THE DECAY OF Ti^{44}* **

E. W. Cybulska and L. Marquez

Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brasil

(Received March 3rd, 1959)

ABSTRACT: The decay of Ti^{44} has been studied with scintillation spectrometers, coincidences and delayed coincidences. It was found that it decays by electron capture to the second excited state of Sc^{44}. This is followed by a gamma ray of 79 Kev and then a gamma ray of 70 Kev. The 70 Kev state is metastable with a half life of 0.18 microseconds.

INTRODUCTION

The nuclide Ti^{44} was found by Sharp and Diamond[1,2] who described it as decaying by electron capture, followed by a gamma ray of 160 Kev. They found that it decays only to the 3.9 h ground state of Sc^{44} and that it does not populate the 2.4 d metastable state in Sc^{44}. Their measurements indicated that the half life was greater than 23 y.

Huizenga and Wing[3] made a careful study of the gamma ray spectrum in the decay of Ti^{44}, and proved that the decay is followed by two gamma rays in coincidence, one with an energy around 68 Kev and the other with an energy around 76 Kev, giving a composite peak at 72 Kev.

---

* Work sponsored in part by the Comissão Nacional de Energia Nuclear and the Conselho Nacional de Pesquisas of Brasil.

** Submitted for publication to The Physical Review.

They found that the cross over transition was less than 2% of the total number of desintegrations. They observed a peak at 144 Kev, but by using Cu absorbers they came to the conclusion that it was all due to pile up, giving the above upper limit. They proposed a decay schema.

We thought that it was worth while to investigate the decay of Ti^{44} with the hope of measuring the energy of gamma rays precisely and to settle the question of the conflicting evidence about the gamma ray of the cross over transition.

There is also a practical reason why we should know the decay scheme of Ti^{44} as well as possible. Since the half life of Ti^{44} is long, it will be useful in Geophysical and Cosmophysical chronology, for instance, Ti^{44} would be a good integrator for the cosmic ray flux received by an iron meteorite for periods of 1/10 of the half life to 4 half lifes before their fall.

The Ti^{44} was prepared by irradiating a sample of 50 mg of Sc_2O_3 of 99% purity, the remaining 1% being mostly a mixture of the other rare earths. The Sc_2O_3 was mounted on a suitable target holder and irradiated with 22 Mev deuterons from the synchrocyclotron of the Comisión Nacional de Energia Atomica, Buenos Aires, Argentina. The integrated current that it received was of 100 microamp-hr. The reaction that produces Ti^{44} is Sc^{45} (d, 3n)Ti^{44}. The irradiated Sc was brought to our laboratory and allowed to decay for two months before processing.

EXPERIMENTAL METHOD

The chemical procedure had to separate the Ti^{44} from the Sc^{46} and other rare earth impurities, from Zr and Hf, and from other

smaller impurities. The Sc_2O_3 was fused with $HNaSO_4$, the melt was extracted with dilute HCl, 10 mg of Cu, 10 mg of Zn and 20 mg of Ti were added and the mixture of hydroxides was precipitated with NH_4OH. The hydroxides were dissolved in 0.1 M oxalic acid and the Ti separated from the sc and the other metals that do not form complex with oxalic acid by means of an anion exchange column, following the technique of Walter[4]. After separating the Sc, the Ti was eluted with 0.1 N HCl. It was concentrated and boiled with HNO_3 to destroy organic matter. It was evaporated to near dryness with H_2SO_4, 10 mg of Zr were added and the solution was poured over a cold mixture of NH_4OH and 20% H_2O_2. The precipitate was filtered and washed. The filtrate and washings were made acid with HCl and boiled thoroughly to destroy the H_2O_2. The Ti was precipitated with NH_4OH.

The precipitate was dissolved in H_2SO_4 and diluted to make it 20% by weight in H_2SO_4, 10 ml of H_2O_2 and 20 mg of Zr were added. The Zr was precipitated at 50°C with 200 mg of secondary ammonium phosphate. The precipitate was filtered and washed with 5% $NaNO_3$. The filtrate was reduced with 4 g of Na_2SO_3 and neutralized with NaOH. The precipitate containing the Ti was filtered, washed and incinerated.

The precipitate was spread over a circle of 1.5 cm diameter, mounted between two plastic foils having 10 mg/cm^2 and then the measurements were carried out. We measured the gamma ray spectrum of the sample up to 800 Kev. In this region it showed peaks at 74 Kev, 149 Kev and the annihilation peak at 511 Kev from the daughter Sc^{44}. No other primary gamma ray could be detected and this showed that the sample was radiochemically pure. We saw of course the spectrum of the Compton

effect from the 511 Kev gamma ray and its back-scattered gamma ray of 170 Kev.

We then made measurements of coincidences and delayed coincidences around the peak at 74 Kev. We verified the result of Huizenga and Wing, namely, there are two gamma rays in coincidence in the unresolved peak. We also found that the low energy gamma ray was delayed in regard to the high energy one. We fixed one of the gamma ray spectrometers to count on the low energy side of the composite peak and the other on the high energy side of it, and we were able to obtain the delayed coincidence curve shown in Figure 1. A prompt coincidence curve taken with annihilation radiation is shown for comparison. This gives for the low energy gamma ray the half life of 0.18 $\pm$ 0.02 microseconds.

Our delayed coincidence spectrometer used two single channel pulse height analyzers with NaI(Tl) crystals of 3/2" diameter by 1" height. The pulses at the output of the analyzers were fed to the delay coincidence circuit. This was of conventional design. The smallest delay that could be introduced was 2.5 microseconds and the width of the coincidence channels was fixed at 2 microseconds. The time was measured with a Tektronix oscilloscope type 531. The instrument was checked by measuring the half life of the delayed state in W^{187} and we found 0.6 $\pm$ 0.1 microseconds in agreement with other measurements[5,6].

We could use the delay to measure the energy of the gamma rays precisely. This was done by introducing enough delay to cut the coincidence counting rate to half its value without delay while one of the spectrometers was set on the low energy side and the other was set

on the high energy side of the composite peak. The spectrum was measured on one spectrometer and then on the other and gave the values of 70 ± 2 Kev and 79 ± 2 Kev. The delay was increased until the coincidence counting rate was one fourth of the value without delay. The measurements were repeated and gave the same results. The lines obtained in these measurements were narrower and looked like single lines.

We carried out measurements on the peak at 149 Kev with the aim of detecting the cross over transition. We tried three techniques to reduce the contribution of the pile up peak. The distance from the source to the detector was varied and Pb and Cu absorbers wer used. It was not possible to detect it. An upper limit of 4% relative to each of the gamma rays of 70 Kev and 79 Kev could be set. The upper limit could not be reduced because our source had only 20,000 dpm and because of the back-scattered gamma ray of 170 Kev.

DISCUSSION

The half life of 0.18 microseconds found for the 70 Kev transition allows us to classify it as M1. The half life given by the formula of Weisskopf[7] for the single particle transition is 8×10^{-11} sec, but experimentally measured half lives of M1 transitions sometimes are more than 1000 times slower than the values given by the single particle formula[7,8].

The spin and parity of Ti^{44} is very probably 0^+, being an even-even nuclide. Its decay to the second excited state in Sc^{44} is allowed, and its decay to the first excited state is forbidden. The decay of the ground state of Sc^{44} to the ground state of Ca^{44} is forbidden, and its decay to the first excited state is allowed. All this

together with the information of this work leads to the assignment of 5^+, 2^+ and 1^+ for the ground state, first excited state, and second excited state of Sc^{44}. The transition of 79 Kev must be then M1 and the cross over transition E2.

All the information leads to the decay scheme shown in Figure 2. This decay scheme is the same as the one of Huizenga and Wing with some improvements. The energies of the gamma rays are known more precisely. Their order is known too. Finally, it has been established the existence of a metastable state in Sc^{44} of 0.18 microseconds. The 2.4 d state is also shown in the decay scheme.

We are greatly indebted to the Comisión Nacional de Energia Atomica, Buenos Aires, Argentina, for making the irradiation for us without which this work could not have been carried out. We are also indebted to N. L. Costa, I. G. Almeida and M. Levi for their help in the chemical separations, and to S. Oschalins for his help with the electronic equipment.

1. R. A. Sharp and R. M. Diamond, Phys. Rev. 93, 358 (1954).

2. R. A. Sharp and R. M. Diamond, Phys. Rev. 96, 1713(1954).

3. J. R. Huizenga and J. Wing, Phys. Rev. 106, 90 (1957).

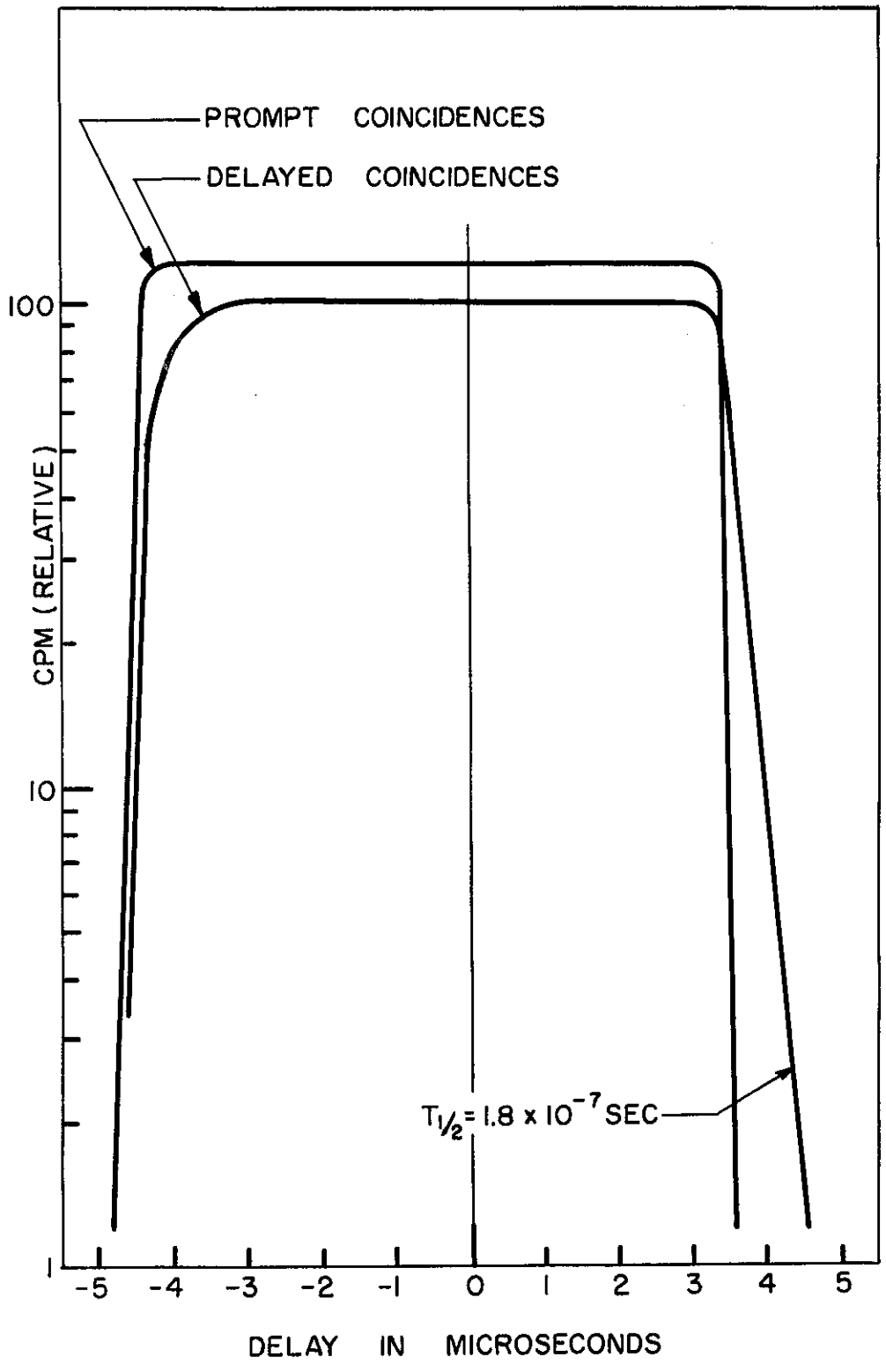
4. R. I. Walter, J. Inorg. Nucl. Chem. 6, 58 (1958).

5. D. E. Bunyan, A. Lundby, A. H. Ward, and D. Walker, Proc. Phys.Soc. (London) 62A, 253 (1949).

6. S. DeBenedetti and F. K. McGowan, Phys. Rev. 74, 728 (1948).

7. A. H. Wapstra, G. J. Nijgh, and R. van Lieshout, Nuclear Spectroscopy Tables (North-Holland Publishing Company, Amsterdam, 1959) p. 71.

8. M. Goldhaber and A. W. Sunyar, in Beta and Gamma Ray Spectroscopy, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955) p. 467.


PROMPT COINCIDENCES
DELAYED COINCIDENCES
100
10
1
CPM (RELATIVE)
$T_{1/2} = 1.8 \times 10^{-7}$ SEC
-5
-4
-3
-2
-1
0
1
2
3
4
5
DELAY IN MICROSECONDS

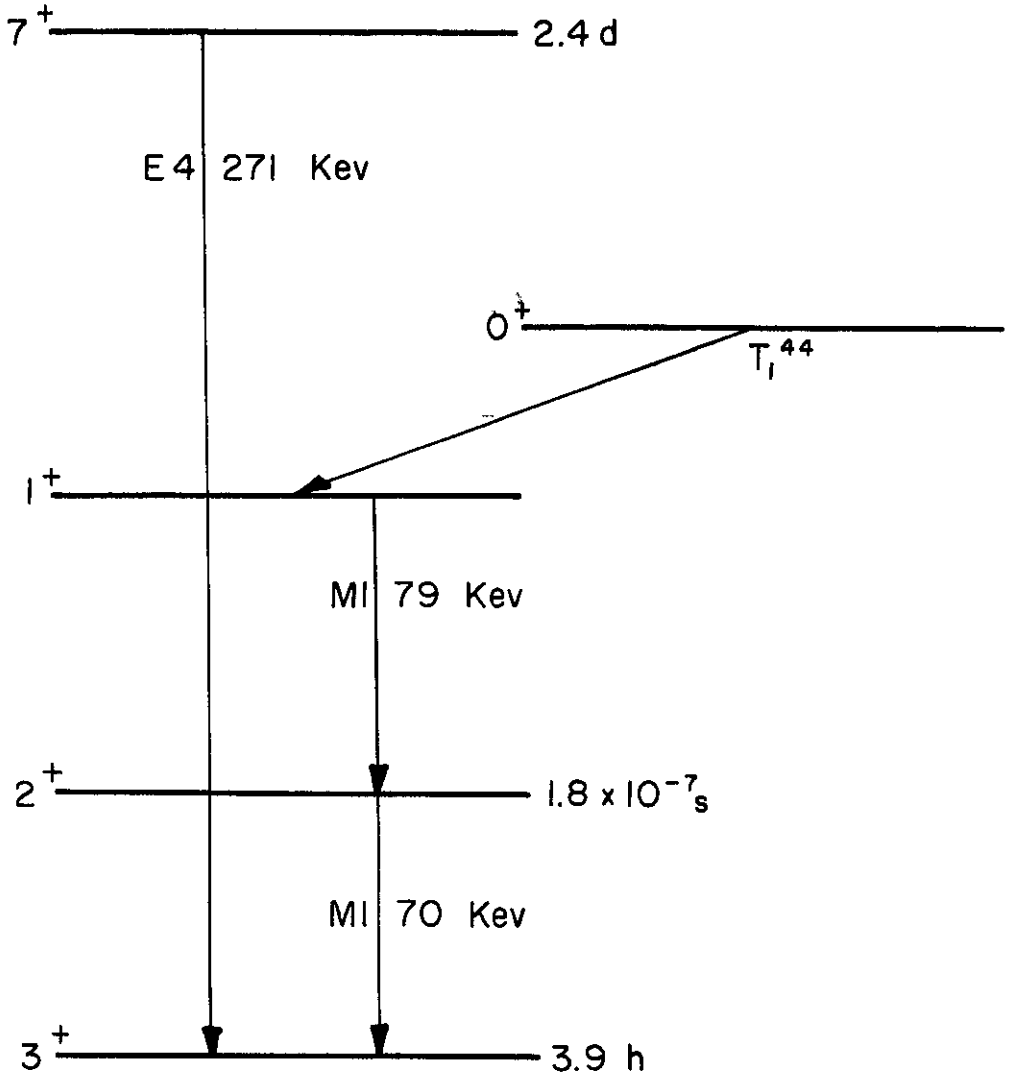


FIG. 2