Energy and Half-Life of the Be^{10} Radioactivity*

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The half-life and upper limit beta-ray energy of Be^{10} have been measured, using a sample prepared from a strongly deuteron-bombarded Be target. The upper limit energy, from the inspection end point of the absorption curve, is 560 ± 10 kev. The half-life, from the specific activity (46 disintegrations per sec. per mg Be) and the directly measured isotopic abundance (one part in 18,600) is $(2.5\pm0.5)\times10^6$ years. A rough excitation curve and good evidence for the absence of a gamma-ray were also obtained.

1. INTRODUCTION

THE activity of Be^{10} is of special interest because of theoretical difficulties in explaining its very long half-life. Its existence has been shown by the work of McMillan and Ruben[1] and Levinger and Meiners,[2] the isotopic assignment has been confirmed directly by Pierce and Brown,[3] and the half-life measured by Hughes, Eggler, and Huddleston.[4] In this paper is reported some work made possible by the kindness of Professor A. L. Hughes of Washington University in sending the author a beryllium target that had received a very strong deuteron bombardment in the St. Louis cyclotron (about 200,000-microampere hours of 11-Mev deuterons at 45° incidence). The part of the surface struck by the intense central core of the beam had spalled off; the portion used consisted of a square inch of surface immediately adjacent to the spalled region.

Even though this target was about two years old when received, it still carried a total activity about 50 times as strong as the Be^{10} activity. The bulk of the contamination activity appeared in the filtrate from the NH_4OH precipitation and had an absorption curve identical with that of Na^{22}, so it probably was due to this substance made from traces of Mg in the target. The chemical procedure used was simpler than that used in reference 1, because of the relatively much weaker contamination and also the fact that experience has shown the simplified procedure to be quite adequate for purifying Be. The Be was dissolved in concentrated HCl, precipitated as hydroxide by NH_4OH, and converted to the basic acetate by dissolving the hydroxide in glacial acetic acid. The basic acetate was then dissolved in chloroform, washed several times by shaking with water, and then dissolved in diluted NHO_3. Finally, the nitrate was ignited to BeO. The activity measurements were made with a G-M counter having a mica window of 2.5 mg/cm² thickness.

2. EXCITATION CURVE

The surface of the target was milled off in 6 layers, each 0.005 in. thick, and the resulting samples were separately purified. Equal portions of these were taken by pipetting out equal volumes of the saturated chloroform solutions of the basic acetate, and the relative activities of these (counted in the form of the acetate) were measured. Nearly all the activity was found in the first three layers. The corresponding energies were computed by assuming the stopping power of Be per electron to be the same as that of air, and taking account of the 45° incidence. These energies are not highly accurate, particularly because of the uncertainty in the initial energy and the angle. The results were as given in

TABLE I.

No. of layer	Energy range	Relative activity
3	2.3–6.3 Mev	0.46
2	6.3–8.9 Mev	1.0
1	8.9–11.0 Mev	0.88

* This work was done under the auspices of the Atomic Energy Commission under contract No. W-7405-Eng-48.

[1] E. M. McMillan and S. Ruben, Phys. Rev. **70**, 123 (1946).
[2] J. Levinger and E. Meiners, Phys. Rev. **71**, 586 (1947).
[3] A. K. Pierce and F. W. Brown, III, Phys. Rev. **70**, 779 (1946).
[4] D. J. Hughes, C. Eggler, and C. M. Huddleston, Phys. Rev. **71**, 269 (1947).

Table I. A check was made with a second pair of pipetted samples, to show that the drop in activity of the first layer compared to the second is significant. A discussion of these results is given in a later paragraph.

3. ABSORPTION CURVE AND BETA-ENERGY

The material from the first three layers was combined and converted to BeO (360 mg were obtained). This was used for all the other measurements. Two absorption curves were taken. Figure 1 shows a curve taken with a thin layer of BeO (46.5 mg spread over a 2.5-cm diameter circle) mounted on paper to minimize backscattering. It was plotted without subtracting the counter background, in order to avoid running off the bottom of the logarithmic paper. On the same plot is shown a curve for Na^{22}, taken on the same apparatus, but with the background subtracted. Since the relative gamma-ray effect of the latter happens to be nearly equal to the background in the former, a good comparison of the shapes can be made. It is seen that the Be^{10} curve shows a slight upward convexity that is not exhibited by the Na^{22} curve. This is not pronounced enough to indicate a line of electrons, but shows that the shapes of the beta-ray energy distributions are slightly different.

The other absorption curve, taken to locate the end point, is shown in Fig. 2. This time a thick sample containing all the material was used. The residual counts beyond the end point, which amount to 1/10,000 of the initial beta-counts corresponding to the amount of material in the sample, are of the order to be expected from x-rays ("Bremsstrahlung") generated in the sample and absorbers by beta-impact. Therefore, there is good evidence against the occurrence of a gamma-ray in the decay of Be^{10}. The end point can be located rather accurately from Fig. 2; it can be given as 185 ± 5 mg/cm² Al. The corresponding upper limit energy, using the best present range-energy relation, is 560 ±10 kev which agrees with the rougher value of reference 1.

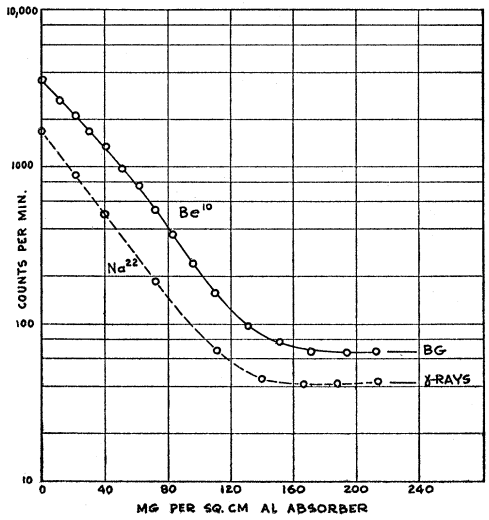

FIG. 1. Absorption of beta-particles in Al. Solid line: Be^{10} absorption data, plotted without subtracting counter background. Dashed line: Na^{22} absorption data, with background subtracted, for comparison of shape.

4. ISOTOPIC ABUNDANCE, SPECIFIC ACTIVITY, AND HALF-LIFE

Hughes *et al.*[4] found the half-life by comparing the specific activity with the isotopic abundance computed from the neutron flux, the time of exposure, and the cross section for the reaction Be^9 (n, γ) Be^{10}. In our case the pertinent reaction is Be^9 (d, p) Be^{10} whose cross section has not been measured, but on the other hand, the isotopic abundance was great enough that it could be measured directly on a Nier mass spectrometer. This measurement was made by A. K. Pierce under the direction of Dr. B. J. Moyer. The material was introduced into the spectrometer ion source in the form of the anhydrous chloride sealed in a glass capillary which was broken after evacuation. Good $(Be^9)^+$ and $(Be^{10})^+$ peaks were obtained, separated by over ten times the total peak width; the galvanometer deflections at the mass 10 peak were around 2 cm. Since the ratio of the mass 9 to the mass 10 current was large, different galvanometer sensitivities had to be used, and the ratio of currents was determined by duplicating the deflections with known currents. Seven measurements with two different fillings of the source gave a mean 9/10 ratio of $15{,}700\pm2700$, the error being estimated from internal consistency only. To check against the possibility of the mass 10 peak being due to $(Be^9H^1)^+$, $(B^{10})^+$, or $(Ne^{20})^{++}$, another run was made using a sample prepared in the same way from inactive Be, and this time the mass 10 peak was much smaller but still observable, with a 9/10 ratio of 100,000. If this is

taken as a correction on the value given above, the ratio Be^9/Be^{10} is $18,600\pm3000$.

The specific activity was measured by comparing the counting rate of a uranium standard (calibrated by Dr. C. Tobias of the Medical Physics Department against an accurately prepared standard) with the counting rates of samples of the active BeO. Three samples were prepared, consisting of 12.0, 13.7, and 23.0 mg of the BeO spread over an area of 3 cm^2 on filter paper, and these were counted with no metal backing in order to minimize back-scattering. The absorption correction for the window plus the air path plus half the sample thickness, evaluated from the initial slope of the absorption curve, was about 20 percent. The mean value obtained for the specific activity was 16.6 ± 1.7 disintegrations per second per mg BeO or 46 ± 5 disintegrations per second per mg Be, the error given being considerably greater than the spread in the three values, in order to allow for the various uncertainties involved in all absolute beta-intensity measurements, particularly when the sample and the standard have different energies.

The half-life is easily computed from the above data. The decay constant λ is given by (disintegration rate per gram)/(number of active atoms per gram), or:

$$\lambda=(46,000\times9\times18,600)/(6.02\times10^{23})$$
$$=(1.28\pm0.24)\times10^{-14}\ \text{sec}^{-1}.$$

The half-life is then $(2.5\pm0.5)\times10^6$ years, in agreement with the value of 2.9×10^6 years given by Hughes *et al.*[4] within the accuracy of the determinations.

5. DISCUSSION OF YIELD

Dr. Serber has made an estimate of the yield expected in the reaction Be^9 (d, p) Be^{10}. First the total cross section for capture of the deuteron to form the intermediate nucleus was estimated from the classical expression: $\sigma=\pi R^2\times(1-E_B/E)$, where R=nuclear radius (taken as the sum of the beryllium and deuteron radii or 5.5×10^{-13} cm) and E_B=barrier height (taken as 1.67 Mev). Then the division between the (d, p) and (d, n) processes was computed, including a penetration factor for the former and otherwise supposing division in the ratio of available volumes in phase space; the (d, α) process was neglected as being probably less important. Finally, the competing reaction $(d, 2n)$ with an estimated threshold at 5 Mev was included, being given a probablity proportional to the volume in phase space and with a coefficient adjusted to match the data in paragraph 2. This process accounts for the decrease in cross section beyond 8 Mev.

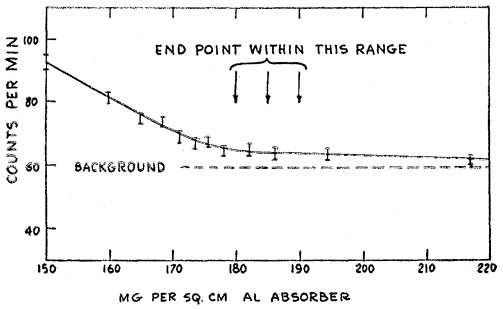

FIG. 2. Detail of Be^{10} absorption curve near the end point. Absorption of counter window plus air path included. Errors indicated are standard errors computed from counting statistics.

From this theory the absolute yield at 11 Mev is estimated to be 0.0016 active atoms per deuteron, and the observed yield of 21,000 dis./sec. or 1.6×10^{18} active atoms in the part of the target used would correspond to 46,000 microampere-hours bombardment of that part, which seems reasonable. Furthermore, the data of reference 1 combined with the measured half-life give an observed yield of 0.0039 active atoms per deuteron at 16 Mev, which can be compared with the value of 0.0026 computed from the above theory at this energy. The difference is well within the accuracy of the rather rough theory. It is interesting to note that the theory gives a neutron yield of 0.008 per deuteron at 16 Mev, in exact agreement with the value measured in the Crocker Radiation Laboratory by H. Yockey. This discussion of the excitation curve and the yield shows that there is no great peculiarity in the formation of Be^{10} to match its abnormal behavior in beta-decay.