The Use of Uranium Lead in the Assignment of Artificial Radioactive Isotopes

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Uranium lead and ordinary lead were bombarded with deuterons under the same conditions in order to establish from which of the stable lead isotopes the 3.3-hour Pb and 6.4-day Bi activities are produced. The intensities of the resulting radioelements were compared with the abundances of the isotopes. The 3.3-hour lead was found to be produced from Pb^{208} and the reaction must be Pb^{208}, *d-p*, Pb^{209}. The 6.4-day Bi is produced from Pb^{206}. Its assignment depends on the type of reaction; the more probable one is Pb^{206}, *d-n*, Bi^{207}.

IN order to assign mass numbers to the 3-hour lead and the 6-day bismuth isotopes studied in the preceding paper[1] we compared their intensities as produced in ordinary lead and in lead obtained from uraninite from Morogoro, Africa.[2] The two samples of lead were bombarded with deuterons under the same conditions and the ratios of the intensities of each of the two periods were calculated. These ratios should correspond to the ratios of percent abundances for the particular stable isotopes of lead from which the activity is produced. Table I gives the percent abundances and the ratios derived from them.

Since the uranium lead was obtained by chemical separation from uraninite, it contains the lead isotope, radium D, which decays to Pb^{206} by the following processes:

$$\underset{Pb^{210}}{RaD} \xrightarrow{\beta} \underset{22\text{ yr.}}{RaE} \xrightarrow{\beta} \underset{Bi^{210}\ 5\text{ days}}{RaF} \xrightarrow{\alpha} \underset{Po^{210}\ 140\text{ days}}{RaG}\ Pb^{206}.$$

After the bombardment a chemical separation of the lead and bismuth was made. Since the RaD was in equilibrium with its daughter products, a separation of bismuth from the lead takes along any RaE present and leaves the RaD with the lead. From this the RaE grows with its 5-day recovery period.

It was necessary, then, to remove the RaE from the lead shortly before bombardment, since its presence would mask the 6.4-day Bi. The pre-separation was made by dissolving the uranium lead chloride in hot water, adding $BiCl_3$, and reducing with alkaline formaldehyde. The metallic bismuth was filtered off and the lead in the filtrate was oxidized to PbO_2 with chlorine.

Known weights of this PbO_2 and ordinary PbO_2 were bombarded, the energy of the beam, 9.5 Mev, and the total bombardment, 1.5 μah, being the same in both cases. The PbO_2 was dissolved in HCl and a known amount of $BiCl_3$ was added as carrier. Both elements were separated by the methods described in the preceding paper. The weights and activities of the resulting $PbSO_4$ and BiOCl were determined. The weight of BiOCl was compared with the original amount of Bi added giving the percent recovered.

The lead fraction from the uranium lead (measured on the Geiger-Mueller counter) showed the decay of the 3-hour period, followed by an increase due to the recovery of RaE (see Fig. 1). The beta-radiation from RaD is extremely soft and only a very small fraction of the particles are counted under the experimental conditions. The total natural activity can be expressed by the formula $A=E(1-e^{-\lambda t})+D$, in which E is the limiting value of the recovering activity, RaE, λ its decay constant, and D is a constant activity. Values for E and D calculated

TABLE I. *Isotopic composition of the uranium lead and ordinary lead.*

LEAD	204	206	207	208	REF.
Morogoro	0.0%	93.1%	6.9%	0.0%	Aston[1]
Morogoro	0.001	94.20	5.63	0.17±0.02	Nier[2]
Ordinary	1.48	23.59	22.64	52.29	Nier[3]
Ratio	0.0007	3.99	0.249	0.00325	Nier

[1] F. W. Aston, Proc. Roy. Soc. **A140**, 535 (1933).
[2] A. O. Nier, Phys. Rev. **55**, 153 (1939).
[3] A. O. Nier, J. Am. Chem. Soc. **60**, 1571 (1938).

[1] K. Fajans and A. F. Voigt, Phys. Rev. **60**, 619 (1941).
[2] O. Hönigschmid and S. Horowitz, Monats. f. Chem. **36**, 355 (1915). I am indebted to Professor Hönigschmid for this preparation. K. F.

from the growth curve A, Fig. 1 (followed for 70 days), were used for numerical extrapolation (curve B). Subtraction from the total curve (C), gives the decay of the 3-hour activity (D).

The Bi activity was corrected (25–50 ct./min. in the different experiments) for the growth of the RaE during the interval of about an hour between its separation from the lead and the end of the bombardment. The intensities of all of the samples were extrapolated to the end of bombardment.

Two independent comparisons of the normal and uranium lead were made. They are not comparable with each other due to a different position of the beam on the target. In experiment 1 the weight of Bi was not determined, and in 2a, the activity of the lead could not be evaluated accurately, due to an interfering short period impurity. For these reasons these two parts have been rejected. The results are shown in Table II.

The intensities of the two periods produced in the various samples were corrected for the different amounts bombarded and recovered and gave the ratios, which are listed in Table III with the nearest ratio expected from the isotopic abundances (see Table I).

As shown in Table I, there is a great difference in the magnitude of the ratios expected, so that an agreement in order of magnitude is all that is necessary for establishing the isotopes from

TABLE II. *Weight and activity of bombarded samples.*

Exp.	Lead Used	Weight Bombd.	Wt. of Pb Measured	Activity of Pb	Percent Bi Recovered	Activity of Bi
1	Ord.	0.0375 g	0.0341g	4.3×10^5 ct./min.		409 ct./min.
	U		0.0130	5.7×10^2		
2	Ord.	0.0365	0.0354	5.3×10^5	70	660
	a *U*	0.0365			69	2.64×10^3
	b *U*	0.0385	0.0316	2.1×10^3	67	2.70×10^3

TABLE III. *Comparison of activity and abundance ratios.*

Period	Exp.	Activity Ratio U Pb/Ord. Pb	Abundance Ratio U Pb/Ord. Pb	Expected for Production from
3-hr. Pb	1	0.0035	0.0033 ± 0.0003	208
	2b	0.0045		
6-day Bi	2a	4.07	3.99	206
	2b	4.04		

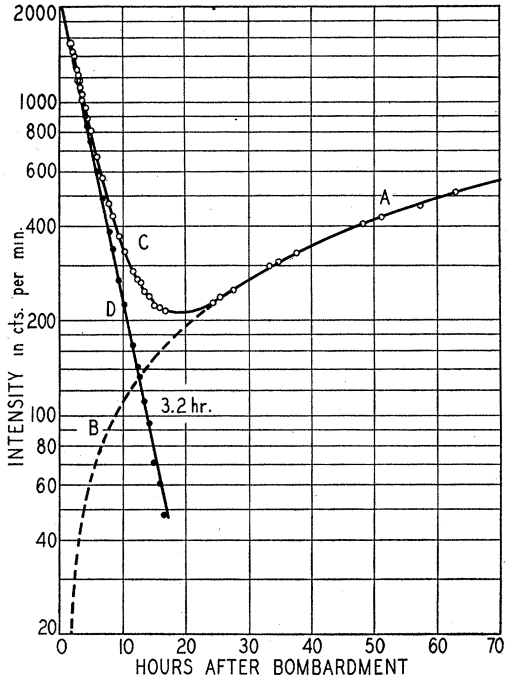

FIG. 1. Decay of Pb^{209} and growth of RaE after bombardment of uranium lead.

which the activities are produced. The two values for lead in Table III agree sufficiently well with the value expected to make certain that the 3-hour lead is produced from Pb^{208}. The process must, therefore, be Pb^{208}, d-p, Pb^{209} as proposed by Thornton and Cork.[3] The two values for bismuth leave no doubt that the 6.4-day bismuth is produced from Pb^{206}. Since the excitation function of this activity seems to be that for a d-n reaction (see the preceding paper), the 6.4-day Bi can be assigned, at least provisionally, to Bi^{207}.

The radioactive samples described in this and the foregoing paper were obtained from the cyclotron of the Physics Department. We wish to express our appreciation to Professor J. M. Cork for his interest and to the other members of the cyclotron group for conducting the bombardments. The investigations were made possible by grants from the Horace H. Rackham Trust Fund.

[3] R. L. Thornton and J. M. Cork, Phys. Rev. **51**, 383 (1937).