TABLE I. Isotopes observed as products of the bombardment of natural copper with 190-Mev deuterons.

| Isotope | Type of radiation[a] | Half-life Literature[b] | Half-life Observed | Yield[c] relative to $Cu^{61}$ | Change in $A$ and $Z$ from $Cu^{65}$: $A$ | $Z$ |
|---|---|---|---|---|---|---|
| $_{30}Zn^{62}$ | $(K)$ | — | 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.[d] | *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.[e] | 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.[f] | 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[g] | −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[g,h] | −14 | −5 |
| $_{23}V^{48}$ | $\beta^+, (K)$ | 16 d. | 16 d. | 0.05[g] | −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[g] | −33 | −14 |

[a] Parentheses indicate that the sign of the radiation has not been directly observed in these investigations.
[b] Unless otherwise noted the reference is to Seaborg, Table of Isotopes, Rev. Mod. Phys. **16**, 1–32 (1944).
[c] A rough estimate indicates that a relative yield of one is equivalent to a cross section of the order of $10^{-25}$ $cm^2$.
[d] Leith, Bratenahl, and Moyer, Phys. Rev. **72**, 732 (1947).
[e] Conn, Brosi, Swartout, Cameron, Carter, and Hill, Phys. Rev. **70**, 768 (1946).
[f] Parmley and Moyer, Phys. Rev. **72**, 82 (1947).
[g] Results of only one bombardment. All other figures represent best values or averages resulting from two to seven bombardments.
[h] Corrected for amount formed by $Mn^{51}$ decay.

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 as a result of the 7.8-hour parent, assigned to $Fe^{52}$.

The yields for the radio-isotopes 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 radio-isotopes. In the most extensively investigated region, from chromium through zinc, practically all known radio-isotopes 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 (>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 percent deuterons) was conducted. The yields of the radio-isotopes 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.

We wish to express our gratitude to Professor G. T. Seaborg for his advice and help in planning the experiments, and to the 184-inch cyclotron crew under the direction of Dr. D. C. Sewell and Mr. J. T. Vale for their cooperation in conducting the bombardments. The interest of Professor E. O. Lawrence and members of the Radiation Laboratory is gratefully acknowledged.

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## Notes on the Beta-Ray Spectra from Copper 64

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IN the investigation of beta-ray spectra one may meet with two possible sources of extraneous electrons: homogeneous internal conversion electrons, which are usually easily recognized as such, and electrons from internal pair production, which have a continuous distribution in energy. If pair electrons are present, and are not recognized as such, they may distort the experimentally obtained beta-ray distributions. This possibility is, therefore, worth excluding before experimentally obtained beta-ray spectra are compared with theoretical predictions.

Cook and Langer[1] have recently investigated the negatron and positron spectra from $Cu^{64}$ by means of a high resolution spectrometer[2] as a test of the Fermi theory of beta-decay.[3] They found in the case of the negatrons a total excess of 6 percent slow negatrons (i.e., below app. 200 kev); and in the case of the positrons a total excess of 9 percent slow positrons (i.e., below app. 250 kev) above the numbers predicted by the Fermi theory. On a Kurie plot[4] these deviations show up in the low energy region as positive deviations from the expected straight-line graph, already found by other investigators.[5]

If one assumes the decay scheme of $Cu^{64}$, as shown in Fig. 1,[6] one can easily calculate that the percentage excess of slow negatrons found by Cook and Langer represents

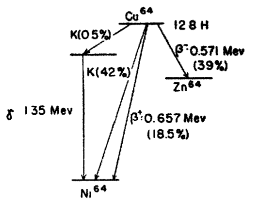


FIG. 1. Decay scheme of $Cu^{64}$.

2.5 percent of the total number of transitions and the excess of slow positrons 1.8 percent of all transitions. It seemed, therefore, worth while to investigate in this case the possibility that this excess might be caused by internal pairs, perhaps formed by a high internal-pair conversion of the 1.35-Mev gamma-ray. This would give rise to pairs of approximately 330-kev total energy, which is not far from the energy at which the excess of slow beta-particles becomes noticeable.

We have looked for pairs from $Cu^{64}$ (obtained through the Atomic Energy Commission from Oak Ridge) in a pair spectrometer of approximately 10 percent resolution for total pair energy. The total pair energy range covered was 100 to 400 kev. Our results show that in this range the number of pairs, if they exist, must be less than 0.2 percent of the total number of transitions, which is about 10 times too small to explain the effect noticed by Cook and Langer.

Incidentally, we have also looked for internal conversion electrons of the 1.35-Mev gamma-ray, using a conventional 180° type magnetic spectrometer of approximately 5 percent resolution. Since there is some question as to the exact energy of this gamma-ray, we have covered an electron range of 1.15 to 1.55 Mev. According to our results the internal conversion coefficient of the 1.35-Mev gamma-ray must be less than $5 \cdot 10^{-3}$.

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## Diffraction by Circular Disks and Apertures

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IN a recent Letter to the Editor, Storruste and Wergeland[1] have reported the acoustical cross sections for scattering and transmission by circular disks and apertures. These results appear to be in fairly good agreement with those previously reported by one of us.[2] At the time we reported these results Professor Zernike pointed out that Bouwkamp[3] had previously reached essentially the same conclusions. It is interesting to note that although all the above calculations have been made with the oblate spheroidal wave functions, Levine and Schwinger[4] have obtained the same results by variational methods.

Calculations for the electromagnetic case have been completed by the authors. The electromagnetic cross sections for scattering and transmission by circular disks and apertures have a wave-length dependence similar to that of the scattering cross section of a circular disk in a sound field. These calculations are for a normally incident plane wave. An expansion obtained by one of us (A. L.) makes possible discussion of the problem at any incidence. Details of these calculations will be reported soon.

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## Mean Life of Negative Mesons in Carbon

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LAST year Conversi, Pancini, and Piccioni[1] found that negative mesons decay in carbon, but not in iron. These results, which are important in the evaluation of the interaction of mesons and nucleons, have been confirmed and extended by other investigators.

In the present experiment, measurements are being made of the separate lifetimes of negative and positive mesons in graphite. The experimental arrangement is shown in Fig. 1. The mesons enter through the solid angle determined by counters $A$ and $B$. Coincidences $AB$ are formed with a resolving time of less than $\frac{1}{4}$ microsecond by using suitable pulse-forming preamplifiers ($P$) and a crystal diode coincidence circuit. Slow mesons are separated with respect to sign and deflected into their respective absorbing blocks ($G$'s) by the magnetic field ($F$), which was about 5000 gauss in iron. $AB$–$E$ triggers the 8-microsecond sweep of the servoscope. A pulse from $C$ or $D$ during the sweep unblanks the scope, and the horizontal position of the pulse on the scope gives the life of the meson. The data are recorded by continuous photography of the face of the scope. Decays

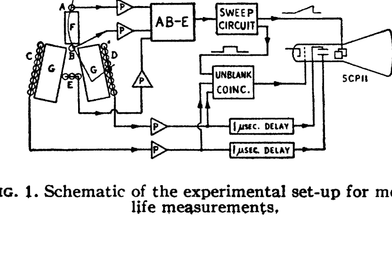


FIG. 1. Schematic of the experimental set-up for meson life measurements.