Artificial Radioactivity Produced by Protons

By the use of a beam of about one microampere of protons at an energy of 3.8 Mev, accelerated by the Princeton cyclotron,[1] we have found that Ni, Cu, Mg and Ag are strongly radioactive after bombardment. The following identifications are suggested for the radioelements formed.

Ni: Four periods are found in the decay of Ni bombarded with protons. The half-lives are 80 ± 2 seconds, 7.9 ± 0.6 minutes, 3.4 ± 0.1 hours, and 12.8 ± 0.3 hours. The relative initial intensities in a thick target, corrected to infinite bombardment time, are about 3:1:31:35, respectively. The three shorter periods all emit positrons, while the 12.8-hour period has been found to emit both electrons and positrons. The last activity is then almost certainly to be identified[2] with Cu^{64}, formed here by the reaction $Ni^{64}(p, n)Cu^{64}$. The 3.4-hour period can also be identified with some certainty[3] as Cu^{61}, formed from the stable isotope Ni^{61} by the (p, n) reaction. Two radioelements of approximately these periods were reported as formed by proton bombardment of Ni in the preliminary data of DuBridge and his collaborators,[4] but were not mentioned in their recent paper.[5]

While chemical identification of the two short periods has not been carried out, the fact that positrons are emitted makes it seem very likely that the radioelements are Cu isotopes, formed by the (p, n) reaction. Our decay curves give no evidence for a half-life of 10 minutes, which is that[6] of Cu^{62}, so that one of the short lived radioelements observed probably arises from Ni^{60}, and the other from Ni^{58}. We may tentatively assign the 80-second period to Cu^{58} and the 7.9-minute period to Cu^{60}, on the doubtful basis of relating the activity ratio of these two radioelements with the abundance ratio of Ni^{58} to Ni^{60}.

Cu: Copper bombarded with protons displays a moderately strong activity in which positrons are emitted. The half-life is 38 ± 1 minutes. This radioelement may be identified[7] as Zn^{63}, formed here by the reaction $Cu^{63}(p, n)Zn^{63}$.

Mg: Measurement of the activity of this element was not begun soon enough after bombardment to detect the presence of Al^{26}, which has a 7-second half-life[8] and could be formed here by the (p, n) reaction. The decay curves of activated Mg showed a fairly strong period of 20 ± 2 minutes, together with a much weaker activity of some hours half-life. The short period radioelement emits positrons and has been chemically identified as an Al isotope. It is presumably either Al^{24} or Al^{25}.

Ag: The decay curves in this element show a weak activity of a few minutes half-life, which has not been investigated, and a very strong activity of half-life 6.67 ± 0.06 hours. Chemical identification of the long lived radioelement shows that it is an isotope of Cd, presumably either Cd^{107} or Cd^{109}. The particles emitted are negative electrons, as has been shown by deflecting them in a magnetic field, and their energies, as measured by absorption in Al, are not greater than about 250 Kev. A very much weaker radiation with greater penetrating power (see Fig. 1) has a mass absorption coefficient in Al which is that of the $K\alpha$ radiation of Ag. There is some indication of a harder radiation still which is of such small intensity that we have not been able to investigate its absorption with the Lauritsen electroscope used in these measurements.

Since neither In^{109} nor In^{107} is a stable isotope, we tentatively regard the negative electrons emitted by this radioelement not as disintegration electrons, but as photoelectrons ejected by a gamma-radiation which follows extranuclear electron capture by the unstable Cd isotope. If the absorption measurements are correct in indicating that the K radiation of silver is also emitted, the production of this radiation is presumably accomplished in two ways; by the filling of the K shell in Ag after the capture by the unstable Cd nucleus of one of its own K electrons, and by the replacement of electrons which have been removed from the atom by the internal conversion process postulated to explain the negative electron emission from this radioelement. The harder radiation suggested by the absorption curve may be the unconverted fraction of the nuclear gamma-radiation postulated above. Rough considerations of intensity lead to the conclusion that the internal conversion coefficient for this gamma-radiation must be about 90 percent. The whole situation in this radioelement is similar to the case of Ga^{67} discussed by Alvarez.[9]

We are glad to be able to thank Mr. R. C. Newton, of the department of chemistry, for suggestions concerning the chemical separations, and Mr. John E. Walter for assistance in making the measurements.

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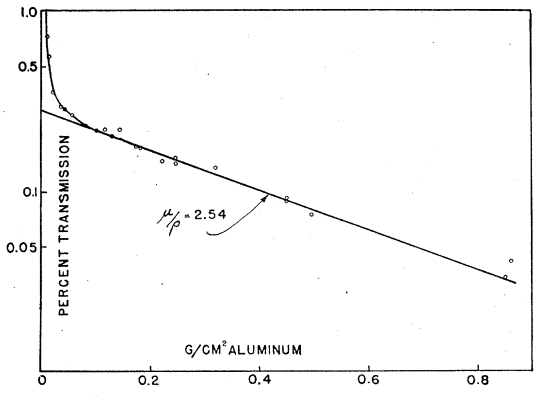

FIG. 1. Absorption in Al of the radiation from silver which has been bombarded with protons (6.67-hour period). The mass range of the electrons is seen to be about 70 mg/cm², while the mass absorption of the gamma-radiation is that of the $K\alpha$ radiation of Ag.

[1] M. G. Henderson and White, Rev. Sci. Inst. **9**, 19 (1938).
[2] Van Voorhis, Phys. Rev. **50**, 895 (1936).
[3] Thornton, Phys. Rev. **51**, 893 (1937); Ridenour and W. J. Henderson, Phys. Rev. **52**, 889 (1937).
[4] Livingston and Bethe, Rev. Mod. Phys. **9**, 245 (1937). See p. 317.
[5] DuBridge, Barnes, Buck, and Strain, Phys. Rev. **53**, 447 (1938).
[6] Heyn, Nature **138**, 723 (1936); Bothe and Gentner, Zeits. f. Physik **106**, 236 (1937); Ridenour and Henderson, reference 3.
[7] Pool, Cork and Thornton, Phys. Rev. **52**, 239 (1937). Also papers of reference 6.
[8] Frisch, Nature **133**, 721 (1934).
[9] Alvarez, Phys. Rev. **53**, 606 (1938).