Spectrometer Studies of the Radiations of Some Neutron-Deficient Isotopes of Xenon and Iodine*

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Neutron-deficient isotopes of xenon have been produced by (p,xn) reactions with high-energy protons on potassium iodide targets. The xenon activities were deposited on foils by the glow discharge technique and their radioactive properties were measured. Nineteen-hour Xe^{122} decays by electron capture to 3.5-minute I^{122}. Gamma rays of 182 and 235 kev accompany this decay. I^{122} decays by emission of 3.12-Mev positrons. Xe^{123} decays with a 1.8-hour half-life into 13-hour I^{123}. Positrons of 1.7±0.1 Mev, 150-kev gamma rays, and x-rays are associated with this decay. Xe^{121} has a half-life of 40±10 minutes for decay into 1.6-hour I^{121}.

I. INTRODUCTION

THE bombardment of iodine with high-energy protons produces xenon isotopes of mass number 127 and lower. This report is concerned with the properties of Xe^{123}, Xe^{122}, and Xe^{121}, and the iodine isotopes formed by their decay. Isolation and study of these iodine isotopes revealed the presence of the known iodine isotopes of mass 123, 122, and 121. Timed separations established the genetic relationship of these to 19-hour Xe^{122}, 1.8-hour Xe^{123}, and an ~40-minute Xe^{121}. Since our results agree with the published abstracts of work done independently and simultaneously by Tilley[1] at McGill University and of Dropesky and Wiig[2] at the University of Rochester, we shall not give complete details of this part of our work.

The purpose of this paper is to record some unpublished observations on the radiations of these isotopes carried out with a scintillation spectrometer and a beta-ray spectrometer. In these studies we took advantage of a novel method for the deposition of xenon activity on thin metallic foils suitable for beta-ray spectroscopy. This method and the spectrometers are briefly discussed at the end of the paper.

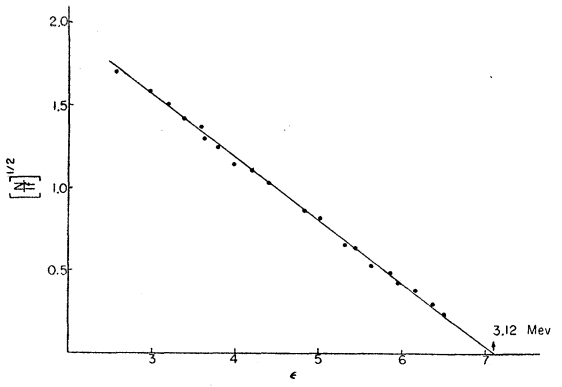

FIG. 1. Fermi-Kurie plot of positron spectrum of I^{122} obtained on Xe^{122}-I^{122} sample. [Data by T. O. Passell (unpublished).]

II. EXPERIMENTAL RESULTS

Xe^{122} and I^{122}

Potassium iodide targets were bombarded for 1 hour with 100-Mev protons. The xenon fraction was isolated 24 hours later and deposited on aluminum foil as described below. At this time the xenon activity was virtually pure Xe^{122}. Decay curves showed a straight-line decay of 19±0.5 hours over more than 5 half-lives. The amount of 18-hour Xe^{125} is slight because the $(p,3n)$ reaction cross section is down at this high proton energy. Separation of iodine activity at this time showed only the 3.5-minute I^{122} activity originally reported by Marquez and Perlman[3] and studied more completely by Young, Pool, and Kundu.[4]

The positron spectrum of the Xe^{122}-I^{122} mixture mounted on 0.1-mil aluminum foil was studied in the double-focusing beta-ray spectrometer by T. O. Passell.

Figure 1 is the Fermi-Kurie plot of this spectrum showing a single component with an end-point energy of 3.12±0.04 Mev. The calibration of the spectrometer was checked with the 1.97-Mev positron of Cs^{130}.[5] Xe^{122} decays by K capture and the 3.12-Mev positron group is assigned to the 3.5 minute I^{122} in equilibrium with it. Our positron energy agrees with the 3.08±0.1-Mev value determined by Young, Pool, and Kundu[4] who used absorption methods.

Figure 2 shows the gamma spectrum taken with the sodium iodide scintillation spectrometer. The only prominent peaks are a 182-kev gamma peak, a smaller gamma peak at 235 kev, and the annihilation gamma ray peak resulting from the positrons of I^{122}. No gamma rays of higher energy were observed. The 182- and 235-kev gamma peaks may be assigned to the decay of Xe^{122} as proved by the curves of Fig. 3. The upper curve taken on the Xe^{122}-I^{122} mixture shows these two peaks while the lower curve taken on a pure sample of I^{122} shows only the Compton smear of the Compton-

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[1] D. E. Tilley, Abstract 77, June Meeting of the Royal Society of Canada, 1952 (unpublished).
[2] B. Dropesky and E. O. Wiig, Phys. Rev. 88, 683 (1952).
[3] L. Marquez and I. Perlman, Phys. Rev. 78, 189 (1950).
[4] Young, Pool, and Kundu, Phys. Rev. 83, 1060 (1951).
[5] Smith, Mitchell, and Caird, Phys. Rev. 87, 454 (1952).

scattered annihilation radiation. This result is not surprising since Te^{122} is an even-even nuclide with an excited state at 568 kev[6] which in all likelihood is the first excited state, according to the systematics of the excited states of even-even nuclei as discussed by Scharff-Goldhaber.[7] The conversion electrons of the 182-kev gamma ray were observed (see below).

Xe^{123}–I^{123}

When the xenon fraction was separated from the potassium iodide target about 4 hours after the end of the bombardment 1.8-hour Xe^{123} and 19-hour Xe^{122} accounted for the greater part of the activity. It was possible to study the radiations of Xe^{123} in such mixtures, but samples which were much purer, although less intense, could be isolated by an alternate method; namely, isolation of Xe^{123} daughter activity from the decay of Cs^{123}.

In a previous publication[8] it was shown that 6-minute Cs^{123} is produced by the bombardment of calcium iodide

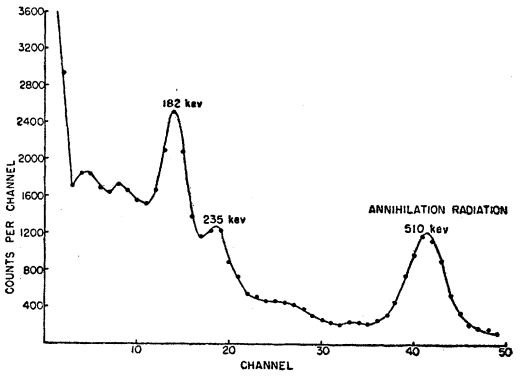

FIG. 2. Gamma spectrum of Xe^{122} taken on scintillation spectrometer.

with 130-Mev helium ions. From cesium fractions isolated quickly immediately after bombardment it is possible to separate Xe^{123} activity >90 percent pure by radioactivity. Some 18-hour Xe^{125} is present from the decay of 45-minute Cs^{125} also produced in the bombardment.

The decay of the activity as followed in a GM tube showed the 1.8-hour decay of Xe^{123} superimposed on the growth and decay of the 13-hour I^{123} daughter.

The gamma spectrum of Xe^{123} shows a major peak of K x-rays from the electron capture decay of Xe^{123}, a gamma ray of 150-kev energy, and a small peak of annihilation radiation (not shown) (see Fig. 4). Repeat runs on the gamma spectrum over a period of 24 hours showed the emergence of the 159-kev gamma peak[9] of

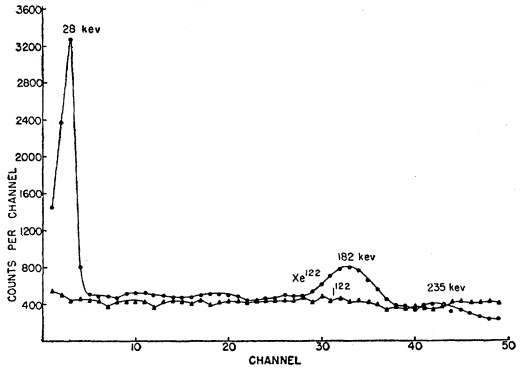

FIG. 3. Gamma spectrum of Xe^{122}-I^{122} mixture and on pure I^{122} showing assignment of 180-kev gamma radiation to Xe^{122}. Triangular points represent pure I^{122}. The 28-kev peak is K x-radiation.

I^{123} as the 150-kev gamma radiation of Xe^{123} decayed. The conversion electrons of these two gamma rays were also observed (see below).

A beryllium absorption curve on the positron activity gave a value of 1.8 Mev as the end-point energy of the positron. The energy of the positron as determined by the anthracene crystal spectrometer is 1.7 ± 0.1 Mev.

Xe^{121} and I^{121}

Xenon samples isolated immediately after bombardment contained a high proportion of 40-minute Xe^{121}. Iodine daughter activity isolated from the xenon fraction within 1 hour of the end of bombardment contained 3.5-minute I^{122}, 1.5-hour I^{121}, and 13-hour I^{123}, but after the rapid decay of the I^{122} the principal activity was I^{121}. A gamma spectrum of such an iodine sample is shown in Fig. 5. In addition to the annihilation radiation a gamma ray of 210 kev is observed; the conversion electrons of the gamma ray were also observed as reported below. Marquez and Perlman[3] had reported conversion electrons of this gamma ray in the original report on the properties of I^{121}.

It was determined that Xe^{121} emits positrons by plotting the decay of the annihilation peak of gamma

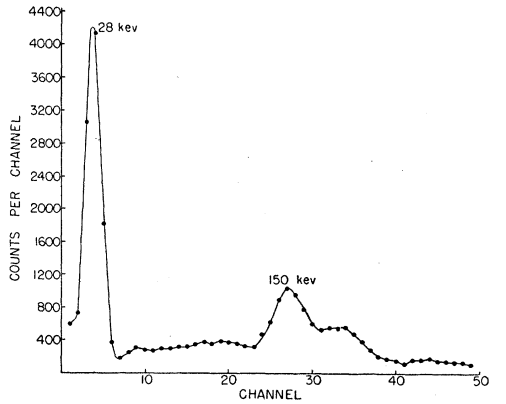

FIG. 4. Gamma spectrum of Xe^{123} sample isolated from Cs^{123}.

[6] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).
[7] G. Scharff-Goldhaber, Phys. Rev. **90**, 587 (1953).
[8] H. B. Mathur and E. K. Hyde, Phys. Rev. **95**, 708 (1954).
[9] Mitchell, Mei, Maienschein, and Peacock, Phys. Rev. **76**, 1450 (1950).

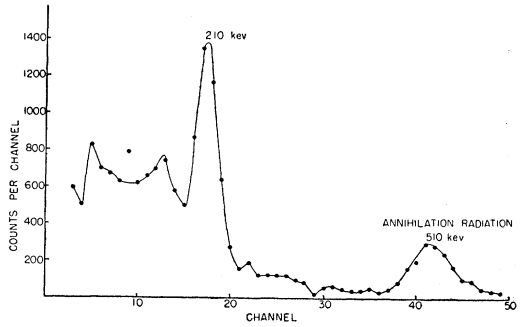

FIG. 5. Gamma spectrum of I^{121}.

spectra determined on xenon samples isolated within 1 hour of the end of the bombardment. A 40 ± 10 minute component was resolved from this curve.

Conversion Electrons of $Xe^{121}Xe^{122}Xe^{123}$ Mixture

The conversion electrons of several of the gamma rays mentioned above were measured in the beta-ray spectrometer using a xenon sample collected on a $\frac{1}{4}$-mil aluminum foil 1 hour after the finish of a 1-hour bombardment of potassium iodide with 100-Mev protons. The conversion electron spectrum was determined about 2 hours after the end of the bombardment (see Fig. 6) and this determination was repeated 5 times over the next 24-hour period. The numbered peaks of Fig. 6 are listed in Table I. The observed half-life and the probable assignment of the isotopes and conversion shell are listed in Table I.

III. EXPERIMENTAL METHODS

Deposition of Xenon on Counting Foils

Samples of xenon radioactivity were deposited on thin metallic foils by the method developed and used extensively by Momyer and Hyde for the study of isotopes of emanation.[10] This method makes use of a glow discharge tube of the type shown in Fig. 7.

Figure 8 shows the glass vacuum system used to isolate the xenon from the cyclotron targets. The base pressure in the manifold was reduced to 10^{-5} mm Hg

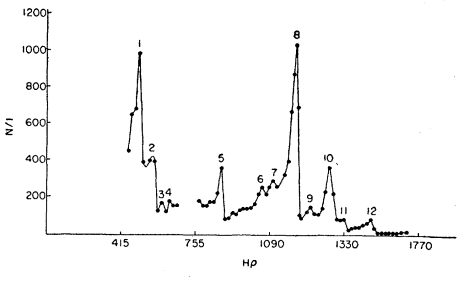

FIG. 6. Conversion electron spectrum in Xe^{121}, Xe^{122}, Xe^{123} mixture. The numbered peaks are listed in Table I.

[10] F. F. Momyer, University of California Radiation Laboratory Report UCRL-2060, 1953 (unpublished).

by a mercury diffusion pump and Cenco Hyvac mechanical forepump. The potassium iodide was dissolved in the closed dissolver flask A by introducing water from the dropping funnel. The off gases were pumped through trap C cooled with a dry ice-acetone cooling bath which removes water vapor and through traps D, E, and F cooled with liquid nitrogen which condensed the xenon. After 2 or 3 minutes stopcock B was closed and the total pressure in the entire system including the glow discharge tube was reduced to 10^{-4}–10^{-5} mm Hg. Then that part of the system including traps D, E, F, and the discharge tube were isolated from the rest of the system by suitable manipulation of the stopcocks and the xenon activity was distilled into the discharge tube by placing a liquid nitrogen cooling bath on the freeze down tip and by warming traps D, E, and F to room temperature. Then stopcock G was closed and the xenon and other condensed material was allowed to vaporize in the glow discharge tube. Usually enough inert vapors were condensed during

TABLE I. Conversion electrons of Xe^{121}-Xe^{122}-Xe^{123} mixture.

Peak No.	Energy (kev)	Approximate observed half-life	Assignment of parent isotope	Conversion shell	Gamma-ray energy (kev)	Gamma-ray energy from scintillation spectrometer (kev)
1	22.2	4 hr	mixture	Auger electrons	...	...
2	27.0	3 hr				
3	31.0	2 hr				
4	34.5	0.5 hr	?	...	...	...
5	63.2	45 min	Xe^{121}	K	95	...
6	91	50 min		L	96	
7	97	1.8 hr	Xe^{123}(?)	...	...	...
8	115.5	2.5 hr	Xe^{123}	K	148	150
10	144	2 hr		L	147	
9	128	20 hr[a]	I^{123}	K	160	160
11	155	14 hr	Xe^{122}	K	187	182
12	180	3 hr	I^{121}	K	212	210

[a] The limited number of points taken and the imperfect resolution of the electron peaks made it impossible to observe the *growth* of this peak from its 1.8-hour parent.

this crude fractionation that the total pressure in the tube rose to the region 100–400 microns mercury. When this was not true, air was bled in until the pressure rose to this value as read on a thermocouple gauge, not shown. A dc potential of 300–800 volts with a limiting resistor of 50 000 ohms was placed across the electrodes (see Fig. 7) to initiate and maintain a glow discharge in the tube. The xenon atoms were ionized and collected on aluminum foils of 0.1-mil thickness clipped to the negative electrode. A collection time of 5 minutes served to affix a variable percentage (2–10 percent) of the xenon activity to both sides of this foil. The excess activity was pumped back into trap F and condensed with liquid nitrogen. The glow discharge tube was then removed from the line and opened. The xenon activity on the foil remained affixed indefinitely unless the foil was warmed above room temperature. It is believed that proper redesign of this method to allow better cooling of the electrodes during deposition

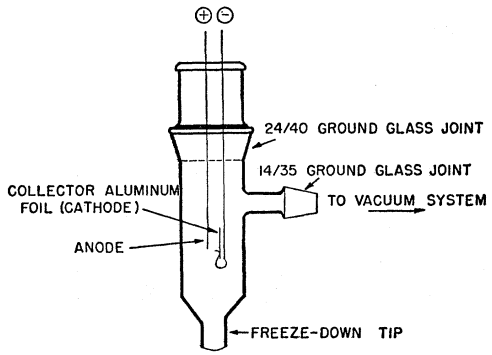

FIG. 7. Glow discharge tube used to deposit xenon on aluminum foils.

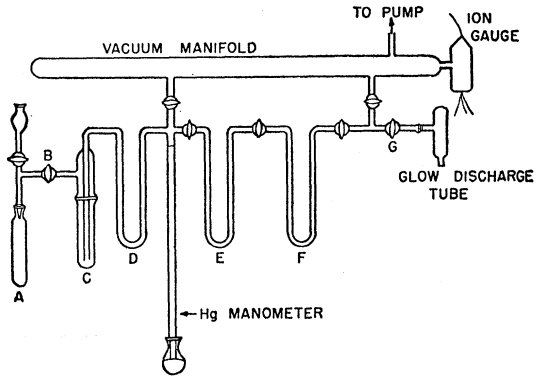

FIG. 8. Glass vacuum system used to isolate xenon activity.

would make possible near quantitative collection of tracer xenon activity.

Beta-Ray Spectrometer

The spectrometer used in this research was one of the double-focusing type proposed by Svartholm and Siegbahn[11] and by Shull and Dennison.[12] A side window GM tube with a thin vinyl plastic window filled with an argon-ethylene mixture was used as a detector. A more complete description of the instrument is given by O'Kelley.[13] We are indebted to Dr. Thomas O. Passell for major assistance in obtaining the data on this instrument.

Scintillation Spectrometer

The gamma-ray scintillation spectrometer was assembled by Ghiorso and Larsh of this laboratory. The initial gamma detection occurred in a 1.5-inch diameter by 1-inch thick crystal of sodium iodide mounted below a Dumont 6292 photomultiplier tube by the methods of Borkowski.[14] The crystal photomultiplier assembly was mounted above a 5-position shelf assembly and encased in an aluminum-lined lead shield.

The photomultiplier output was amplified in a preamplifier and linear amplifier and then introduced to a 50-channel differential pulse-height analyzer. This analyzer is of a new design of Ghiorso and Larsh. The channel-width stability was better than 1 percent operating at a 5-volt channel width and remained so for periods of weeks. Gain and bias controls permitted the inspection of any desired energy interval with the full 50 channels. Energy calibrations were carried out with known radiations from Na^{22}, Cs^{137}, Am^{241}, Cd^{109}, U^{235}, and other isotopes. Further details on the spectrometer and pulse-height analyzer will be given later by Ghiorso and Larsh.[15]

IV. ACKNOWLEDGMENTS

The authors are indebted to T. O. Passell for assistance with the beta-ray spectrometer. The bombardments were carried out by James T. Vale, Lloyd B. Houser, and the 184-inch cyclotron crew.

[11] N. Svartholm and K. Siegbahn, Arkiv Mat. Astron. Fysik **A33**, No. 21 (1946); see also Hedgran, Siegbahn, and Svartholm, Proc. Phys. Soc. (London) **A63** (1950).

[12] F. Shull and D. Dennison, Phys. Rev. **71**, 681 (1947); **72**, 256 (1947).

[13] G. D. O'Kelley, University of California Radiation Laboratory Report UCRL-1243, March 15, 1951 (unpublished).

[14] C. J. Borkowski, Oak Ridge National Laboratory Report ORNL-1336, September, 1952 (unpublished).

[15] A. Ghiorso and A. E. Larsh (to be published).