the second subgroup. The counting rate for the 136.2 keV γ-rays from the ^{181}W source was adjusted to be three times higher than that from the Ta target. This way the muon spectrum was only slightly contaminated by accidental events from the source. This contamination can be determined from the 152.5 keV line in the decay of ^{181}W and was corrected for. Only one detector with one analogue-to-digital converter (with buffer register) was used to detect the γ-rays from both sources, therefore drifts affect both spectra in the same way.

Part of the data taken in a 23.5 hour period are shown in Fig. 2. Of the large amount of information contained in these data only the following will be discussed: a nuclear γ-ray appears at 136 keV and another weak one at 165.2 keV corresponding to the 9/2 to 7/2 and 11/2 to 9/2 transition, respectively. The intensity has been estimated to be not inconsistent with the 22.6 % and 2.1 % populations mentioned above. Due to the poor statistics of the 165 keV line a shift was not determined in this experiment.

The line positions for the 136 keV photo peaks in the two spectra have been determined by fitting the data to gaussians including the close by 2p-1s line of oxygen. The difference turned out to be (123 ± 12) eV. The stated error is purely statistical as given by the computer result.

Several test experiments have been performed in order to ensure that no background lines occur underneath the 136 keV peak. The absence of X-ray lines in the corresponding energy region was established by replacing the tantalum target by tungsten. As expected from calculations no lines of importance were found. Furthermore, it was checked that no lines appear in the region of 136 keV due to fast muons or pions or in the delayed muon X-ray spectrum. However, a 136 keV line was observed in the pionic X-ray spectrum. According to the low pion contamination of the muon beam, however, this effect can be neglected in the muon X-ray spectrum.

A number of points have to be considered in the analysis of this shift.

a) The two radiation sources are different in shape and position with respect to the Ge diode. The dependence of photo peak position on the angle of incidence has been studied. Such a dependence has been observed. For the given arrangement an uncertainty in peak position of ± 20 eV was estimated.

b) The two sources were not identical with respect to absorption. The 136 keV γ-rays have to emerge from the Ta metal sheets, while ^{181}W γ-rays have to penetrate 6.5 mm Cu which was needed to shield the detector from the intense electronic X-rays. Small angle Compton scattering produce low energy tails which are not properly taken into account when fitted to a gaussian curve. Even though a more complex function should and will be used, it was experimentally established that a shift smaller than ± 20 eV results from this effect.

c) As mentioned above, part of the calibration spectrum appears in the muon spectrum and vice versa. This effect diminishes the difference and a correction of (+11 ± 2) eV has to be applied.

d) Due to the magnetic hyperfine interaction four transitions are to be expected. The two $\Delta F=1$ transitions are identical within 40 eV whereas the $\Delta F=0$ transition is shifted by -2 keV [8)] and the $\Delta F=2$ transition by +2 keV. The intensities of these four lines 1.7 : 54.6 : 43.3 : 0.4 are calculated taking into account an E2 admixture of

17 % 9) and a statistical population of the excited sublevels F=4 and F=5, which should be approximately correct. Because only the two main $\Delta F=1$ lines are analyzed this results in a shift of (+24 ± 6) eV which has to be subtracted from the detected shift.

Taking these effects into account we obtained in this preliminary analysis a shift of:

(+110 eV ± 60) eV.

Since the muon is essentially inside the nucleus, it is not a simple matter to evaluate a change in nuclear radius as is usually done in Mössbauer work. An evaluation of $\Delta < r^2 >$ depends on the shape of the change of the nuclear charge distribution. For the analysis a Fermi type charge distribution was used with the parameters c = 6.57 fm and t = 1.50 fm 5). With the assumption of constant surface thickness t a change of $\Delta < r^2 > = (1.4 \pm 0.7) \times 10^{-3}$ fm^2 and with the assumption of constant half width radius c a change $\Delta < r^2 > = (1.6 \pm 0.8) \times 10^{-3}$ fm^2 has been evaluated. The values for these two extreme assumptions agree within error. As a final result we quote $\Delta < r^2 > = (1.5 \pm 0.8) \times 10^{-3}$ fm^2 for the radius difference between the 9/2 and 7/2 state in ^{181}Ta.

We wish to acknowledge the many illuminating discussions we have had with Professor P. Brix and A. Winther. We thank Professor E. Baldinger, Basel, who made the Ge-detector for us. Dr. Gerdau has kindly supplied us with the ^{181}W source. We should also like to thank the MSC division at CERN for their assistance during the experiment. This work was supported by the Bundesministerium für Wissenschaftliche Forschung.

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FIGURE CAPTIONS

Fig. 1 Experimental set-up.

1,2: 10 mm plastic scintillator
3: 3 mm plastic scintillator
4: Anticoincidence counter, 16x10x8 cm box out of 3 mm plastic scintillator
Pb: Lead shielding
c: Graphit absorber
Target : 0.5 mm, $d_{eff} = 3.3$ gr cm^{-2}

Fig. 2 Muonic isomer shift in ^{181}Ta.

E_{theor}: Calculated energies of the corresponding lines.

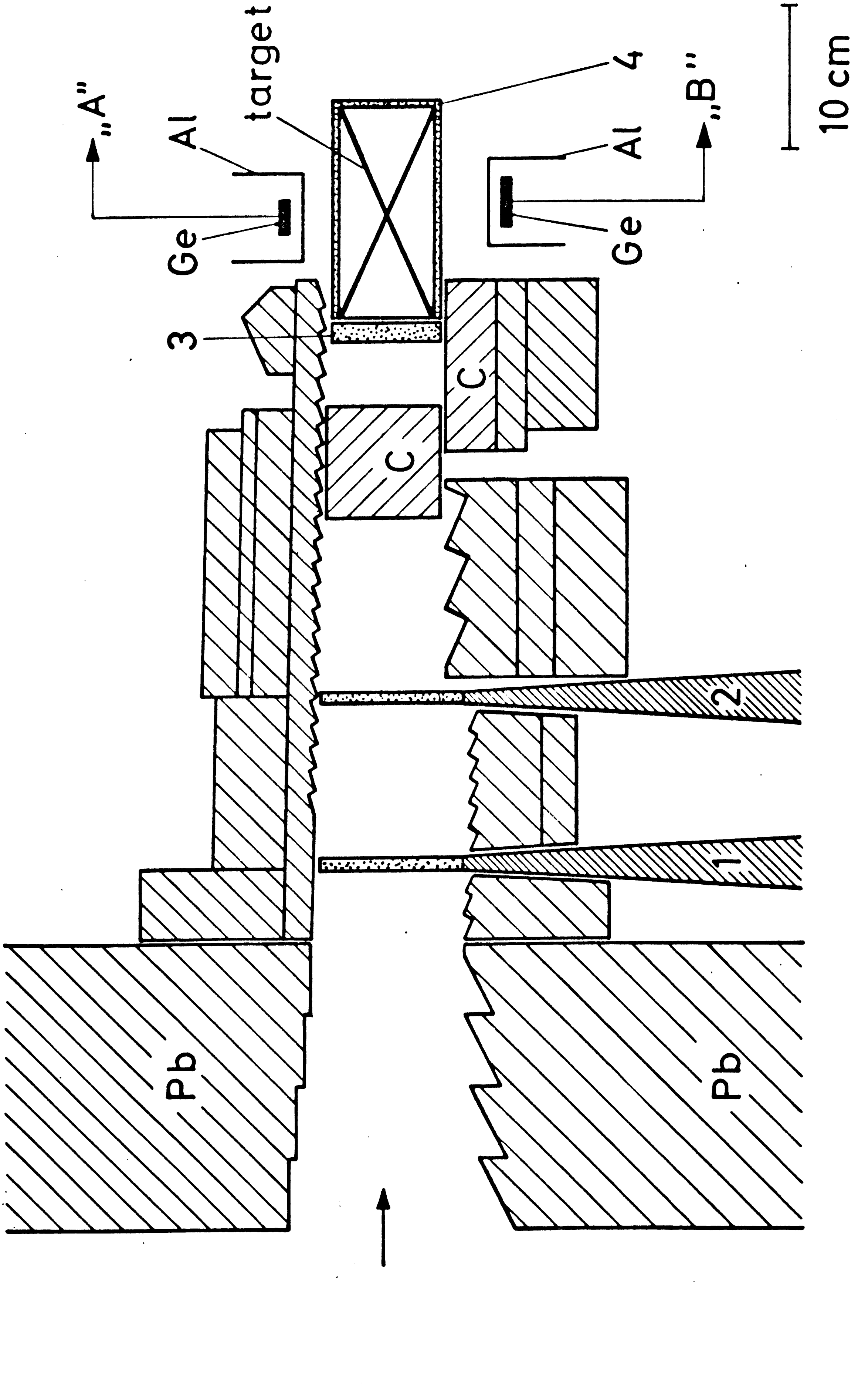

Fig.1

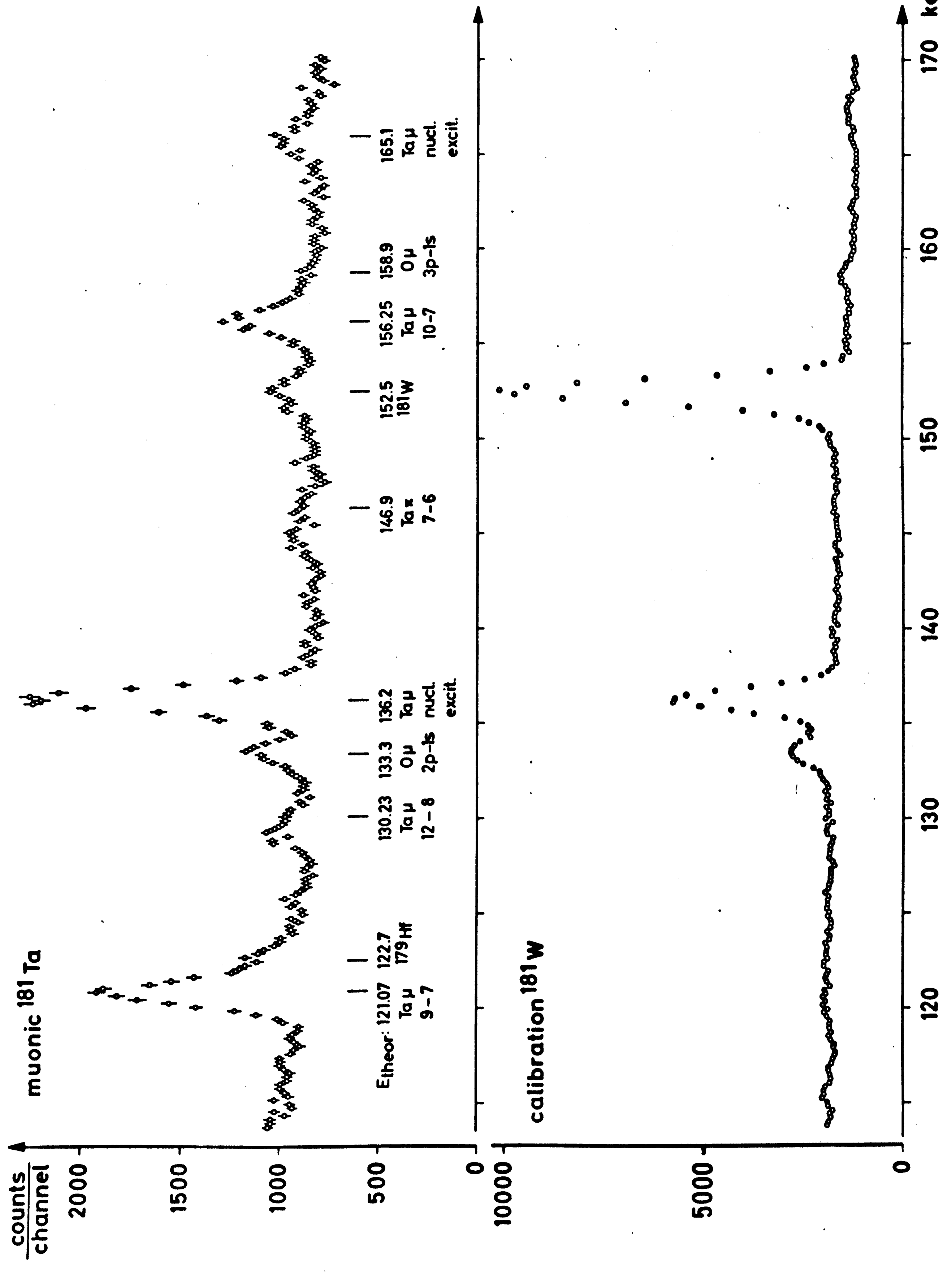
counts / channel
2000
1500
1000
500
0
10000
5000
0
muonic ^{181}Ta
calibration ^{181}W
E_{theor}: 121.07 Ta μ 9–7
122.7 ^{179}Hf
130.23 Ta μ 12–8
133.3 O μ 2p–1s
136.2 Ta μ nucl. excit.
146.9 Ta κ 7–6
152.5 ^{181}W
156.25 Ta μ 10–7
158.9 O μ 3p–1s
165.1 Ta μ nucl. excit.
120
130
140
150
160
170
keV

Fig. 2