Half-Life of Pa^{232} *

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The half-life of Pa^{232} from two methods of preparation ($Pa^{231}+n$, and $Th^{232}+d$) has been measured and found to be 1.32 days.

I. INTRODUCTION

THE half-life[1] of Pa^{232} has been measured on samples of Pa^{232} prepared by two different reactions: (1) by $Th^{232}(d,2n)Pa^{232}$ and (2) by $Pa^{231}(n,\gamma)Pa^{232}$. The half-lives were determined only incidentally in the course of other experiments and are of but limited accuracy. However, they are being reported here because values of greater accuracy have not as yet been published.

Both samples of Pa^{232} had long-lived contaminants, whose activities had to be subtracted in order to get the desired half-life. In the bombardment of Th^{232}, Pa^{233} was also formed by the reaction

$$Th^{232}(d,p)Th^{233} \xrightarrow{\beta^-} Pa^{233} \quad \text{and} \quad Th^{232}(d,n)Pa^{233}.$$

Although the 17-day beta-emitter[2] Pa^{230} was also formed by the reaction $Th^{232}(d,4n)$, its concentration was much lower than that of the Pa^{233}, because of the relatively low energy of the deuteron beam (about 19 Mev). Its activity, therefore, had no measurable effect on the tail of the decay curve. The long-lived activity in the Pa^{232} formed by the $Pa^{231}(n,\gamma)$ reaction was due to the Pa^{231} itself. Because Pa^{231} has several alpha-particles with energies differing by several hundred kev,[3] the differences in energy are released in the form of gamma-rays, which are partially converted. Thus, Pa^{231} gives a rather sizeable amount of Geiger activity.

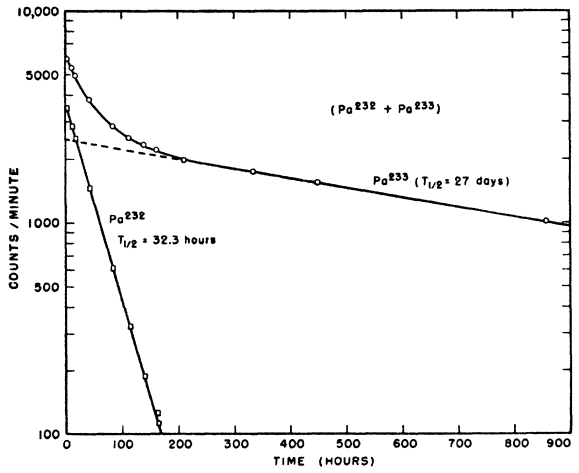

FIG. 1. Decay curve of Pa^{232} prepared from $Th^{232}+d$.

II. EXPERIMENTAL

In the first experiment, thorium metal was bombarded with approximately 100μa hr. of 19-Mev deuterons in the 60-in. cyclotron at Berkeley. The protactinium was isolated from the thorium and from the fission products and other interfering activities by a multiple stage solvent extraction procedure based on the work by Hyde and Wolf[4] This method employed diisopropyl ketone to extract the protactinium from an aqueous phase. The decay of samples taken at the end of this procedure and at the end of two repetitions of it was followed with a mica-window G-M counter supported in a standard shelf arrangement.[5]

TABLE I. Half-life values from Pa^{232} formed by $Th^{232}(d,2n)$.

Number of purification cycles involving diisopropyl ketone extraction	Half-life values for various samples	Relative precision[a] of decay curve	Average value for half-life
	32.0 hr.	Good	
1	31.5	Fair	32.4±0.5
	33.3	Good	
	32.3	Good	
	32.3	Good	
2	33.4	Fair	32.4±0.3
	32.3	Good	
	32.0	Fair	
3	31.8	Good	31.8
			32.3±0.4[b]

[a] Represents the closeness of fit of the points to the decay curve. Curves labeled "Good" are arbitrarily given twice the weight of those labeled "Fair."
[b] Direct average taken for all the decay curves without regard to purification cycles.

* This paper, which will appear as Paper No. 9.20 of the National Nuclear Energy Series, Division IV, Vol. 17B, is based on work done in 1945.
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[1] J. W. Gofman and G. T. Seaborg, "Production and properties of U^{232} and Pa^{232}," Paper No. 19.14, *The Transuranium Elements* (McGraw-Hill Book Company, Inc., New York, 1949), National Nuclear Energy Series, Division IV, Vol. 14B.
[2] M. H. Studier and E. K. Hyde, Phys. Rev. **74**, 591 (1948).
[3] Tsien San-Tsiang, Bachelet, and Boulssieres, Phys. Rev. **69**, 39 (1946). Clark, Spencer-Palmer, and Woodward, "Alpha-ray analysis of uranium isotopes," British Report 522 (October 10, 1944). S. Rosenblum and E. Cotton, Comptes Rendus **226**, 171 (1948). G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).
[4] K. Hyde and M. J. Wolf, Paper No. 3.12, National Nuclear Energy Series, Division IV, Vol. 17B, Argonne National Laboratory Report CB-3810 (April 30, 1947).
[5] Jaffey, Kohman, and Crawford, "A manual on the measurement of radioactivity," Report MCC-1602 (January, 1944), declassified as MDDC-388.

The second experiment involved the bombardment of Pa^{231} with neutrons in the center of the Argonne heavy-water pile, in order to determine the $Pa^{231}(n,\gamma)$ cross section.[6] In this case, the cross section was so large that the amount of extraneous activity due to the slight fission of Pa^{231} was considered negligible and no purification was carried out. Aliquots were prepared and the decay followed with a mica-window G-M counter. Toward the end of the decay of the Pa^{232}, the G-M tube started to fail and the decay curve was continued with a new mica-window G-M tube. It was possible to count the samples on both tubes several times before the first tube finally failed. The ratio of these counts was used to correct the data subsequently taken with the second tube. The tails of the decay curves consist of data taken with the second tube corrected to what they presumably would have been had the first tube been used. This procedure may have been slightly in error, due to the difference in window thickness (3.4 and 2.7 mg/cm^2, respectively) and other possible differences. However, since the Pa^{231} contributed only a small fraction of the initial count, a slight error in the measurement of its Geiger activity would hardly affect the half-life determination.

Because of their high initial disintegration rate, the samples were at first counted on the second shelf of the standard G-M tube support,[5] and later, as they decayed further, they were counted on the first shelf. The second-shelf counts were normalized to the first shelf by taking several ratios between the counts at the first- and second-shelf positions at times when the counting rates were suitable.

In both experiments, the resolution losses were corrected for, the split-pair technique described by Kohman[7] being used to evaluate the properties of the G-M tubes. The G-M tubes used were the brass-walled, mica-window type described elsewhere,[5] which were quenched by Neher-Harper circuits. These were used with the Cyclotron Specialties scaler.[8]

III. RESULTS

For the Pa^{232} samples coming from the thorium plus deuteron bombardment, the half-life values determined were somewhat less precise than those determined from the decay of pile-produced Pa^{232}, i.e., the deviation of the points from the straight line was greater. Table I shows the half-life values for various samples, while Fig. 1 shows the decay of a typical sample.

TABLE II. Half-life values from Pa^{232} formed by $Pa^{231}(n,\gamma)$.

Half-life values for various samples	Average
31.4	
31.3	
31.3	
30.8	
31.3	31.2±0.2 hr.

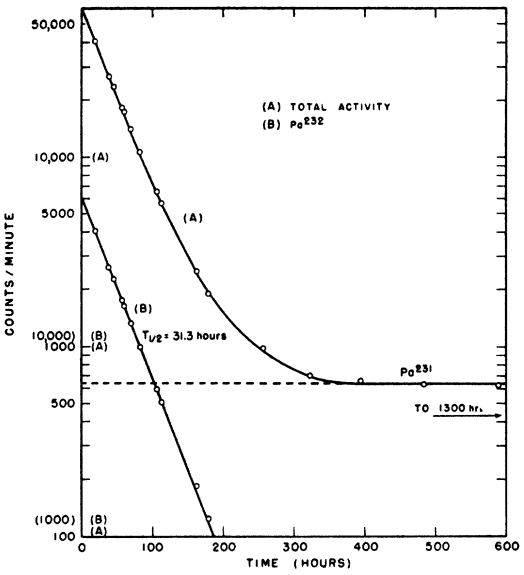

FIG. 2. Decay curve of Pa^{232} prepared from $Pa^{231}(n,\gamma)$.

There is no evidence that more than one purification cycle was necessary for isolating the protactinium fraction.

For the samples of Pa^{232} formed by $Pa^{231}(n,\gamma)$, Table II shows the half-life values for various samples and Fig. 2 shows the decay of a typical sample.

The deviations shown in Tables I and II represent the mean deviation of the individual values from the average. The two values for the half-life are 32.3±0.4 hr. (from $Th^{232}+d$) and 31.2±0.2 hr. (from $Pa^{231}+n$). Although the data in Table II are the more precise, both half-life values are averaged, since there is the possibility of consistent errors in either measurement.

We may take the half-life from these experiments to be 31.7 hr. or 1.32 days.

IV. RESULTS OF OTHER EXPERIMENTS

Pa^{232} was first reported by Gofman and Seaborg to be 1.6 days. Their Pa^{232} was formed[1] by deuteron bombardment of Th^{232} in the Berkeley cyclotron, and was purified by two complete cycles, each cycle involving precipitation with zirconium phosphate, solution in HF and low temperature precipitation with zirconium hydroxide. The protactinium was finally electrolyzed onto a copper cathode. The longer half-life found in this experiment may have been due to incomplete separation from fission products or activities formed from impurities in the thorium. It has been found in this laboratory that purification with diisopropyl ketone is more effective in purifying protactinium from such radioactive impurities than is precipitation with zirconium carriers.

[6] A. H. Jaffey and Q. Van Winkle, "Radiations of Pa^{232}," Argonne National Laboratory Report ANL-4193 (1948) and "Thermal neutron capture cross section of Pa^{231}," Argonne National Laboratory Report ANL-4283 (1948), National Nuclear Energy Series, Division IV, Vol. 17B.

[7] T. P. Kohman, "A general method for determining coincidence corrections of counting instruments," Paper No. 22.50, National Nuclear Energy Series, Division IV, Vol. 14B.

[8] Cyclotron Specialties Company, Morago, California.

Pa^{232} has also been made[9] by the reaction $Pa^{231}(d,p)Pa^{232}$ and the half-life was found to be 33 hr. In view of the fact that this determination of the half-life was complicated by the presence of considerable amounts of the two long-lived impurities Pa^{230} (17 days) and Pa^{231}, the agreement with the measurements presented here is quite satisfactory.

The advice and assistance of W. M. Manning and G. T. Seaborg under whose general supervision this work was done are gratefully acknowledged.

[9] Osborne, Thompson, and Van Winkle, "Products of the deuteron and helium-ion bombardments of Pa^{231}," Paper No. 19.11, National Nuclear Energy Series, Division IV, Vol. 14B.

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Gamma-Rays from the Reaction $H^1(n,\gamma)D^2$ and the Binding Energy of the Deuteron

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The binding energy of the deuteron has been determined directly as 2.230±0.007 Mev by measuring the energy of the gamma-radiation from the reaction $H^1(n,\gamma)D^2$. The energy of this gamma-radiation was compared with that of the 2.615-Mev gamma-ray of ThC″ by a spectrometer study of the photo-electrons ejected from a thin uranium radiator. The probable error of 0.007 Mev includes a probable error of 0.004 Mev in the energy of the ThC″ gamma-ray.

I. INTRODUCTION

THE present paper describes a direct determination of the binding energy of the deuteron, BE(D), by measuring the energy of the gamma-radiation from the reaction $H^1(n,\gamma)D^2$ in a beta-ray spectrometer. A preliminary value of BE(D) measured in this way has been published previously.[1]

The experiments designed to measure BE(D) directly may be classified as follows: (a) photo-disintegration of the deuteron and measurement either of the energy of the emitted particles, or of the gamma-ray threshold energy for photo-disintegration; (b) synthesis of the deuteron by the reaction $H^1(n,\gamma)D^2$ and measurement of the energy of the gamma-radiation emitted at the instant of neutron capture. Many measurements have been made by method (a) and all have given values consistent with an average value of 2.187±0.011 Mev, as is given in a review by Stephens.[2] The probable error quoted for this average is low, but each of the individual experiments contains uncertainties such as an imperfect knowledge of the proton range-energy and ionization-energy relations, or an imperfect voltage calibration of high voltage generators. Method (b) is very direct but has not been used in the past for an accurate determination because of the lack of a sufficiently intense neutron source. The early attempts[3] to measure the energy of the neutron-proton recombination gamma-radiation used absorption methods and merely succeeded in showing that the energy was of the expected order of magnitude. In the present work the energy of this gamma-radiation was compared with that of the 2.615-Mev gamma-ray of ThC″ by a spectrometer study of the photo-electrons ejected from a thin uranium radiator. The result for BE(D) obtained in this experiment, 2.230±0.007 Mev, is much higher than the previously accepted value.

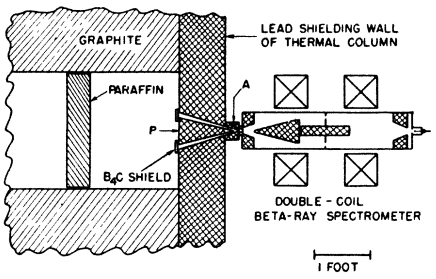

FIG. 1. Schematic diagram of the experimental arrangement used in run 1. The graphite thermal column extends to the left beyond the diagram to the reacting core of the pile.

II. EXPERIMENTAL PROCEDURE

The gamma-radiation from the reaction $H^1(n,\gamma)D^2$ was produced in paraffin irradiated with thermal neutrons. The energy of the gamma-radiation from the paraffin was measured in a beta-ray spectrometer by comparing the momenta of the photo-electrons ejected from a thin uranium radiator by this radiation and those ejected by the 2.615-Mev gamma-ray of ThC″. The ThC″ gamma-ray was chosen as a standard since its energy has been well studied and is close to that of the paraffin gamma-radiation. Two separate determinations (referred to hereafter as run 1 and run 2) were made using two slightly different experimental arrangements. In a third experiment the paraffin

[1] R. E. Bell and L. G. Elliott, Phys. Rev. **74**, 1552 (1948).
[2] W. E. Stephens, Rev. Mod. Phys. **19**, 19 (1947).
[3] R. Fleischmann, Zeits. f. Physik **103**, 113 (1936); Kikuchi, Aoki, and Husimi, Nature **137**, 186 (1936).