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Search for a β^- Branch in I^{124}†

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A mass spectrometric search for a β^- branch in 4.2-day I^{124} has been made by examining the isotopic composition of xenon from deuteron-irradiated tellurium. The expected β^- branch, based on nuclear mass data and ft values, is 0.017%. There was good agreement between calculated and measured isotopic composition. No Xe^{124} was detected, so an upper limit of 0.1% was established for this branching.

I. INTRODUCTION

THE six lightest isotopes of meteoritic xenon show systematic excesses relative to terrestrial xenon.[1–3] These general anomalies have not been satisfactorily explained. It is known that Xe^{126}, Xe^{128}, Xe^{129}, Xe^{130}, and Xe^{131} are produced by β^- decay of the corresponding iodine isotopes, although such a branch is to date undetected in I^{124}. If the general anomalies are to be explained in part by deuteron or proton irradiation of tellurium, the existence of a β^- branch in I^{124} must be established.

The existence or lack of a β^- branch is of interest because 4.2-day I^{124} lies between the two stable isotopes Te^{124} and Xe^{124}. Mitchell and co-workers[4] made a direct search for emitted electrons using a 180° magnetic spectrometer and found only internal conversion electrons from the iodine decay products Te^{123} and Te^{124}. They set no quantitative limit to the β^- branch.

Consideration of atomic masses (doublet method)[5] indicates energy is available for decay to Xe^{124}:

$$\text{mass of } Xe^{124} = 123.945320 \pm 300 \text{ amu},$$

$$\text{mass of } Te^{124} = 123.942400 \pm 300 \text{ amu}.$$

The observed maximum kinetic energy of the emitted positrons from I^{124} is 2.136 ± 0.010 Mev, identified as decay to the ground state. This corresponds to 0.003392 amu. Therefore:

$$\text{mass of } I^{124} = 123.945792 \pm 310 \text{ amu}.$$

This shows that 0.440 Mev are available for β^- decay to Xe^{124}.

The $\log ft$ value for the observed positron decay to the Te^{124} ground state is 7.9.[4] A Fermi analysis of the positron distribution of the highest energy group indicates a shape corresponding to the classified unique first forbidden ($\Delta I = 2$, yes).[4] The ground state of I^{124} has been identified as having spin 2 and negative parity.[4,6] Te^{124} is 0+. Since Xe^{124} is also an even-even nucleus, it is expected to be 0+ as well, so the β^- decay to Xe^{124} should be of the same degree of forbiddenness.

For the unique first-forbidden transformations, it is possible to determine the comparative half-life $f_1 t$, knowing the available energy. Davidson[7] has shown that

$$f_1 = f_0[a(Z)(W_0^2 - 1) + b(Z)(W_0 - 1)],$$

for any Z and W_0. He gives curves for the coefficients $a(Z)$ and $b(Z)$, and a histogram showing that $\log_{10} f_1 t$ is approximately constant for the unique first-forbidden transformations. Tables for determination of $f_0(\pm Z, W_0)$ are given by Feenberg and Trigg.[8] Equating the $\log f_1 t$ value for the proposed β^- decay to Xe^{124} to the average $\log f_1 t$ value gives a theoretical branching of 0.017%.

II. CALCULATION OF EXPECTED YIELD

A calculation of the expected yield of Xe^{124} in a deuteron irradiation of tellurium was made. The 0.017% branching ratio calculated above was assigned to I^{124}.

Cross sections for the formation of the compound nucleus by deuterons were taken from Shapiro.[9] Above 17 Mev, the high energy approximation was used:

$$\sigma_c = \pi (R + \lambda\!\!\!^{-})^2 \left[1 - \left(\frac{R}{R + \lambda\!\!\!^{-}} \right) \frac{1}{x} \right].$$

This was adjusted slightly to a smooth fit with the tabulated values. The percentage decay of the compound nucleus via single, double, and triple neutron emission were taken from Balestrini.[10] Extrapolation was required above 20 Mev. Balestrini's curves were obtained from consideration of the compound nucleus Xe^{129}. In this calculation they were applied to the compound nuclei I^{125}, I^{126}, I^{127}, I^{128}, I^{130}, and I^{132} obtained from deuteron capture by the stable isotopes Te^{123}, Te^{124}, Te^{125}, Te^{126}, Te^{128}, and Te^{130}. (Te^{120} and Te^{122} do not lead to stable xenon isotopes so were not considered.) This procedure is expected to be valid on the basis of the constancy of the binding energy per nucleon within limited ranges of A. Using the range-energy curves of Aron

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et al.,[11] the yield was computed for successive layers of the target within which the beam energy loss was about 1 Mev. The total compound nucleus yield was then the sum of the yields in all layers. The tellurium target was roughly ten times the thickness required to stop the 23-Mev deuterons.

III. EXPERIMENTAL PROCEDURE

A mass spectrometric search for a β^- branch in I^{124} has been made by examining the isotopic composition of xenon produced by deuteron irradiation of tellurium.

Pure (99.999%) tellurium metal was heated briefly under vacuum in a graphite crucible to a temperature just above its melting point. This evaporated away the surface oxide and partially outgassed the sample. The tellurium in its graphite holder was inserted in a cyclotron mount, covered with aluminum foil, and bombarded with 23 Mev deuterons for 80 minutes at 5 μa beam current in the Crocker laboratory 60-in. cyclotron.

The sample was allowed to cool for 30 days, after which its activity was 20 mr/hr. Then it was vaporized at 600°C under vacuum in a rare-gas extraction line described elsewhere,[12] and the xenon was removed on activated charcoal at dry ice temperature in a sample takeoff. The xenon was analyzed with a mass spectrometer similar to that described by Reynolds,[13] but without an electron multiplier detector.

IV. RESULTS AND DISCUSSION

The calculated and measured yields are listed in Table I. Figure 1 illustrates this graphically. The calculated 0.017% β^- branch was assigned to I^{124}. The other branching ratios were taken from the Seaborg tables.[14]

TABLE I. Calculated and measured xenon production from Te(*d,xn*) thirty days after bombardment. The measured amount has been normalized to the same total as was calculated.

Isotope	Calculated amount (number of atoms)	Measured amount (number of atoms)
Xe^{124}	0.0017×10^{13}	$<0.01\times10^{13}$
Xe^{126}	5.7×10^{13}	8.1×10^{13}
Xe^{128}	23.1×10^{13}	23.6×10^{13}
Xe^{129}	1.5×10^{6}	...
Xe^{130}	32.8×10^{13}	26.5×10^{13}
Xe^{131}	12.3×10^{13}	15.8×10^{13}
Total	74.0×10^{13}	74.0×10^{13}

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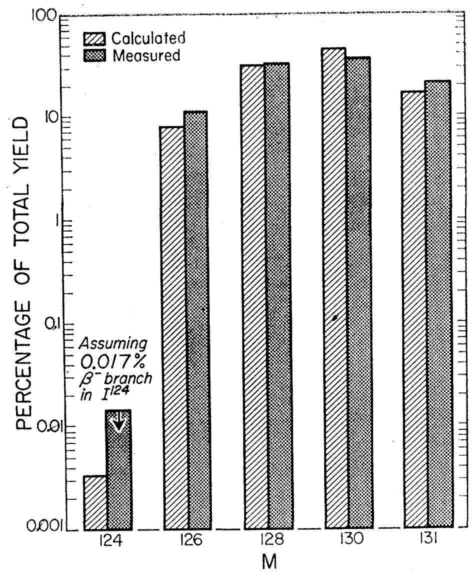

FIG. 1. Calculated vs measured xenon yields. Calculated Xe^{124} yield based on a calculated 0.017% branch in I^{124}. From the absence of detectable Xe^{124} production, an upper limit of 0.1% can be set for the β^- branch in I^{124}.

On the basis of this measurement the β^- branch for I^{124} must be less than 0.1%, based on the mass spectrometer noise at mass 124. No peak was found. This is in good agreement with the calculated value. Use of a mass spectrometer with an electron multiplier detector would increase the sensitivity for Xe^{124} detection by many orders of magnitude. However, the highly anomalous nature of this xenon would so contaminate the spectrometer as to render impossible any subsequent high-sensitivity xenon analyzes.

The magnitude of this upper limit excludes deuteron or proton irradiation of tellurium as an important mechanism for the production of the general isotopic anomalies of xenon.

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