Angular Distribution of Fragments from the Fission of Bismuth by 450-Mev Protons*

M. V. RAMANIAH† AND NATHAN SUGARMAN
Enrico Fermi Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received November 4, 1959)

Test experiments on the "bead-cone" method used for the measurement of the angular distribution of fission fragments from the 450-Mev proton fission of bismuth have been performed. These experiments make doubtful the conclusions of the previous measurement.

I. INTRODUCTION

WOLKE and Gutmann[1] measured the angular distributions of $Ga^{72,73}$, $Sr^{91,92}$, and $Cd^{115,117}$ fragments in the laboratory system from the 450-Mev proton fission of bismuth by the "bead-cone" method. On the assumption that the angular distribution in the system of the moving fissioning nucleus is of the form $a+b\cos^2\theta'$, where θ' is the polar angle relative to the proton beam direction in the moving system, b/a was determined to be ~ 0.1 in all three cases. This value of b/a for $Sr^{91,92}$ agreed within experimental error with b/a values determined for Sr^{91} and Sr^{92} from bismuth by Porile and Sugarman[2] by the "stacked-foil" method.

The method of Wolke and Gutmann was applied to the measurement of the angular distributions of $Sr^{91,92}$ and $Pd^{109,112}$ in the laboratory system from the 450-Mev proton fission of uranium. The angular distributions were found to be almost identical with the three cases measured by Wolke and Gutmann.[1] Also, the b/a values were again determined to be ~ 0.1, this time in contradiction with "stacked-foil" results from uranium targets.[3] These results cast doubt on the method and led us to the investigation of possible systematic errors in the method not revealed in previous test experiments.

Experiments designed to test the method were performed with uranium and bismuth targets using the 450-Mev proton beam of the University of Chicago synchrocyclotron. These experiments were similar, in principle, to an earlier test experiment of Wolke[4] with a bismuth target. Since a section of the cone is cut away (Fig. 1), the angular distribution in θ, polar angle in the laboratory relative to the proton beam, should be independent of ϕ, the azimuthal angle around the cone axis, for the method to be successful. The test, then, involved the measurement of the angular distribution in θ as a function of ϕ. The results were shown to depend upon ϕ to an extent much larger than tolerable.

* This work was supported in part by the U. S. Atomic Energy Commission.

† Present address: Radiochemistry Laboratory, Atomic Energy Establishment, Trombay, Bombay, India.

[1] R. L. Wolke and J. R. Gutmann, Phys. Rev. **107**, 850 (1957).
[2] N. T. Porile and N. Sugarman, Phys. Rev. **107**, 1410 (1957).
[3] N. Sugarman and coworkers (unpublished).
[4] R. L. Wolke (unpublished).

II. EXPERIMENTAL PROCEDURE AND RESULTS

The aluminum catcher cone (Fig. 1) used in these experiments has a "cut-away" section to allow the proton beam to strike the bead target, bismuth-coated brass or uranium, without excessive scattering. The catcher cone, when unrolled, is a semicircle. The sections analyzed for the angular distribution about the angle θ are circular sections as seen in Fig. 2, (a) or (b). The values of θ_1, θ_2, and θ_3 are 30°, 60°, and 90°, respectively, for forward recoil experiments, and 150°, 120°, and 90°, respectively, for backward recoil experiments. The ϕ' angle[5] used in the Wolke experiment[4] was 60° [Fig. 2(a)], so that for each θ section there were two pieces, one twice the area of the other. In the present experiment, cuts were made at ϕ' values of 45° and 135° [Fig. 2(b)] and the ϕ' sections from 0° to 45° and 135° to 180°, which are symmetric about the "cut-away" section, for a given θ value were combined ("end" section) and the activity compared with the section at the same θ value for ϕ' between 45° and 135° ("middle" section). Any dependence of the measured θ-angular distribution on the angle ϕ' is thus accentuated in the present experiment.

In the experiment of Wolke[4] the $Sr^{91,92}$ activity from a bismuth bead target $\frac{3}{32}$ in. in diameter, was isolated radiochemically from the recoil catcher. The ratio of activity for a given θ section from the two ϕ' sections

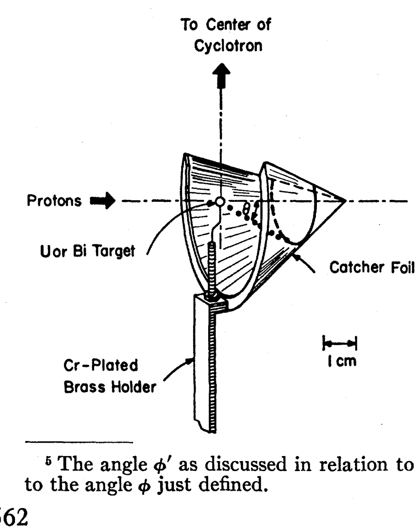

FIG. 1. Target and recoil catcher (same as Fig. 1 of reference 1).

[5] The angle ϕ' as discussed in relation to Fig. 2 is proportional to the angle ϕ just defined.

changed by only 4% from the 0°–30°θ section to the 60°–90° section. Because of the low total activity produced with a bismuth target, it was felt that this variation was not outside of the expected experimental error for an angular distribution independent of ϕ'.

The results of the present test experiments are given in Table I. The entries are the fractional activities of $Sr^{91,92}$ from either a uranium or bismuth bead target of about $\frac{3}{32}$-in. diameter for a given θ-ϕ' section relative to the total activity for a given ϕ' section ("end" or "middle") from either a "forward" or "backward" recoil experiment. Thus, the fractional activities of $Sr^{91,92}$ for the "end," or "middle," section for the θ sections 0°–30°, 30°–60°, 60°–90° add up to unity.

In a given experiment, the total activity in the "middle" ϕ' section for all θ sections is about 35% less than that in the "end" ϕ' section because the recoils caught in the "middle" section are generated in the side of the target bead further away from the center of the cyclotron than the recoils caught in the "end" sections. The proton intensity at the target decreases with distance from the center of the synchrocyclotron because of scattering in the target.

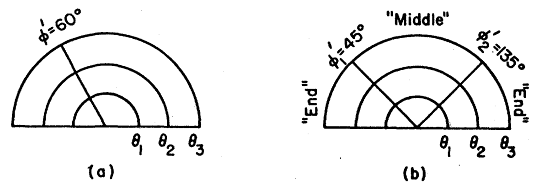

FIG. 2. Sections of aluminum cone recoil catcher used for measurement of dependence of angular distribution of fission fragments on the angle ϕ'; (a) Wolke experiment (reference 4); (b) Present experiment.

An examination of the data of Table I for bismuth and uranium shows that the fractional activity of $Sr^{91,92}$ in a given θ section is not the same for the two ϕ' sections, with an extreme variation in the ratio of "middle" to "end" of about 25%. Furthermore, the same effect is evident for both the uranium and bismuth targets. The results of these experiments are consistent with those of Wolke[4] when analyzed in accordance with his experimental arrangement.

TABLE I. Results of $Sr^{91,92}$ angular distribution measurements.

θ section, degrees	Fractional activity Bismuth "End"	Bismuth "Middle"	Uranium "End"	Uranium "Middle"
0–30	0.132	0.158	0.141	0.157
30–60	0.369	0.389	0.355	0.373
60–90	0.498	0.453	0.504	0.469
90–120	0.532	0.465	0.531	0.477
120–150	0.339	0.375	0.342	0.365
150–180	0.129	0.160	0.127	0.158

III. CONCLUSION

Wolke and Gutmann[1] analyzed the activity data of the 0°–30°, 30°–60°, 60°–90° θ sections of the "bead-cone" geometry with a bismuth target by dividing the fractional activity in each θ section by the fractional solid angle. The numbers so obtained[6] showed a variation of about 20% from the 0°–30° section to the 60°–90° section. A similar analysis of the θ sections of the "end" and "middle" ϕ' sections of Table I gives quite different results for the two different ϕ' sections. It is obvious, then, that the ϕ' (or ϕ) dependence of the angular distribution is too large to be ignored. The irregular behavior of the laboratory angular distributions noted by Wolke and Gutmann[7] may also be attributed to the failure of the method.

The variation in radial intensity of the proton beam at the target is responsible for the ϕ dependence of the angular distribution. The magnitude of the ϕ dependence noted in Table I is consistent with a change in proton intensity of about a factor of two from the "hot" to "cold" side of the bead. Although, as stated by Wolke and Gutmann, "No perturbation of the angular distributions [in θ], . . . is introduced by a radially varying beam intensity," the ϕ dependence *does* lead to a "perturbation" when a ϕ section of the cone is missing and the proton intensity variation is not negligible, as in this case. The perturbation introduced by the radially dependent proton intensity is about the same for uranium and bismuth (brass) targets. The "apparent" anisotropy in θ resulting from this source is much larger than that from the angular distribution of fragments emitted in the fission of uranium and bismuth.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the many helpful discussions on this problem with Professor Anthony Turkevich and Dr. Helmut Münzel.

[6] See Table I of reference 1.
[7] See Figs. 2, 3, and 4 of reference 1.