Negative Pion Activation of Bromine*†

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Radiochemical studies of the reactions of π^- mesons with bromine, silver, and the light elements present in photographic emulsions should assist considerably in the interpretation of data obtained with photographic plates. The results for bromine with 122-Mev negative pions expending their full range in the element include: Peak yield of about 7 percent for As^{76} (ejection of 1 proton and 2 or 4 neutrons depending on which Br isotope absorbs the pion); the ratio of the number of neutrons to the number of protons ejected was three to four in the most probable cases; the distribution of radioactivities appears to be reconcilable with photographic plate data if one guesses that the silver data will resemble those for bromine.

THE very considerable intensity of negative pions available from the 170-inch synchrocyclotron at the University of Chicago makes possible radiochemical studies of meson reactions.[1] Such studies with the elements bromine, silver, and the light elements carbon, nitrogen, and oxygen should be of great assistance in the interpretation of data obtained with photographic plates. The results for the element bromine are reported in this communication.

The initial intensity of mesons at the beryllium target is of the order of 1 curie. An appreciable fraction of this intensity is available as negative pions. Deflection by the magnetic field of the main cyclotron magnet allows selection of a 122-Mev beam by the use of a channel several square inches in cross section traversing a 6-foot thick iron shield. (This shield was increased to 12 feet in thickness toward the end of this research.) The pion beam emerging from the iron shield is further purified by deflection with an auxiliary magnet. The target bromine was placed just beyond this auxiliary magnetic field. The usual intensity ran between 200,000 and 600,000 mesons per minute, and irradiation was conducted for periods between 1 and 6 hours. Background experiments were performed by turning off the auxiliary deflecting magnet and operating the cyclotron at its usual meson output.

The sample itself consisted of about 6 pounds of liquid bromine in the standard commercial bottle. This gave a cylindrical target about 8 cm in diameter and about 20 cm long. The range of 122-Mev negative pions is about 55 grams per cm^2 in bromine, so the target is thicker than the range of the incident beam. Carriers of selenium, arsenic, germanium, gallium, and zinc were added to the irradiated bromine and subsequently separated by shaking with a hydrochloric acid solution. The various elements then were separated chemically from the aqueous layer and the individual isotopes identified by half-life and absorption curves. Table I presents the results. Percent yields are quoted in terms of the activity that would have been observed had all of the negative pions formed the individual isotope in question. The yields shown in column 4 are the mean of at least two determinations.

The samples were counted on a large cylindrical counter of thin wall (2.7 mg/cm^2), developed for this research. The counter was 1.5 inches in diameter and 10 inches long. On the inner surface of the thin plastic wall gold had been deposited to the extent of about 0.1 mg/cm^2. This foil is commercially available, its principal use being for gilding. By the use of an atmospheric pressure filling such as "*Q* gas" the wall was supported by a slight excess pressure of gas in the counter. The sample was placed intimately around the counter with a geometry of 35 percent. Anticoincidence shielding was used to keep the background rate at about 6 cpm. Absolute assays were obtained by calibration with absolute standards, and the use of the general methodology of correction for self-absorption were observed to hold for close geometries of the type involved in this counting arrangement.

An experiment was performed to test for possible deleterious activation effects of the 5 or 6 neutrons emitted per pion captured. This experiment consisted in irradiating a stack of solid bromine cylindrical disks, each of which was 15 g/cm^2 thick and had a cross-section diameter of about 3.5 inches. The results of this experi-

TABLE I. Absolute yields for negative pions on bromine.

Isotope	Observed half-life	Literature half-life	Yield (%)
Se^{72}	9.5 days	9.5 days	3.2±0.9
Se^{73}	6.7 hr	6.7 hr, 7.1 hr	3.6±1.0
As^{77} (+As^{71})	40 hr	40 hr, 50 hr	3.6±1.0
As^{76} (+As^{72})	26.8 hr	26.8 hr, 26 hr	6.3±1.7
As^{74}	17.5 days	17.5 days	7.0±1.8
As^{78}	80 min	90 min	0.8±0.3
Ge^{69}	40 hr	39.6 hr	0.6±0.15
Ge^{75}	90 min	82 min	0.3±0.08
Ga^{68}	68 min	68 min	1.2±0.4
Ga^{72}	14.1 hr	14.1 hr	0.6±0.15
Ga^{73}	5.0 hr	5.0 hr	0.4±0.1

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[1] A. Turkevich and J. B. Niday, Phys. Rev. 84, 1253 (1951).

TABLE II. Activation *vs* range data.

Br traversed (g/cm^2)	Yield in % for As isotopes: 17.5-day As^{74}	40-hr As^{77} ($+As^{71}$)	26.8-hr As^{78} ($+As^{72}$)
0–15	1.16	0.56	0.92
15–30	1.36	0.65	1.06
30–45	2.0	0.95	1.58
45–60	2.8	1.39	2.27
60–75	...	...	0.22
75–90	...	...	0.08

ment are given for three arsenic isotopes in Table II. It should be observed that these data were obtained with a somewhat divergent pion beam, so the exact shape of the yield *vs* range curve should not be taken too seriously. It is clear, however, from these data that the arsenic activities are formed by the negative pions and only slightly by the secondary neutrons. Some small correction has been made for the secondary neutron formation in compiling the data in Table I.

By chemical group separations an upper limit was set on the yield of all isotopes other than those of selenium, arsenic, germanium, and gallium. For those having a half-life in the range 30 min to 15 days and which do not decay exclusively by K capture, the total maximum yield is estimated to be less than 3 percent.

By plotting arsenic isotope yields against mass number, a curve is obtained that is roughly symmetrical about a vertical axis. The peak seems to be at mass 74 or 75. As a first approximation it is assumed that selenium and germanium yield curves will have the same shape as the arsenic curve. The arsenic curve is chosen as the standard since more data are available for it. The gallium curve is taken to be somewhat flatter and broader. When such interpolation and extrapolation are used to obtain yields of the stable isotopes, the total yields per element can be calculated. These are shown in Table III.

TABLE III. Element yields for negative pion activation of bromine.

Element	Yield (%)
Selenium	34
Arsenic	31
Germanium	21
Gallium	7

These values appear to correspond roughly with those obtained in photographic plate studies when emulsion data are corrected to consider heavy nuclei capture only. However, this point will be more conclusively settled when the data for silver and the lighter elements in the emulsion are determined more completely.

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