ISOTOPIC DISTRIBUTION OF Rb AND Cs PRODUCED BY 10.5-GeV PROTONS ON U, Th, Ta, AND IDENTIFICATION OF NEW ISOTOPES: ^{77}Rb, ^{78}Rb, ^{120}Cs, ^{121}Cs, ^{122}Cs, AND ^{124}Cs

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Cross sections for high-energy fission or spallation reactions have been extensively studied by radiochemistry, and in the case of stable or long-lived isotopes, by mass spectrometry. It is well known, however, that there are limitations due to half-lives, insufficient knowledge of decay schemes, etc.

By the same mass-spectrometric technique[1] used in the experiment on Na fragments described in the preceding paper,[2] it is possible to measure cross sections for the production of Rb and Cs isotopes of the shortest half-lives.

This report deals with an experiment done at the CERN proton synchrotron in parallel with the experiment on lighter fragments which is reported separately.[2]

Technical differences between the two experiments include the fact that for surface ionization of Rb and Cs a Ta surface at 1500°C was preferred,[3] and that mass analysis was performed by a more dispersive (30-cm radius, 90° deflection) magnetic prism. Another important difference is that diffusion here is somewhat slower than with Na.[2] While some atoms were diffusing in a typical case with half-times of 13, 64, and 367 msec (relative proportions, respectively, 18, 29, and 53 %), a sizable fraction diffused in a much slower fashion, and curve *b* of Fig. 1 shows that 8 sec after the proton pulse there is a residual peak due to these slowly diffusing atoms.[4] It is safe, however, to assume that this slow component is constant in 8 sec, so that the difference between measurements *a* and *b* (Fig. 1) is proportional to the number of atoms diffusing according to the above-mentioned three fast modes, hence to the total number of atoms produced in the reaction. Care was taken that the diffusion times did not vary appreciably from one isotope to the other whether neutron excessive or neutron deficient.

For isotopes of half-lives shorter than 2 sec, it was necessary to correct for radioactive decay during diffusion. This correction[1] amounted to a maximum of 26 % for ^{96}Rb (0.23 sec).[5]

It was possible, without mass discrimination, to explore three mass units at a time in the mass spectrum (Fig. 2) with the overlap of one mass serving as a relative monitor. A proton-flux monitor was also used, with reasonable agreement between both procedures.

Results.—The results are shown in Fig. 2. Because of the short time scale involved in diffusion, these are again independent yields. To date, the cross sections we present are relative, but an absolute calibration is presently being done by a radiochemical measurement on shielded isotopes.

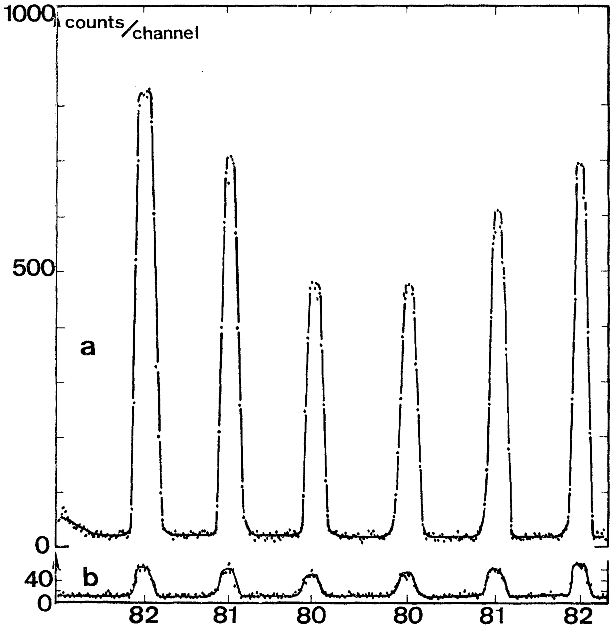

FIG. 1. A portion of the mass spectrum of Rb isotopes from a Th target. Spectrum *a* taken just after the proton burst for some 60 to 200 msec represents the fast diffusing part of the reaction products. Spectrum *b* represents the residual due to the slow diffusion. The symmetry is due to the triangular modulation of the accelerating potential.

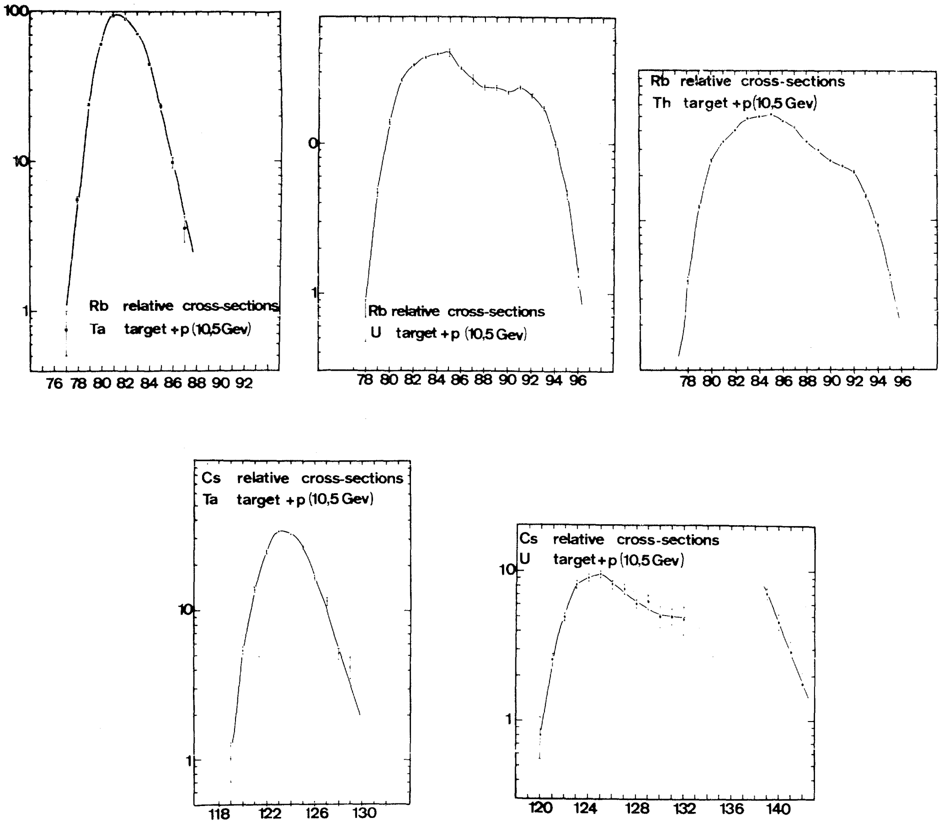

FIG. 2. Experimental isotopic distribution of Rb and Cs isotopes.

New isotopes.—In the spallation of Ta, two new isotopes of Rb, ^{78}Rb and ^{79}Rb, were distinctly seen. ^{76}Rb was looked for but could not be separated from the background. This is believed to result from the sharp drop in cross section rather than from a very short half-life. Similarly ^{119}Cs, ^{120}Cs, ^{121}Cs, ^{122}Cs, and ^{124}Cs were recorded. Again, the steep fall in cross section should be noticed. No provision was made during this run to measure the half-lives of these isotopes. We contemplate to count β decays instead of ions as was done at Orsay in a similar experiment.[5]

Relative cross sections.—The isotopic distribution of Rb and Cs from Ta is narrow and peaks strongly on the neutron-deficient side, which is rather typical of spallation reactions.

In case of Th and U, the curves are much broader and extend from the neutron-excessive to the neutron-deficient side as one expects from high-energy fission reactions.[6] Isotopes at masses 133 through 138 could not be recorded because of a natural Ba impurity. This was accidental and we think that these isotopes could be recorded in another run as was indeed the case in similar measurements done at 150 MeV.[1] The two branches of the curve for Cs from U in Fig. 2 were monitored by proton-flux measurements, and their relative position may thus be in error by an estimated 10 to 15%.

We feel that these results show that it is possible to obtain more detailed and precise information with this technique than was possible by more conventional methods.[6]

Detailed work on the interpretation of these data is presently under way.

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[1] R. Klapisch, J. Chaumont, C. Philippe, I. Amarel, R. Fergeau, M. Salomé, and R. Bernas, Nucl. Instr. Methods 53, 216, 228 (1967).

[2] R. Klapisch, C. Philippe, J. Suchorzewska, C. Detraz, and R. Bernas, Phys. Rev. Letters 20, 740 (1968).

[3] At 1500°C on Ta, the efficiency of ionization taken from the Saha-Langmuir formula is 100 % for Cs and Rb while Ba and Sr have efficiencies, respectively, 1000 and 6000 times smaller. Thus, among the reaction products it is safe to consider this method as selective for Rb and Cs. Natural barium present in great quantities can, of course, be ionized (see text).

[4] Any contamination by a stable isotope will of course be included in measurement *b*. The difference between *a* and *b* is usually significant except in one case at masses 133 to 138 (see text).

[5] I. Amarel, R. Bernas, R. Foucher, J. Jastrzebski, A. Johnson, J. Teillac, and H. Gauvin, Phys. Letters 24B, 402 (1967).

[6] G. Friedlander, in Proceedings of the Symposium on the Physics and Chemistry of Fission, Saltzburg, 1965 (International Atomic Energy Agency, Vienna, 1965), Vol. II, p. 265, and references therein.

CHARGE DISTRIBUTION IN NUCLEI

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In recent years there has been great improvement in the accuracy of experiments on muonic x rays and electron scattering by nuclei. Analysis of these experiments by Ravenhall, Herman, and Clark[1] has yielded much improved knowledge on the charge distribution in nuclei. In particular it has been established that one way to fit the experiments is to use a charge distribution inside the nucleus of Pb^{208} that has a wine-bottle shape.

Ravenhall has already pointed out, and we wish to emphasize further, that such a detailed determination of the charge distribution, which yields some third shape parameter, is only possible by a combination of the experimental evidence from electron scattering and muonic x rays. These two experimental techniques measure different properties of the charge distribution. (In this statement, we exclude the scattering of low-energy electrons, of 20-50 MeV, which measures essentially the mean square radius of the charge, just like the mu x rays. These two pieces of evidence on $\langle r^2\rangle$ are in excellent agreement.)

The electron scattering at medium energy (150-750 MeV) measures essentially the value of r at which $\rho(r)$ has its steepest slope. This was shown by one of us (L.R.B.E.) in explicit calculations of the electron scattering from various assumed charge distributions.[2] He used the standard "Fermi" distribution, the distribution suggested by one of us (H.A.B.) on theoretical grounds, and a distribution calculated by himself from single-particle wave functions. The first two of these are

$$\rho_F/\rho_0 = \left[1+\exp\left(\frac{r-R_1}{a_1}\right)\right]^{-1} \quad \text{(Fermi)}, \tag{1}$$

$$\rho_B/\rho_0 = \left[1-\exp\left(\frac{r-R_2}{a_2}\right)\right]^{2} \quad \text{(Bethe)}. \tag{2}$$

When the parameters were adjusted for best fit to the experimental electron-scattering cross section, all three distributions gave essentially the same location of the position of steepest slope, viz. 6.5 F. The agreement is within about 0.03 F. Similar results were obtained by Lin[3] who did similar calculations for distributions (1) and (2), using the approximate method of Yennie, Boos, and Ravenhall.[4] The values of $\langle r^2\rangle^{1/2}$ derived from these various charge distributions differ quite appreciably, by up to 0.2 F.[5]

The empirical result that electron scattering measures the steepest slope of the charge distribution can be understood by using the Born approximation for scattering. We are of course well aware that the Born approximation is not valid for electron scattering by Pb. However, the approximation provides a heuristic guide and has been used for this purpose in the past. Especially the work of Yennie, Boos, and Ravenhall[4] has shown that modification of the Born approximation, taking into account the distortion of the electron wave functions by the Coulomb field, can give a good account of the scattering. In the Born approximation the scattered amplitude is given by