Some Neutron Deficient Strontium Isotopes*

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Bombardment of rubidium with protons produced Sr^{81}, half-life 29 minutes, Sr^{82}, half-life 25 days, and Sr^{83}, half-life 38 hours. Sr^{81} and Sr^{83} are assigned on the basis of their positron decay to known Rb^{81} and Rb^{83}, respectively. The half-life of Rb^{83} has been redetermined as 83 days, and it has been shown that it decays in part to the 1.8-hour Kr^{83m}. Sr^{82} probably decays by electron capture to a short-lived isomer of Rb^{82}, which in turn decays by emission of 3.15-Mev positrons. In this case, the mass assignment is based on the energy required to produce the activity in a bombardment, because the known Rb^{82} was not observed as a decay product.

BY bombarding rubidium chloride with protons at energies from 25 Mev to 100 Mev in the Berkeley 184-inch synchrocyclotron, we have prepared three new strontium isotopes and have studied their radioactivities. Sr^{81} and Sr^{83} have been identified by their decay to Rb^{81} and Rb^{83}, whose masses were assigned by Karraker and co-workers[1,2] with a mass spectrograph. The third activity is assigned to Sr^{82} on the basis of the energy required to produce it. There seems to be no previous report of any strontium isotopes of mass less than 84.

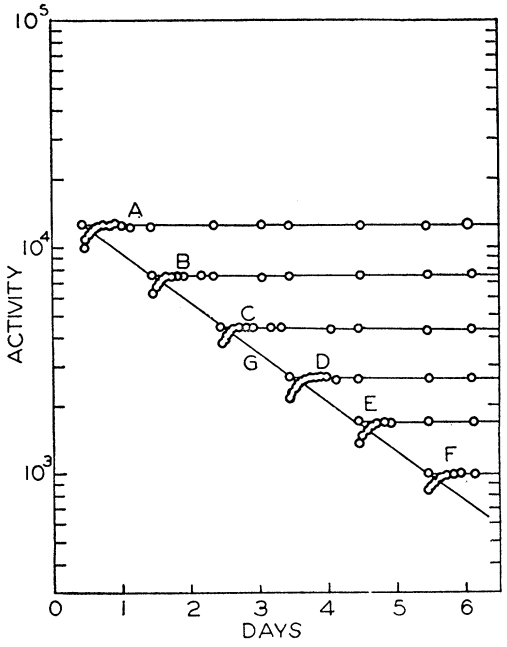

FIG. 1. Yield of Rb^{83} as a function of time of separation from Sr^{83}, curve *G*. Curves *A* to *F* show the growth of Kr^{83m} into the individual rubidium samples. Each curve is corrected for chemical yield of rubidium.

Sr^{83}

In a bombardment of a thick target of rubidium chloride for 1 hour with 25-Mev protons, the strontium fraction, isolated as described below, showed the following activities: Sr^{85m}, 70 minutes half-life; Sr^{85}, 65-days half-life, Sr^{87m}, 2.7-hours half-life; and an unknown activity of 38-hours half-life. Subsequent bombardments at higher energy also produced this new activity. From a single aliquot of strontium activity, rubidium was separated at 24-hour intervals for a week. The slope of the yield *vs* time curve (Fig. 1) corresponded to a 34-hour half-life. Each rubidium sample showed an initial growth at a rate consistent with the 1.8-hour half-life of Kr^{83m}. The assignment of Kr^{83m} has been checked by Bergström, Thulin, and Andersson[3] with an electromagnetic isotope separator. The subsequent decay, measured in four cases for more than 2 years, corresponded to a half-life of 83 days. Thus the 38-hour activity is Sr^{83}, decaying to Rb^{83} which in turn decays in part to Kr^{83m}. The discrepancy between the half-life of Sr^{83} determined by decay and that determined by the yield of rubidium is probably due to a small loss of strontium in each step, and the former value is considered more reliable. The value 83 days determined here for the half-life of Rb^{83} is much more reliable than the value 107 days reported previously[2] which was based on decay of a much weaker sample. The decay of Rb^{83} to Kr^{83m} was not observed previously.

Measurements on the $\pi\sqrt{2}$ beta-spectrometer described by Hyde and O'Kelley[4] have shown that Sr^{83} has positrons with 1.15 ± 0.05 Mev energy limit as determined by a Kurie plot of the spectrum (Fig. 2), and electron lines corresponding to *K* and *L* conversion of gamma-rays of energies 0.040, 0.074, 0.101, 0.151, and 0.165 Mev. Absorption measurements with beryllium, silver, and lead showed the presence of *K* x-rays and gamma-rays. The energies of the gamma-rays are not estimated because of interference from other activities.

Rb^{83}

Aluminum, beryllium, and lead absorption measurements show that Rb^{83} (half-life 83 days) emits elec-

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† Now with E. I. du Pont Company, Oak Ridge, Tennessee.
[1] Reynolds, Karraker, and Templeton, Phys. Rev. **75**, 313 (1949).
[2] D. G. Karraker and D. H. Templeton, Phys. Rev. **80**, 646 (1950).
[3] Bergström, Thulin, and Andersson, Phys. Rev. **77**, 851 (1950).
[4] E. K. Hyde and G. D. O'Kelley, Phys. Rev. **82**, 944 (1951).

trons, K x-rays, and gamma-rays. The most energetic gamma-ray is estimated to be 0.8 Mev in energy. Measurements with a crude beta-spectrograph ("bender") indicate that the energies of the electrons correspond to gamma-rays of 0.15 and 0.45 Mev, but these values are only approximate.

Sr^{81}

With protons of 60-Mev energy and above, another activity, with half-life 29 minutes, was observed in the strontium fraction. Separation of rubidium at 20-minute intervals for 4 hours resulted in yields which fell off with time according to a half-life of 22 minutes. Again the discrepancy was assumed to be due to loss of strontium at each separation step. This rubidium decayed with a 4.7-hour half-life. Its identity as Rb^{81} was further confirmed by the detection with the "bender" of soft electrons ($\sim$0.2 Mev) whose intensity was decreased by flaming, but which rapidly grew in again. These electrons are due to Kr^{81m}, with 13-second half-life. The "bender" also showed positrons, whose energy by aluminum absorption was 1.1 Mev, compared with 0.990 Mev reported by Karraker and Templeton.[2] Thus the 29-minute activity is Sr^{81}.

To eliminate the possibility that growth of daughters distorted the original decay curve and thereby caused an incorrect half-life to be derived, the following experiment was carried out. Strontium was separated from several aliquots at regular intervals and immediately counted. A plot of these initial activities, which are substantially free of daughter activities, represents the decay of the strontium itself. Such a curve gave 31 minutes as the half-life of Sr^{81}.

Sr^{81} emits both positrons and conversion electrons, but time did not permit determination of their energies.

Sr^{82}

With protons of 40-Mev energy and above, a strontium activity of 25-day half-life was observed. A search for a rubidium daughter activity revealed none with half-life between a few minutes and 1 year. This activity is tentatively assigned to Sr^{82} on the basis that more energy is required to produce it than Sr^{83}, and less than Sr^{81}. Because of the failure to observe the 6.3-hour Rb^{82} as a daughter, additional chemical tests were made to verify that the activity was actually a strontium isotope. Passage through a cation exchange resin produced no change in the ratio between the 25-day and 38-hour activities. In addition, no activity of similar half-life and radiation characteristics has been reported for any other element. Thus we are forced to conclude that Rb^{82} exhibits isomerism, and that little or none of the Sr^{82} decays to the 6.3-hour state.

Measurements with the $\pi\sqrt{2}$ spectrometer have shown that Sr^{82} emits positrons with 3.15$\pm$0.03 Mev energy limit (Fig. 3). Because of their high energy, these positrons probably come from a short-lived rubidium daughter rather than from Sr^{82} itself. Lead

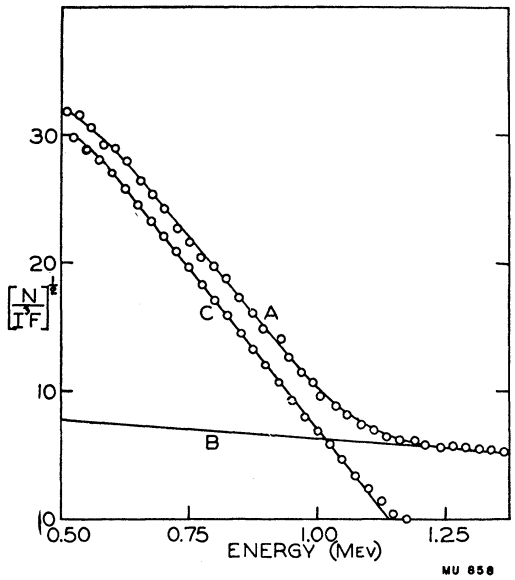

FIG. 2. Kurie plot of positron spectra of Sr^{82} and Sr^{83}. A, combined spectra; B, extrapolation of Sr^{82} spectrum; C, spectrum for Sr^{83}.

absorption measurements indicate gamma-rays of 0.95 and 0.15 Mev. The "bender" showed electrons corresponding to at least two gamma-rays in the range 0.15 to 0.40 Mev. Without more data it is impossible to say which of these radiations belong to Sr^{82} and which to Rb^{82m}.

TARGET PREPARATION

Spectrographic analysis of stock rubidium nitrate showed its cation to consist of 86 percent rubidium, 5 percent cesium, 8 percent potassium, and 1 percent sodium. About 1 gram of this salt was purified by elution from a Dowex-50 cation exchange column 11 mm in diameter and 81 cm in length, washing with 6 M HCl at a rate of 0.2 ml per minute. The sodium and cesium were eluted in peaks well separated from the rubidium, and most of the potassium was removed. About 0.6 g of rubidium chloride was obtained containing 0.4 percent potassium and spectroscopically free of sodium and cesium. Targets for bombardment in the 184-inch cyclotron were made by wrapping 25 to 50 mg of this purified rubidium chloride in aluminum foil 0.001 inch thick.

CHEMICAL SEPARATIONS

After bombardment with protons the rubidium chloride was dissolved in water. The solution was boiled to expel any inert gas isotopes. Strontium carrier was added and precipitated with excess fuming nitric acid. The resulting suspension was chilled in an ice bath for 5 minutes and then centrifuged. The supernatant solution containing the rubidium was removed, and the strontium nitrate was dissolved in a small amount of water. A few milligrams of the stock rubidium nitrate

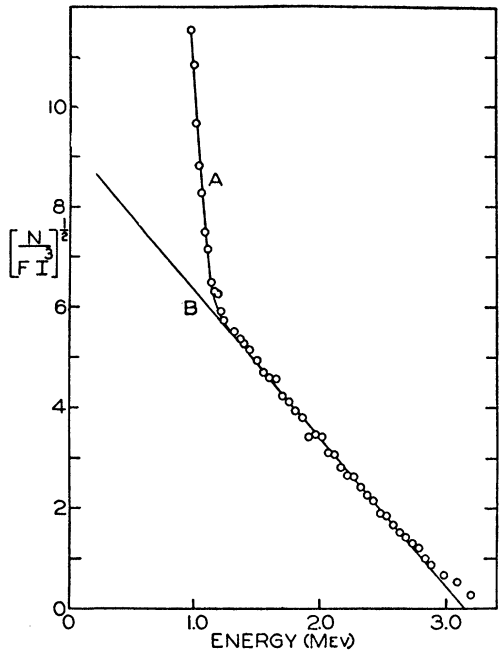

FIG. 3. Kurie plot of positron spectrum of Sr^{82}, curve B; these positrons probably belong to a short-lived Rb^{82m}. The initial part of the curve, marked A, contains activity due to Sr^{83}.

was added to the solution, and the strontium was reprecipitated with fuming nitric acid. After removal of the supernatant, the precipitate was redissolved and diluted to an arbitrary volume from which several accurately measured aliquots were taken. The strontium in an aliquot was again reprecipitated with fuming nitric acid. After removal of the supernatant, the precipitate was dissolved in water and the solution neutralized by bubbling ammonia through the solution. A few milliliters of a saturated solution of ammonium oxalate was added to precipitate the strontium as $SrC_2O_4 \cdot H_2O$. After removal of the supernatant, the precipitate was washed once with water, once with 95 percent ethanol and finally slurried up in 0.5 ml of 95 percent ethanol and placed on a previously weighed aluminum dish 0.002 inch thick and approximately 1.0 inch in diameter. The ethanol was evaporated to dryness with a heat lamp. The sample was allowed to cool and was then weighed to determine the chemical yield of the strontium. The dish was mounted for counting. In the initial bombardments, the purification procedures were extended to include a silve chloride precipitate scavenge, and a portion of the strontium fraction was passed throguh a Dowex-50 cation resin column. As no differences were noted between the decay curves of the strontium which had undergone these additional steps of purification, and the decay curves of the strontium which had not undergone such measures, these steps were omitted in subsequent bombardments as consuming too much time.

To isolate the radioactive rubidium in an aliquot which resulted from the strontium decay, the following procedures were used: a solution containing a known amount of stable rubidium was added to the aliquot. The strontium was precipitated with excess fuming nitric acid. The resulting suspension was chilled in an ice bath for 5 minutes and then centrifuged. The supernatant was removed to a clean centrifuge cone and evaporated to approximately 0.5 ml. A few milligrams of strontium was added and precipitated with more fuming nitric acid. Again the supernatant was removed to a clean centrifuge cone and evaporated to about 0.5 ml. The solution was chilled and 0.5 ml of 70 percent $HClO_4$ was added to precipitate the rubidium as $RbClO_4$. This precipitate was washed once with 50 percent ethanol, once with 95 percent ethanol and finally slurried up with 0.5 ml of 95 percent ethanol onto a previously weighed aluminum dish. The ethanol was evaporated with a heat lamp. The sample was allowed to cool and was then weighed to determine the chemical yield of rubidium. The sample was mounted for counting.

Radioactive krypton was expelled from rubidium samples by heating the rubidium sample with a bunsen burner to dull redness. For the purposes of this separation, the rubidium was mounted on 0.020-inch Monel metal disks.

Decay and absorption measurements were made with Amperex, chlorine-quenched, argon-filled, end-window Geiger-Müller counters. The window thickness was approximately 4 mg/cm² of mica.

Samples for the $\pi\sqrt{2}$ beta-spectrometer were mounted on Tygon films of 20 to 30 μg/cm² with about 10 to 50 μg of material in the sample.