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FORMATION OF THE 50-YEAR ELEMENT 94 FROM DEUTERON BOMBARDMENT OF U^{238} (1)

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Abstract

It has been shown by bombardment with deuterons of a sample of U^{238}, greatly depleted in U^{235} and U^{234}, that the 50-year 94 activity and 2.0 day 93 activity are formed in approximately the same yield as with the natural mixture of uranium isotopes. These activities are thus shown to arise from the U^{238} nucleus, and from considerations of the energy of the compound nucleus (U^{238} + d), it appears most probable that they are produced by a d, 2n reaction as follows:

$$U^{238}(d,2n)93^{238} \xrightarrow[2.0\ day]{\beta^-} 94^{238}$$

Introduction

Two isotopes of element 94 are known. They are artificially produced, emit alpha-particles, and have been assigned half-lives of ~50 years[2,3] and ~30,000 years[4].

The ~30,000-year 94^{239} grows from the 2.3-day 93^{239} which in turn grows[5] from the 23-minute uranium made from U^{238} by neutron capture.

The 2.3-day 93^{239} is also produced in the bombardment of uranium with deuterons[3]. It has not been determined whether 93^{239} is produced directly by the d,n reaction, whether it grows from the 23-minute U^{239} produced by the d,p reaction, or whether it is produced by both mechanisms. The growth of 94^{239} has not been

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observed from the deuteron-produced 93^{239} because it is masked by the growth of the 50-year 94 from the 2.0-day 93 also produced in the deuteron bombardment of uranium[3]. If the 2.0-day 93 is produced at all in the neutron bombardment of uranium its yield (in terms of the number of atoms) is less than 1/10,000 that of the 2.3-day 93^{239}. In a 13 Mev deuteron bombardment the ratio of the same yields[3] is 1/8. (These are the relative thick-target yields obtained from the 60-inch Berkeley cyclotron.) These data did not make possible the assignment of a definite mass number to the 50-year 94 and its 2.0-day 93 parent. The mass numbers 235 and 238 seemed the most probable.

In order to study further the problem of assigning a mass number to the 50-year 94 and 2.0-day 93 we have bombarded with deuterons, in the 60-inch Berkeley cyclotron, a sample of separated U^{238} isotope which had been prepared in the 37-inch Berkeley spectrograph. In this U^{238} sample the ratio of U^{238}/U^{235} had been increased by a factor of 30 over that of the normal uranium. The experimental details follow.

Experimental Procedure

Sixteen mg of $U_3O_8(U^{238})$ was mounted in a uniform layer covering an area of 9 cm^2 on a 5-mil platinum disc 4 cm in diameter. The platinum disc was soldered to an oblique (11° incidence) copper target and bombarded with deuterons for 315 microampere-hours in the 60-inch Berkeley cyclotron. The 14 Mev deuteron beam passed through two 1-mil aluminum windows and about 10 cm of helium at a pressure of 25 cm of mercury before striking the U_3O_8. For comparison, 16 mg U_3O_8(natural isotopic mixture) was mounted in the same way and bombarded for 500 microampere-hours. As a

check to see that the two targets got the relative bombardment indicated by the number of microampere hours, the gamma-ray activities of the U_3O_8 samples and the platinum backings were measured at equal intervals after the bombardments. The gamma-ray ratios of U_3O_8 (natural mixture) to $U_3O_8(U^{238})$ and their platinum backings were 1.4 and 1.6 respectively, in agreement with the number of microampere-hours received.

Thirty hours after the end of each bombardment, the U_3O_8 targets were dissolved in nitric acid and the 93 and 94 fractions isolated by the usual rare earth fluoride precipitations from oxidizing and reducing media(7). Elements 93 and 94 were separated from each other about 50 hours after the end of the bombardments.

The 94 fractions were mounted on platinum and the alpha-particles counted on a linear amplifier. One per cent aliquots of the 93 fractions were evaporated on platinum and the growth of the alpha-particles followed. The alpha-particles in both samples grew with a 2.0 ± 0.2 day period. Other aliquots of the 93 fractions were mounted on cellophane and aluminum absorption curves taken on a Lauritsen electroscope. By extrapolating the hard portions of the beta-ray absorption curve as has been done before(3), the yield of the 2.0-day 93 as well as the yield of the 2.3-day 93^{239} can be calculated. The summary of the yields of the various transuranic isotopes produced in the bombardment of the thin U_3O_8 targets with 13 Mev deuterons is given in Table 1. The calculations have taken into account the conversion electrons in the 93^{239} beta-ray spectrum and the lower ionizing efficiency of the 1 Mev beta-particles of the 2.0-day 93 (as compared to the efficiency of the soft beta-particles from 93^{239}).

Table 1

Isotope	Microcuries per Microampere-Hour	
	from U_3O_8 (greatly depleted in U^{235} and U^{234})	from U_3O_8 (natural mixture of isotopes)
50-year 94 (after decay of 93)	5.2×10^{-5}	4.4×10^{-5}
2.0-day 93 (at end of a short bombardment)	0.31	0.25
2.3-day 93^{239} (at end of a short bombardment)	1.4	1.3

Discussion

The fact that the yields are not dependent on the amount of U^{235} or U^{234} in deuteron bombarded uranium samples clearly proves that the 50-year 94 and the 2.0-day 93 are made from U^{238}, and confirms the assignment of the mass number 239 to the 30,000-year 94, 2.3-day 93, and 23-minute uranium.

The half-life of the 50-year 94 calculated from the yields in Table 1 is about 30 years. This is in substantial agreement with the 50-year half-life previously reported[3] considering that the estimated error for both values is about a factor of two.

The relative thin-target yields of the 2.0-day $93/93^{239}$ (and the 50-year $94/94^{239}$) are 1/5 as compared to 1/8 for thick-target yields. The difference between these numbers, 1/5 and 1/8, is not necessarily significant because the aluminum absorption curves, on which the relative yields are based, were taken on different instruments. (The absorption curves of 93 radiation

from thin targets were taken with an electroscope, those from thick targets with an electrometer(3).

From a consideration of the energy of the compound nucleus ($U^{238}+d$) the d,2n reaction seems the most probable, the d,n reaction possible, and the d,3n rather improbable. Of the two more probable schemes, the $U^{238}(d,2n)\ 93^{238}$, $93^{238} \xrightarrow{\beta^-} 94^{238}$ scheme is favored, although it encounters the minor difficulty that 94^{238} falls at a considerable distance from the uranium curve in the Geiger-Nuttall plot. Choice of a scheme involving $U^{238}(d,n)93^{239}$ (2.0-day) followed by 93^{239} (2.0-day) $\xrightarrow{\beta^-}$ 94^{239} (50-year) would lead to the more serious difficulty of having to postulate isomeric pairs in 93^{239} and 94^{239}, each pair decaying independently. For these reasons we believe that the most probable assignments of the 2.0-day 93 and 50-year 94 are 93^{238} and 94^{238} produced by the following reactions:

$$U^{238}(d,2n)93^{238}$$

$$93^{238} \xrightarrow[2.0\ day]{\beta^-} 94^{238}$$

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