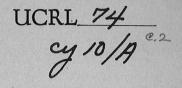# Lawrence Berkeley National Laboratory

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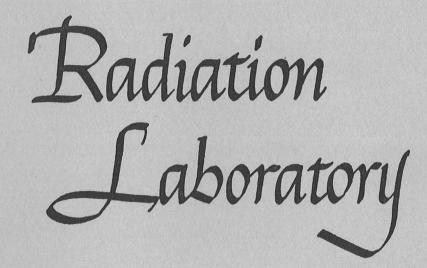https://escholarship.org/uc/item/0z02761w

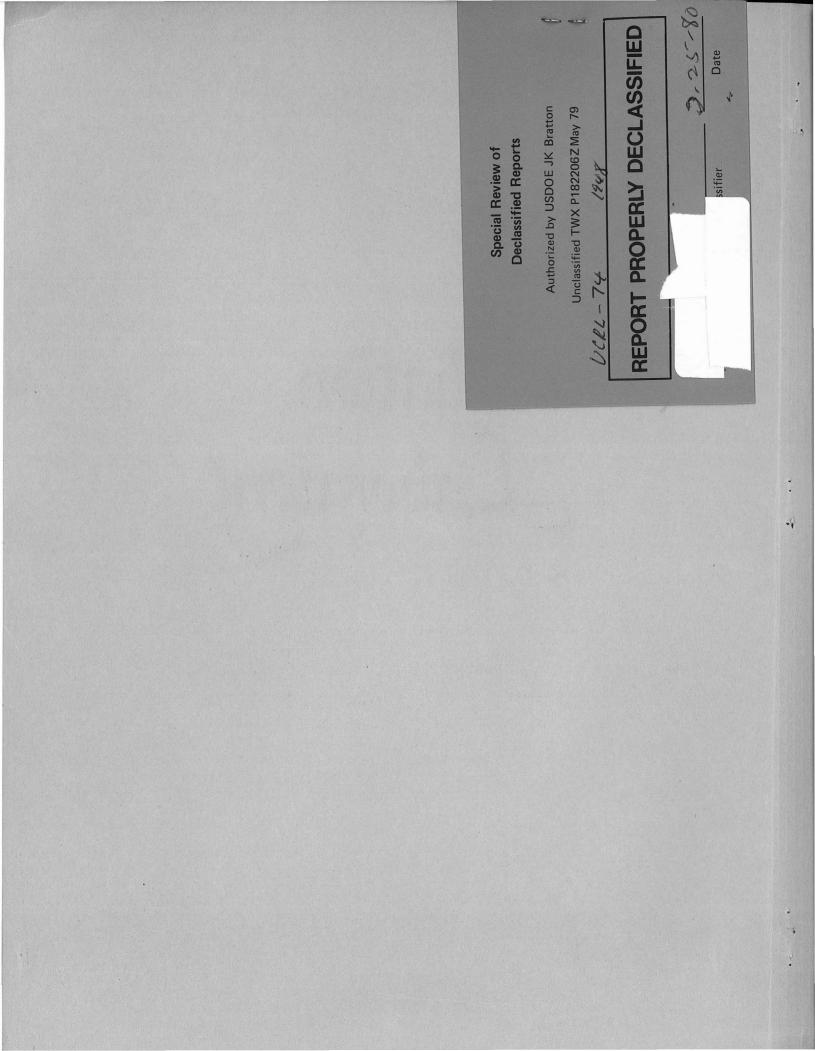**Author**
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# PRODUCTS OF HIGH-ENERGY DEUTERON
## AND HELIUM ION BOMBARDMENTS OF COPPER

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April 6, 1948

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## Abstract

The identity and relative yields of about twenty of the radioisotopes produced by the bombardment of natural copper with 190 Mev deuterons and 380 Mev helium ions have been determined. Two previously unreported isotopes were detected: $Zn^{62}$, decaying by orbital electron capture with a 9.5-hour half-life, and $Fe^{52}$, decaying by positron emission with a 7.8-hour half-life.

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This communication summarizes the preliminary observations made when natural copper (stable mass numbers 63 and 65) was bombarded with 190 Mev deuterons and 380 Mev helium ions produced by the 184-inch frequency-modulated cyclotron[2].   After a 10 to 40 minute bombardment with a beam of about 0.5

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(2)   Brobeck, Lawrence, MacKenzie, MacMillan, Serber, Sewell, Simpson and Thornton, Phys. Rev. 71, 449 (1947).

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microamperes for the deuterons or of unknown intensity for the helium ions, the spectrographically pure metallic copper target was dissolved in acid, inactive carrier elements added, and chemical separations performed until pure elemental fractions were isolated.  Aliquots of these fractions were evaporated on platinum foil discs and the rate of decay carefully followed with a thin-window (ca. 3 mg./cm$^2$ mica) Geiger-Müller counter.   Identification of radioactive product isotopes was made by these half-life determinations supplemented in most cases by at least one of the following methods: (a) observation of parent-daughter relationships when possible; (b) observation of the sign of the radiation by counting through a magnetic field; (c) rough energy determinations by counting through aluminum, beryllium or lead absorbers; and (d) differential counting through different absorbers. The results of the deuteron bombardments are summarized in the following table.

## Isotopes Observed as Products of the Bombardment
## of Natural Copper with 190 Mev Deuterons

| Isotope | Type of Radiation [3] | Half-life | | Yield [5] Relative to $Cu^{61}$ | Change in A and Z from $Cu^{65}$ | |
|---|---|---|---|---|---|---|
| | | Literature [4] | Observed | | A | Z |
| $_{30}Zn^{62}$ | (K) | – | 9.5 h. | 0.035 | –3 | +1 |
| $Zn^{63}$ | ($\beta^+$) | 38 m. | 36 m. | 0.05 | –2 | +1 |
| $_{29}Cu^{60}$ | ($\beta^+$) | 24.5 m [6] | ca. 25 m. | 0.3 | –5 | 0 |
| $Cu^{61}$ | $\beta^+$, (K) | 3.4 h. | 3.3 h. | 1.0 | –4 | 0 |
| $Cu^{62}$ | $\beta^+$ | 10.5 m. | ca. 11 m. | 2.3 | –3 | 0 |
| $Cu^{64}$ | ($\beta^+,\beta^-$,K) | 12.8 h. | 13 h. | 0.6 | –1 | 0 |
| $_{28}Ni^{57}$ | $\beta^+$ | 36 h. | 37 h. | 0.04 | –8 | –1 |
| $Ni^{65}$ | $\beta^-$ | 2.6 h. [7] | 2.5 h. | 0.04 | 0 | –1 |
| $_{27}Co^{55}$ | $\beta^+$ | 18.2 h. | 17 h. | 0.04 | –10 | –2 |
| $Co^{61}$ | $\beta^-$ | 1.8 h. [8] | 1.7 h. | 0.14 | –4 | –2 |
| $_{26}Fe^{52}$ | $\beta^+$ | – | 7.8 h. | 0.003 | –13 | –3 |
| $Fe^{53}$ | ($\beta^+$) | 8.9 m. | 9 m. | 0.07 | –12 | –3 |
| $Fe^{59}$ | $\beta^-$ | 47 d. | 49 d. | 0.07 | –6 | –3 |
| $_{25}Mn^{51}$ | ($\beta^+$) | 46 m. | 45 m. | 0.04 [9] | –14 | –4 |
| $Mn^{52}$ | $\beta^+$, (K) | 6.5 d. | 6 d. | 0.1 | –13 | –4 |
| $Mn^{56}$ | $\beta^-$ | 2.59 h. | 2.5 h. | 0.15 | –9 | –4 |
| $_{24}Cr^{49}$ | $\beta^+$ | 41.9 m. | 41 m. | 0.01 | –16 | –5 |
| $Cr^{51}$ | (K) | 26.5 d. | 27 d. | ca.0.02 [9,10] | –14 | –5 |
| $_{23}V^{48}$ | $\beta^+$, (K) | 16 d. | 16 d. | 0.05 [9] | –17 | –6 |
| $_{17}Cl^{38}$ | $\beta^-$ | 37 m. | 38 m. | 0.0005 | –27 | –12 |
| $_{15}P^{32}$ | ($\beta^-$) | 14.30 d. | 15 d. | 0.0005 [9] | –33 | –14 |

(3) Parentheses indicate that the sign of the radiation has not been directly observed in these investigations.

(4) Unless otherwise noted the reference is to Seaborg, Table of Isotopes, Rev. Mod. Phys. 16, 1-32, 1944.

(5) A rough estimate indicates that a relative yield of one is equivalent to a cross section of the order of $10^{-25}$ $cm^2$.

(6) Leith, Bratenahl, and Moyer, Phys. Rev. 72, 732 (1947).

(7) Conn, Brosi, Swartout, Cameron, Carter, and Hill, Phys. Rev. 70, 768 (1946).

(8) Parmley and Moyer, Phys. Rev. 72, 82 (1947).

(9) Results of only one bombardment. All other figures represent best values or averages resulting from two to seven bombardments.

10) Corrected for amount formed by $Mn^{51}$ decay.

Two previously unreported isotopes were found. Freshly precipitated zinc fractions showed a growth corresponding to ca. 11 minutes half-life, followed by a 9.5-hour decay. Removal of copper from the zinc fractions yielded in the copper fractions a pure 11-minute activity which was identified as $Cu^{62}$; the 9.5-hour activity was therefore assigned to $Zn^{62}$. The number of counts per minute of the 11-minute copper activity removed from the zinc fraction (extrapolated back to the time of separation) was the same within $\pm 10\%$ as the number of counts per minute of the 9.5-hour activity in the zinc-copper mixture immediately before copper-zinc separation. Since $Zn^{62}$ was thus apparently detected only by virtue of the activity of its daughter, it is presumed to decay by orbital electron capture; decay by a positron of energy too small to have been detected efficiently by our Geiger-Müller tubes is not ruled out, however. A 7.8-hour activity was noted in the iron fractions and was shown by iron-manganese separations to give growth to a 21-minute manganese daughter activity. An aluminum absorption curve of the parent-daughter equilibrium mixture showed, in addition to a component of ca. 2.3 Mev attributable to the 21-minute $Mn^{52}$, a component of ca. 0.55 Mev maximum energy presumably due to the 7.8-hour parent, assigned to $Fe^{52}$.

The yields for the radioisotopes of any one element increase as the

difference between the mass number of the product isotope and mass number of maximum stability for that element decreases; it seems probable that the total yield of stable isotopes is of the same order of magnitude as the total yield of radioisotopes. In the most extensively investigated region, from chromium through zinc, practically all known radioisotopes which could have been observed in view of half-life and experimental time considerations were identified. Intermittent deuteron bombardment of one target over a period of several months, in which the total bombardment was about 20 times that of the usual shorter bombardment, resulted in observation of long-lived activities ($\gtrsim$ 70 d.), which have not been positively identified, in the zinc, cobalt, manganese, and titanium fractions. Assuming that the activities in the zinc, manganese, and titanium fractions are due solely to $Zn^{65}$ (250 d $\beta^+$, K), $Mn^{54}$ (310 d K), and $Ti^{51}$ (72 d $\beta^-$), the maximum relative yields are calculated to be 0.007, 0.12, and 0.0005, respectively. Since three or four isotopes are probably contributing to the long-lived activity in the cobalt fraction, a relative yield figure is of no significance. It is noteworthy that little or no positron activity was found in the chlorine fraction; the yield of $Cl^{34}$ (33 m $\beta^+$) is $\leqslant$ 0.00005.

One bombardment with approximately 380 Mev helium ions (contaminated with about 20% deuterons) was conducted. The yields of the radioisotopes in the fractions investigated (copper, iron, manganese, chromium, and chlorine ) were in all cases except one within the range of the yields obtained from the several deuteron bombardments (within a factor of about 2). The exception was $Cl^{38}$, which was produced with a yield six times as great as that from deuteron bombardments.

cooperation in conducting the bombardments. The interest of Professor E. O. Lawrence and members of the Radiation Laboratory is gratefully acknowledged.