different oscillator parameters for $1s$ and $1p$ protons. The most likely parameter for $1p$ protons is $a \approx 2.2$ F. The Li^6 curves of Fig. 1 indicate that a slightly bigger value of the oscillator parameter is desirable, although the curve for $a=2.2$ F would lie fairly close to the experimental points.

The comparison of experiment and theory exhibited in Fig. 1 shows that one is on the borderline of understanding the results with a simple theory. On the experimental side it would be desirable to have some points at higher and lower momentum transfers. It would also be desirable to improve the values for the photon point, although these are difficult experiments. However, a lower value for the C^{12} photon point would remove much of the disagreement.

The interpretation of the 180° cross-section measurements at lower energy would be more complicated in that distortion effects[13] on the electron waves can be important. For the points included in the present experiments, they are not likely to have much effect.

Ultimately, more accurate experiment and calculation may show that for these $M1$ form factors the simple harmonic-oscillator radial functions are just not adequate. The use of $M1$ transitions provides a more sensitive test than elastic charge scattering since only outer shell nucleons are involved.

ACKNOWLEDGMENT

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[13] T. A. Griffy, D. S. Onley, J. T. Reynolds, and L. C. Biedenharn, Phys. Rev. **128**, 833 (1962).

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Independent Fission Yield of Sb^{127}†

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The fractional independent yield of Sb^{127} has been found to be 0.057 ± 0.010 from the thermal-neutron fission of U^{235}. This value leads to a calculated value of 49.5 ± 0.1 for the "most probable charge" Z_P for fission products with $A=127$ and implies that there is no pronounced effect of the 50-proton shell on the Z_P function. It was also found that $40.4 \pm 2.4\%$ of fission-product Sb^{127} is formed by beta decay of 4.4-min Sn^{127} and that $53.9 \pm 2.1\%$ is formed by beta decay of 2.15-h Sn^{127}.

INTRODUCTION

IT has been suggested[1] that the "most probable charge" Z_P for fission products in the mass region below $A \cong 130$ stays close to and just above 50. This suggestion is based primarily on the independent yield of I^{128}. Wahl and Nethaway[2] have shown that the fractional independent yield of $_{50}Sn^{121}$ is small and, therefore, that Z_P for $A=121$ is <50. It seemed desirable to determine the independent yields of other fission products in the mass region between $A=121$ and $A=130$ in order to learn more about the behavior of the Z_P function. Therefore, experiments were undertaken to determine the independent yield of Sb^{127}. A description of these experiments and of the results obtained is given below.

EXPERIMENTAL

Irradiations

Irradiations were made at the Oak Ridge Research Reactor in the pneumatic tube facility where the thermal-neutron flux density was $\sim 6 \times 10^{13}$ neutrons cm^{-2} sec^{-1}. A cadmium ratio for U^{235} fission of ~ 35 was determined by comparing the amount of Sb^{127} produced by fission of unshielded uranium samples with the amount produced by fission of samples shielded by a cadmium absorber 0.40 in. thick. One-milliliter solutions containing 100 micrograms of uranium (93% U^{235}) in ~ 0.1 M HNO_3 were irradiated in high-density polyethylene capsules for periods of 20 sec.

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[1] T. J. Kennett and H. G. Thode, Phys. Rev. **103**, 323 (1956).
[2] A. C. Wahl and D. R. Nethaway, Phys. Rev. **131**, 830 (1963).

Chemical Procedures

After irradiation the polyethylene capsule was punctured with a hypodermic needle, and the contents were drawn into a mixing vessel containing Sb (III) carrier in H_2SO_4 solution. The capsule was washed with 1.0 ml of water, which was added to the contents of the mixing vessel. After this addition, the mixing vessel contained ~10 ml of a solution of Sb (III) (4 mg/ml) in 30% H_2SO_4. After being stirred, this solution was divided into two approximately equal portions.

Antimony was separated from the other fission products in one portion by a modification of the procedure of Greendale and Love.[3] The solution was poured onto hot zinc granules, and the resulting SbH_3 was swept by nitrogen into a Br_2–HCl solution which decomposed the SbH_3. Fifteen seconds after the solution was poured onto the zinc, the gas flow was diverted from the Br_2–HCl solution. The midpoint of this fifteen-second interval was taken to be the time at which separation occurred. The time interval between this time and the mean irradiation time was taken to be the time between occurrence of fission and separation of antimony from precursors.

After a delay of at least 24 h to allow decay of Sn^{127} to Sb^{127}, antimony was separated from the second portion of the irradiated solution plus carrier by the same procedure.

Experiments with Sn^{113} tracer indicated that the decontamination factor for the separation of antimony from tin was greater than 10^3. Other experiments with Sb^{124} tracer and antimony carrier solutions containing Sb(V) as well as Sb(III) confirmed Greendale and Love's[3] findings that the chemical yield is the same for Sb(V) as for Sb(III).

After allowing time for decay of 4.6-h Sb^{129}, the antimony in each Br_2–HCl solution was purified by the method of Flynn, Glendenin, and Steinberg.[4]

Counting

All samples were filtered, dried, and weighed on filter paper circles $\frac{7}{8}$ in. in diameter. The circles were mounted with "two-sided" Scotch tape on aluminum counting plates and covered with $\frac{1}{4}$-mil Mylar film. Counting was delayed until 9.6-h Sb^{128} had decayed and 9.3-h Te^{127} had grown into transient equilibrium with Sb^{127}. The decay of the beta activity of a sample was followed for at least forty days on a flow-type proportional counter.

CALCULATIONS

Consider the fission product chain shown in Fig. 1. Define: y_1, y_2=fractional cumulative yields of 4-min Sn^{127}, and 2-h Sn^{127}, respectively, based on the cumulative yield of Sb^{127}. z=fractional-independent yield of Sb^{127}, based on the cumulative yield of Sb^{127}. $z+y_1+y_2=1$. T=duration of irradiation producing fissions at a constant rate. t, t'=time intervals between the end of an irradiation and the separation of Sb^{127} from Sn^{127}. $\tau=T/2+t$, $\tau'=T/2+t'$. Q=ratio of activity of Sb^{127} separated after t to activity of Sb^{127} separated after a longer time t', corrected for chemical yield, to the same number of fissions, and for decay to the same time.

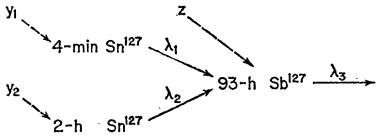

FIG. 1. Early members of the mass-127 decay chain.

For the conditions employed ($\tau'\gg 2$ h and $T\ll 4$ min) the following equation, which has been derived from the standard equations of radioactive transformation, is applicable.

$$(1-Q)\exp(-\lambda_3\tau) = \frac{a(1-y_2-z)\exp(-\lambda_1\tau)+by_2\exp(-\lambda_2\tau)}{z+a(1-y_2-z)+by_2}, \quad (1)$$

where

$$a=\lambda_1/(\lambda_1-\lambda_3)$$
$$b=\lambda_2/(\lambda_2-\lambda_3).$$

The equation was programmed for the CDC-1604 computer, and the half-lives $t_{1/2}(1)$ and $t_{1/2}(2)$ and the fractional yields z and y_2 were evaluated by a least-squares analysis[5] in which the data were weighted in proportion to the reciprocal of the square of the esti-

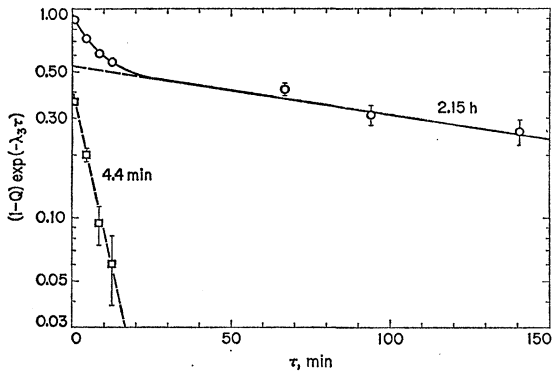

FIG. 2. Decay of Sb^{127} precursors. Values represented by ○ were determined from experimental measurements of Q; the value plotted at $\tau=0.75$ min is the average of three values determined for $\tau=0.69$, 0.75, and 0.80 min. The solid line represents the least-squares fit of Eq. (1) to the data. The broken lines represent the two terms of Eq. (1) corresponding to decay of the individual components. Values represented by □ were obtained by subtraction of the 2.15-h component from the experimental values.

[3] A. E. Greendale and D. O. Love, Anal. Chem. 35, 632 (1963).
[4] K. F. Flynn, L. E. Glendenin, and E. P. Steinberg, quoted by W. J. Maeck, Radiochemistry Monograph NAS-NS-3033 [National Academy of Sciences—National Research Council, Washington, D. C., 1960 (unpublished].
[5] W. R. Busing and H. A. Levy, Oak Ridge National Laboratory Report ORNL-TM-271, 1962 (unpublished).

mated uncertainty in the value of $(1-Q)$. The half-life of Sb^{127} was taken to be 93 hours.

Analysis of the data from 9 experiments gave the following results:

$$t_{1/2}(1)=4.2\pm1.4 \text{ min}$$
$$t_{1/2}(2)=2.25\pm0.75 \text{ h}$$
$$z=0.056\pm0.011$$
$$y_2=0.537\pm0.077$$
$$y_1=0.407\pm0.078 \quad (y_1=1-z-y_2).$$

The uncertainties are standard deviations from the computer program. The 2.25±0.75-h value for $t_{1/2}(2)$ is in agreement with the 2.2±0.2-h value reported by Hagebo, Kjelberg, and Pappas,[6] and with the 2.15 ±0.1-h value reported by Dropesky and Orth.[7] The 4.2±1.4-min value for $t_{1/2}(1)$ is in good agreement with the 4.6±0.4-min value reported by Hagebo, Kjelberg, and Pappas,[6] and with the value of 4.25±0.5 min reported by Hahn.[8]

Since the information from our experiments is not extensive enough to permit the determination of half-lives to a high degree of accuracy, the data were reanalyzed using 4.4 min (the average of 4.25 and 4.6 min) and 2.15 h as the half-lives of the Sn^{127} isomers. The following results were obtained; $z=0.057\pm0.0045$, $y_1=0.404\pm0.018$, $y_2=0.539\pm0.017$. The uncertainties are standard deviations from the computer program and do not take into account uncertainties in half-lives and τ values.

Estimated uncertainties of ±0.3 min in $t_{1/2}(1)$, ±0.2 h in $t_{1/2}(2)$, and ±7.5 sec in τ result in uncertainties in z of ±0.0022, ±0.0008, ±0.0083, respectively. The total uncertainty in z is taken to be the square root of the sum of the squares of all the uncertainties mentioned above. The uncertainties in y_1 and y_2 are estimated in a similar way. The final values and uncertainties are

$$z=0.057\pm0.010,$$
$$y_1=0.404\pm0.024,$$
$$y_2=0.539\pm0.021.$$

A plot of $(1-Q)\exp(-\lambda_3\tau)$ as a function of τ is shown in Fig. 2. The errors shown represent an estimated ±5% error in the radiochemical determination of Q. The solid line is the curve derived from the half-life and yield values given above, and the broken lines are the 4.4-min and 2.15-h components [terms in Eq. (1)] into which the curve is resolved.

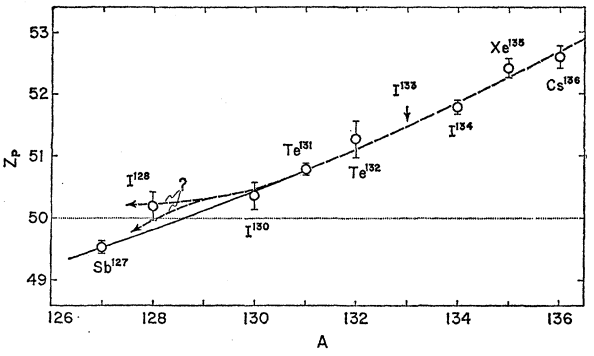

FIG. 3. Z_P function near $Z=50$ for fission products from thermal-neutron fission of U^{235}. Values, except for Sb^{127}, and the empirical Z_P function (broken lines) are from Ref. 9.

DISCUSSION

It has been shown[9] that for those mass chains for which two or more fractional independent or cumulative yields have been measured the charge dispersion can be represented by a Gaussian distribution curve,

$$P(Z)=(c\pi)^{-1/2}\exp[-(Z-Z_P)^2/c], \qquad (2)$$

where $P(Z)$ is the fractional independent yield of a fission product with atomic number Z and where c is a constant with a value of 0.94±0.15. On the assumption that this curve applies to the mass-127 chain, the Z_P value derived from the fractional-independent yield of 0.057±0.010 is 49.5±0.1.

What is known of the Z_P function near $Z=50$ is shown in Fig. 3. The broken line represents the empirical Z_P function derived by Wahl *et al.*[9]; the branching below $A=129$ illustrates the uncertainty that existed concerning the function near the 50-proton shell edge. The new Z_P value at $A=127$ indicates that the Z_P function crosses the 50-proton shell edge smoothly with little or no inflection (solid line in Fig. 3).

The high value at $A=128$ could indicate a small inflection in the Z_P function (e.g., the lower broken line), or it could indicate that the charge dispersion curve for $A=128$ is somewhat broader ($c=1.2$) than the one assumed ($c=0.94\pm0.15$). It should be remembered that none of the Z_P values plotted in Fig. 3 have been determined directly. The Z_P values have been estimated from measured independent yield values and a charge distribution curve which represents the charge dispersion for some other mass numbers.[9]

[6] E. Hagebo, A. Kjelberg, and A. C. Pappas, J. Inorg. Nucl. Chem. 24, 117 (1962).
[7] B. J. Dropesky and C. J. Orth, J. Inorg. Nucl. Chem. 24, 1301 (1962).
[8] R. L. Hahn (private communication from the Oak Ridge National Laboratory, 1963).
[9] A. C. Wahl, R. L. Ferguson, D. R. Nethaway, D. E. Troutner, and K. Wolfsberg, Phys. Rev. 126, 1112 (1962).