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Radioactivity of Be^{10}

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The formation of radioactive Be^{10} by the (d, p) reaction from beryllium has been observed. The assignment of the activity to beryllium is the result of very careful chemical separations. Be^{10} emits negative electrons with an upper limit of 560 ± 50 kev (end point in Al $=180\pm20$ mg/cm^2). The half-life is very long; data are given from which its value could be computed if the yield were known.

I. INTRODUCTION

IT has been known for a long time that the nucleus Be^{10} is formed in the reaction:[1]

$$Be^9+H^2\rightarrow Be^{10}+H^1, \qquad (1)$$

and that its mass is such as to make it unstable against β-decay into B^{10}. Several attempts have been made to observe the activity of this substance. The first was by McMillan.[2] A beryllium target which had been used as a neutron source with 2- to 3-Mev deuterons in the 37″ cyclotron for about a year (no record of total bombardment) ending June, 1935, was put into a Lauritsen electroscope; a very long period β-activity was found, with low energy as shown by absorption in Al. This energy was later measured by Libby and Lee,[3] who gave the value 13 ± 5 kev as its upper limit. It was later shown by O'Neal and Goldhaber[4] that H^3, with β-energy 15 kev, formed in a Be target by the reaction:

$$Be^9+H^2\rightarrow Be^8+H^3, \qquad (2)$$

is occluded in the metal to a considerable extent. Therefore, we can safely attribute the activity observed above to H^3 rather than Be^{10}.

A second attempt to observe the Be^{10} activity was made by Pollard.[5] He bombarded a Be target with 60-microampere hours of 3.1-Mev deuterons, and observed (again without chemical separation) an activity having an upper limit of 0.75 Mev (range of β-particles $=250\pm30$ mg/cm^2 in Al). No mention was made of a soft component; the H^3 radiation would not have been observed unless the counter window were extremely thin. This activity may have come

* Died in a laboratory accident on September 29, 1943, while engaged in war research. The unfortunate death of Dr. Ruben, and the absence of the other author from Berkeley during the war years, account for the delay in the publication of this work.

[1] Oliphant, Kempton, and Rutherford, Proc. Roy. Soc. **A150**, 241 (1935).

[2] E. M. McMillan, Phys. Rev. **49**, 875 (1936).

[3] W. F. Libby and D. D. Lee, Phys. Rev. **55**, 245 (1939).

[4] R. D. O'Neal and M. Goldhaber, Phys. Rev. **57**, 1086 (1940).

[5] E. Pollard, Phys. Rev. **57**, 241 (1940).

from a contamination, since no chemical separation was made.

A third attempt to find the Be^{10} activity was made by Bretscher,[6] using the postulated reaction:

$$B^{10}+n\rightarrow Be^{10}+H^{1}. \quad (3)$$

In this case, Be was separated chemically, and no activity was found. Using Pollard's half-life (380 years) Bretscher found for the above reaction the abnormally small cross section of $<2\times10^{-28}$ cm^2; it is probable from the work reported in this paper that the half-life is much longer.

The availability of large currents at high energies from the Berkeley cyclotrons has enabled us to pursue a more rigorously controlled search for the elusive Be^{10} activity, with the results reported below.

II. TARGETS USED

All the Be targets used in this investigation had been employed as neutron sources. Their history is given below:

Target *A*: Bombarded with 16-Mev deuterons in 60″ cyclotron; no record of amount of bombardment.

Target *B*: Old target used in 37″ cyclotron at 8 Mev; no record of amount of bombardment.

Target *C*: Three pieces of Be, each 1″×1″×$\frac{1}{16}$″, soldered to water cooled copper plate. Bombarded with 12,000-microampere hours of 16-Mev deuterons, during period April 8 to August 28, 1940, in 60″ cyclotron. This figure comes from beam integrator readings, and is fairly accurate.

III. CHEMICAL SEPARATION OF Be

The treatment was essentially the same for all the samples. It consisted of two parts: a rough purification to get out the bulk of the contamination, and a specific beryllium separation using the solubility of the basic acetate $Be_4(C_2H_3O_2)_6O$ in chloroform. In the rough purification, the following steps were taken:

1. Target dissolved in HCl, solution boiled to drive out volatile components.
2. Pt, Cu, and Sn carriers precipitated by H_2S in slightly acid solution.
3. Mg, Mn, Fe, Co, Ni, Zn carriers precipitated in conc. NaOH (under these conditions Be stays in solution).
4. $PO_3^{=}$ and $SO_4^{=}$ carriers precipitated by Ba, in alkaline solution. (All filtrations were repeated until the filtrates were clean and colorless.)
5. Last filtrate neutralized, $Zn(NO_3)_2$ added (to prevent Zn being carried down, since Zn can go through the basic acetate procedure in small amounts), and $Be(OH)_2$ precipitated with NH_4OH. This precipitate was washed very thoroughly with water. Its activity was found in all cases to be very small compared to that of the original sample, showing the abundance of contamination activities.

The basic acetate procedure was as follows:

1. Dissolved the $Be(OH_2)$ in glacial acetic acid, boiled just to dryness, added more acetic acid, boiled down again, repeated. This converted the $Be(OH)_2$ to the basic acetate.
2. Dissolved in chloroform, discarding undissolved residue. Filtered to take out any suspended particles.
3. Washed chloroform solution with water in separatory funnel three times.
4. Evaporated chloroform, dissolved residue in HNO_3, precipitated $Be(OH)_2$ with NH_4OH.
5. Calcined $Be(OH)_2$ to convert to BeO. (The activity was always reduced by an appreciable amount in the basic acetate procedure, showing that the first part of the purification alone was not good enough).

IV. COUNTING TECHNIQUE

Counts were made in screen wall counters, of the kind described in reference 3. The samples were applied in the form of BeO on the inside surface of brass cylinders, which slide so that the sample is either around the counter or away from it. Readings were made by alternating sample and background counts a number of times, to eliminate drift effects. Two counters were used:

	screen		*sample*		*solid angle factor*
	length	*diam.*	*length*	*diam.*	
large	8 cm	2.5 cm	8 cm	6.2 cm	0.14
small	8 cm	2.5 cm	6.3 cm	4.8 cm	0.21

The Al absorbers were wrapped around the counter screen. The background averaged about 120 counts/min.; all the readings given have the background subtracted. The errors given with the counting rates are mean errors calculated from the counting statistics.

V. RESULTS

1. Sample A-1

This sample consisted of 0.65 g of Be, etched to a depth of 1 mm from the part of the surface

[6] E. Bretscher, Nature **146**, 94 (1940).

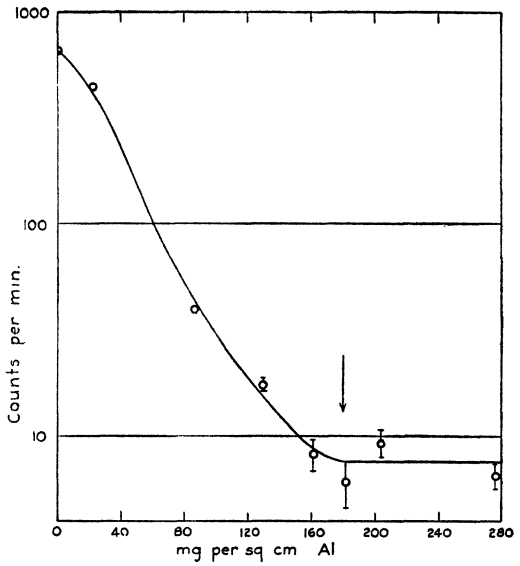

FIG. 1. Absorption of Be^{10} beta-rays in aluminum.

of target A showing most evidence of strong bombardment. After chemical purification (done April 4–5, 1940), 500 mg of BeO (36 percent of original sample) remained, which was put into the large counter. The counting rate was 530 ± 20 counts per minute, or a specific activity of 350 ± 13 disintegrations per second per gram Be.

This sample was then taken out, put through the basic acetate procedure a second time, reintroduced into the counter (250 mg BeO) where it gave a rate of 280 ± 4 counts per minute, or a specific activity of 370 ± 5 disintegrations per second per gram Be. The agreement of this value with the first count, after the sample had been subjected to a very specific Be separation, with such thorough washing that half of the sample was lost, is a very strong indication that the activity observed here is actually carried by an isotope of Be.

Some Al absorption points were also taken on this sample, both before and after the second purification; the data are not included, since better values were obtained on a stronger sample, but they served as confirmation that the same activity was being observed.

2. Sample A-2

This consisted of the rest of the surface of target A, etched off to a depth of about 1 mm. After purification (April 18, 1940), 1500 mg of BeO were obtained and placed in the large counter, giving a rate of 1320 ± 30 counts per minute. This sample was used to get a good absorption curve of the β's in Al, shown in Fig. 1. The value with no absorber may be a little low because of self-absorption; the sample had a thickness of about 8 mg/cm, including a little paraffin that had to be added as a binder to keep this thick layer from peeling off.

This absorption curve indicates a γ-ray, with an intensity of the order of a quantum per β-disintegration (by comparison with Na^{22}). As a further check of the assignment of the γ-ray to Be, a second basic acetate purification was carried out. The specific γ-ray activity was not changed appreciably. It is, therefore, probable that the γ-ray comes from a Be isotope.

The β-ray activity of this sample (950 g BeO remained after the second purification) was then followed in the large counter. The rates observed were:

July 17, 1940 — 914 ± 20 counts per minute,
October 18, 1940 — 860 ± 40 counts per minute,
December 27, 1941 — 890 ± 20 counts per minute,

showing no change outside the mean error during 17 months.

3. Sample A-3

This consisted of the rest of target A. After purification its activity, measured on a Lauritsen electroscope, was small compared to that of A-1+A-2, although its weight was greater. This serves to show that the activity is concentrated in the surface of the target, and is therefore a deuteron rather than a neutron effect.

4. Check Sample

Some old pieces of various materials that had had long bombardments in the 60″ cyclotron (Al window, Fe target, MgO target, brass holder), with an activity before purification ten times that of target A, were dissolved together with some inactive Be and subjected to the chemical purification. The resulting sample was inactive.

5. Sample B

This consisted of a thin layer scraped off the surface of target B. It was purified April 13,

1940, and showed the highest specific activity of all the samples. 110 mg BeO in the large counter gave:

Absorber	*Rate*
21.7 mg/cu²A	2030±80 counts/min.
148 mg/cu²A	23.4±4 counts/min.
278 mg/cu²A	21.6±3 counts/min.

These values are seen to be in agreement with sample *A*-2, if a small allowance for self-absorption in the latter is made.

This sample was used to study the γ-ray. Ninety mg of the BeO in the small counter, covered with 169 mg/cm² of lead, gave a counting rate equal to half the background. Absorption of the recoil electrons in Al showed an energy of 400±100 kev. The most important observation was that the γ-rays decayed; $7\frac{1}{2}$ months after the first measurement, the γ-activity had practically disappeared.

6. Sample C

In this case the whole target *C* (5.7 g Be) was dissolved. After the chemical purification (September 7–23, 1940) 6.3 g of BeO remained, or 40 percent of the original amount. One hundred ninety mg of this material were put into the small counter, where they gave 1310±50 counts per minute. The specific activity is therefore 1460±56 disintegrations per second per gram Be. The total activity in the target was then 9200 ±350 disintegrations per second.

VI. DISCUSSION

1. β-Particle Activity

There seems to be no doubt that this activity must be assigned to an isotope of Be; by far the most probable assignment is to Be^{10}. The end point in Al is 180±20 mg/cm², corresponding to an upper limit energy of 560±50 kev.

2. γ-Ray Activity

The observed decay of the γ-ray shows that it does not come from the β-emitter. Its most probable source is Be^{7}, formed by deuteron impact on Li impurity in the target. This substance gives γ-rays alone, of energy 485 kev and half-life 43 days.

3. Energy Relations

The energy available in the β-decay of Be^{10}, as computed from Allison's[7] values of the masses of Be^{9} and B^{10}, and Oliphant, Kempton, and Rutherford's[1] value of the energy output in reaction (1), is 580±240 kev. This is in agreement with the observed energy of 560±50 kev.

4. Half-Life

The half-life of the β-emitter could be determined only if the yield were known. Since this information is lacking, the result of the measurement on sample *C* can be expressed in the following way:

Number of deuterons in 12,000 microampere hours $= 2.7\times10^{20}$.

Yield in active atoms per deuteron $= Y$.

Total disintegration rate $= 9200\pm350$ per second.

Then:

$$\text{Half-life} = \frac{2.7\times10^{20}Y}{9200}\times\frac{0.693}{3.16\times10^{7}} = 6.4\times10^{8}Y \text{ years.}$$

Any reasonable guess for the thick-target yield of reaction (1) at 16 Mev thus leads to a very long half-life.

ACKNOWLEDGMENTS

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[7] S. K. Allison, Phys. Rev. **55**, 624 (1939).