realized. We have been able to produce superheated liquid hydrogen and to trigger its boiling with minimum ionization particles.

The apparatus is shown in Fig. 1. The chamber itself was a pyrex bulb which could be observed by eye through the unsilvered nitrogen and hydrogen Dewars. The bulb communicated through a pyrex capillary with input and exhaust hydrogen lines. The pressure was controlled by means of valves on these lines. The temperature of the bulb was controlled by a resistance wire heater which opposed the conduction cooling of the pyrex capillary whose lower end was at the temperature of the liquid hydrogen bath.

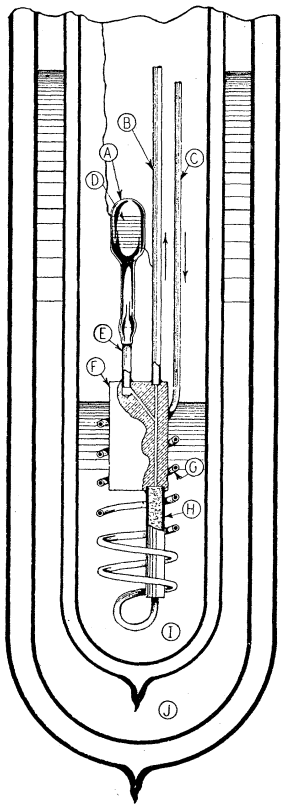

FIG. 1. Liquid hydrogen bubble chamber. *A*: Pyrex bulb. Volume 3 cm³. Inside diameter 12 mm. *B*: Exhaust tube. *C*: Input tube for purified hydrogen gas. *D*: 23-ohm heater wire wound on pyrex bulb. Operating current 80 milliamperes. *E*: Kovar tube. *F*: Copper block. *G*: Coil to condense incoming hydrogen. *H*: Glass wool trap to keep particles out of bulb. *I*: Liquid hydrogen bath. *J*: Liquid nitrogen jacket.

By controlling the temperature and pressure inside the bulb the chamber could be filled with liquid hydrogen in equilibrium with its vapor. Raising the pressure slightly would cause the vapor phase to disappear in the bulb. Thereafter, when the pressure was lowered well below the equilibrium vapor pressure the liquid could be kept in the bulb without boiling for considerable lengths of time.

The temperature was such that the liquid hydrogen was in equilibrium with its vapor at 3 atmospheres. In order to fill the bulb in a short time a filling pressure of $3\frac{2}{3}$ atmospheres was used. When the bulb was completely full the pressure was suddenly reduced from $3\frac{2}{3}$ to 1 atmosphere.

In the absence of radiation other than cosmic radiation the liquid hydrogen would remain superheated for periods up to 70 seconds before boiling. The average delay for 40 such expansions was 22 seconds. The boiling triggered immediately, however, when the bulb was exposed to a 15-millicurie Co^{60} source at a distance of 5 meters. Occasionally delays up to 2 seconds were observed but in nearly every one of 37 such expansions the delay was too short to be observed by eye.

Similar results were obtained with liquid nitrogen using higher temperatures and pressures.

The authors wish to thank Dr. Donald Glaser for his cooperation in planning this experiment. We are also much indebted to Dr. Lother Meyer for much advice and for assistance in operating the cryostat. Dr. Earl Long has been most generous in making the facilities of the Low Temperature Laboratory of the Institute for the Study of Metals available to us.

[1] Donald A. Glaser, Phys. Rev. **87**, 665 (1952); **91**, 496, 762 (1953).

Bromine Isotopes Produced by Carbon-Ion Bombardment of Copper*

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IN addition to providing a novel means for the synthesis of transplutonium elements,[1] the accelerated carbon-ion beam of the Berkeley 60-inch cyclotron may also be used conveniently for the study of neutron-deficient nuclides, for it is a property of carbon-ion-induced transmutations in any but the lightest elements that the ratio of protons to neutrons added to the target nucleus is virtually always larger than unity.

The 60-inch cyclotron, which accelerates He^4 (+2) ions to ~40 Mev, should in theory produce C^{12} (+6) ions of ~120 Mev. However, unpublished experiments with G. B. Rossi and A. Ghiorso[2] have shown that the energy spread of the internal carbon ion beam is wide, a most probable energy being perhaps nearer to 90 than to 120 Mev. Beam currents measured through 1.5 mils of tantalum absorber, corresponding to the passage of ions with kinetic energies exceeding ~80 Mev, have averaged between 0.01 and 0.1 μa.

Copper foils have been bombarded in the carbon beam, and bromine chemical fractions subsequently isolated. Their decay curves showed two activities, with half-lives of 95±3 minutes and 36±2 minutes, as shown in Fig. 1. The first of these is to be identified with the 1.7-hour bromine isotope discovered by Woodward, McCown, and Pool,[3] and assigned by them to Br^{75}, on the basis

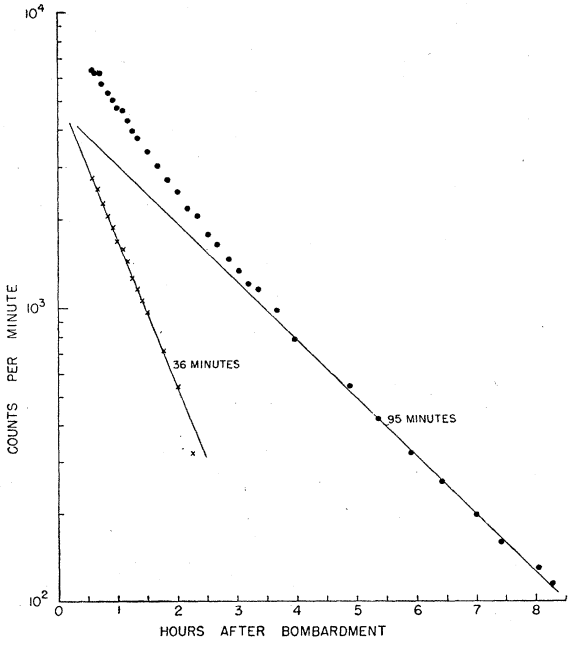

FIG. 1. Typical decay curve of bromine fraction from Cu+C^{12} bombardments.

of proton and deuteron bombardments of enriched Se^{74}. In the present experiments, the reaction producing this isotope would be $Cu^{65}(C, 2n)Br^{75}$. The 36-minute activity has not been reported previously.

The 16-hour positron emitter Br^{76} has not been observed in any carbon ion bombardments of copper. From the gross activity curves, which decay to background without tailing out into a longer component, a lower limit of ~30 can be set on the ratio of the $Cu^{65}(C, 2n)Br^{75}$ to the $Cu^{65}(C, n)Br^{76}$ reaction.

In an attempt to fix the isotopic assignment of the 36 minute bromine relative to 95 minute Br^{75}, carbon ion bombardments of isotopically enriched CuO targets[4] were made. The CuO samples carried the following analyses:

CuO I: Cu^{63}, 99.7±0.3%; Cu^{65}, 0.3%.
CuO II: Cu^{63}, 1.84±0.02%; Cu^{65}, 98.16±0.02%.

Br^{75} can be produced by carbon ions only from Cu^{65}, since a $Cu^{63}(C, \gamma)Br^{75}$ reaction would not be likely. Thus, from CuO I, any Br^{75} which is produced should have come only from the ~0.3 percent Cu^{65} remaining in that sample. One would then expect the ratio Br^{75} (from CuO II)/Br^{75} (from CuO I) to be ~300. Actually observed in two bombardments were ratios of 50 and 100, which, considering the experimental uncertainties in carbon ion beam current and chemical yields, are not inconsistent with the isotopic enrichment reported.

The cross sections for the $Cu^{65}(C, 2n)Br^{75}$ reaction and the $Cu^{65}(C, xn)$ 36 min $Br^{<75}$ reaction were roughly equal, indicating that the latter activity may be due to the $Cu^{65}(C, 3n)Br^{74}$ or $Cu^{65}(C, 4n)Br^{73}$ reaction. However, there was no appearance of the 7.1-hour Se^{73} in any of the bromine decay curves, so it is fairly certain that the 36-minute bromine does not decay through that state. In addition, the following evidence points to its assignment to Br^{74}: in spite of over a fiftyfold enrichment of Cu^{63} in CuO I as compared with CuO II, the ratio of 36 minute/95 minute activities was only slightly enhanced in CuO I, and the absolute yield of the 36-minute activity was lower by a factor of about 50 in CuO I than in CuO II, indicating that the 36-minute activity has been made in Cu^{63} by a reaction with a very low cross section, and hence may be assigned tentatively to Br^{74}, by the $Cu^{63}(C, n)Br^{74}$ reaction.

In carbon-ion bombardments of $Cu^{63}O$, but not in those of $Cu^{65}O$, a 4±1 minute bromine activity has also been observed but no further details are presently known about this activity.

I am greatly indebted to Drs. I. Perlman and M. I. Kalkstein for their helpful comments, and to G. B. Rossi and the crew of the 60-inch cyclotron for their help in making these bombardments.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Ghiorso, Thompson, Street, and Seaborg, Phys. Rev. **81**, 154 (1951).
[2] J. M. Hollander, University of California Radiation Laboratory Report UCRL-1395, June, 1951 (unpublished).
[3] Woodward, McCown, and Pool, Phys. Rev. **74**, 870 (1948).
[4] These enriched samples were kindly loaned by the Stable Isotopes Division of the Oak Ridge National Laboratory.

High-Energy (γ,d) Reactions*

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USING a technique which electronically separates deuterons from protons,[1] we have measured $(\gamma,d):(\gamma,p)$ ratios at 90° in the laboratory system using C, Cu, and Pb targets. Figure 1 shows the experimental arrangement. The γ-ray beam from the 310-Mev Cornell synchrotron strikes a target and the product particles are analyzed in a two-crystal telescope. The energy of the particle is measured in the second crystal, 5.5 g/cm² of NaI, and dE/dx of the particle is measured in the first crystal of 0.35 g/cm² of NaI. The pulses from the two crystals are multiplied electronically; the product pulse EdE/dx being approximately proportional to $M^{0.8}Z^2E^{0.2}$. The mass dependence of the product makes possible the identification of protons and deuterons, and since the product varies slowly with energy, a large range of energies can be examined at the same time.[2]

In practice, an energy interval is set by upper and lower biases on the second crystal, for example, 27–37 Mev for most of this experiment. The experiment is now sensitive to two groups of particles. Particles of group 1 have energies between 27 and 37 Mev after going through the first crystal and stop in the second crystal. Group 2 with energies between about 70 and 90 Mev for

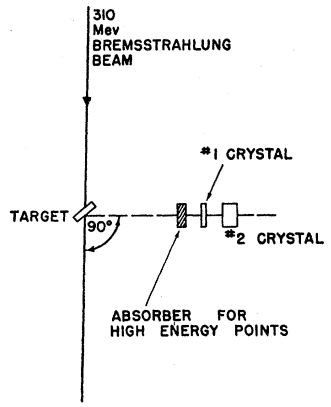

FIG. 1. Arrangement of apparatus.

protons and 115 and 145 Mev for deuterons go completely through the second crystal and lose 27–37 Mev in it. Since $dE/dx \sim M^{0.8}/E^{0.8}$, group 2 particles lose much less energy in the first crystal than do the particles of group 1. We are therefore able to discriminate against the second group by setting a lower limit to the pulses accepted from the first crystal. This technique provides a convenient method of obtaining a variable energy interval and at the same time eliminates the need for a separate anti-coincidence crystal.

The multiplication is accomplished essentially by charging a condenser at a rate proportional to the pulse height in one crystal and for a time proportional to the pulse height in the second crystal. The accumulated charge is then proportional to the product of the pulse heights. Figure 2 shows the distribution of

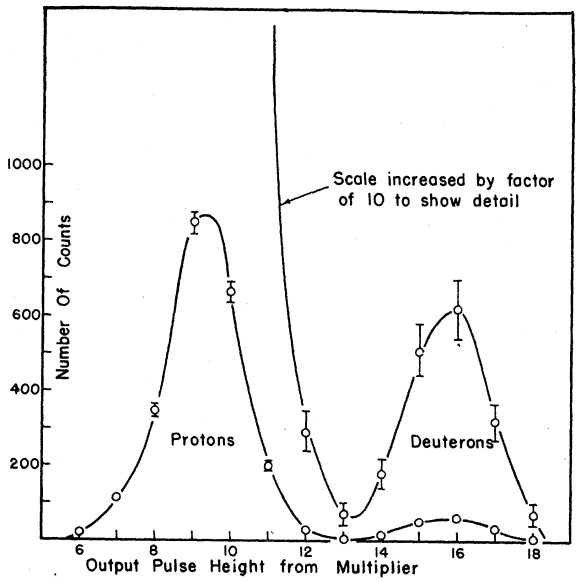

FIG. 2. Illustration of the resolution of the deuteron detector. The data above were obtained using a Cu target with the system sensitive to 43–51 Mev deuterons.