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Roger T. Batzel and Glenn T. Seaborg

May 29, 1950

Berkeley, California

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"FISSION" OF MEDIUM WEIGHT ELEMENTS

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The fission reaction has been observed with high energy accelerator projectiles for elements as light as tantalum[1] but has not been reported for medium weight elements. The present note presents evidence for the occurrence of reactions which are probably most properly described by the term "fission" and which seem to occur with very small yield throughout the region where this type of reaction is only slightly exoergic or even endoergic with respect to mass balance.

In the course of detailed investigation of the spallation of copper and the variation of the product yields with energy of the bombarding particle the threshold for formation of radioactive Cl^{38} (38-minute half-life) from elemental copper was studied. The energetically most economical way in which Cl^{38} might be formed by spallation reactions is by emission from the bombarded copper nucleus of nucleons in groups such as alpha-particles instead of single nucleons. The energetic requirements for the reaction $Cu^{63}(p,pn6\alpha)Cl^{38}$, in which the maximum number of alpha-particles are emitted, include (1) the mass difference between the reactants and the products and (2) the excitation energy which the alpha-particles must have in order to pass over the coulombic barrier. Since the reaction is endoergic with respect to atomic masses, about 50 Mev must be supplied by the impinging proton to make up the mass difference. If the alpha-particles are considered as coming out consecutively, a value of about 50 Mev can be obtained for the coulombic requirement and thus the threshold for this spallation reaction is roughly 100 Mev.

The production of Cl^{38} was definitely observed at proton bombardment energies beginning at about 60-70 Mev with a cross section of some 10^{-32} cm^2 which increased smoothly with energy to about 10^{-31} cm^2 at 100 Mev. The identification was made in all cases through chemical separation, measurement of half-life with a Geiger counter and observation of the sign of the beta-particles with a simple beta-ray spectrometer. The possibility that the observed activity might be due to impurities in the copper was eliminated through analysis by radioactivation methods for all possible impurities which might account for the observed yield of Cl^{38}. In order to explain the low threshold it must be assumed that substantially larger particles than alpha-particles are emitted and the reactions are therefore of a type which might more properly be termed fission. As an example, the extreme reaction $Cu^{63} + p \longrightarrow Cl^{38} + Al^{25} + n$, which is energetically most economical but still endoergic, has a threshold of about 50 Mev as calculated by adding the amount of energy necessary to make up the mass difference to the excitation energy required for the potential barrier assuming that the fragments are spherical and tangent at the nuclear radii (taken as $1.48 \times 10^{-13} A^{1/3}$ cm). This calculated threshold is admittedly very rough, but illustrates that the threshold for this type of reaction is definitely lower than for the above described spallation reaction. The cross section is calculated on the basis of the single isotope observed and does not correspond to a total fission cross section, in the sense that the term is ordinarily used, where the yield of all the fission products is summed.

This result made it seem worthwhile to investigate other elements in the middle portion of the periodic system in order to see whether analogous reactions might occur as a general rule. Bromine was bombarded and the variation with energy of the yield of radioactive Sc^{44} (3.9-hr. isomer) was studied. The threshold for the reaction $Br^{79}(p,p7n7\alpha)Sc^{44}$ is about 180 Mev and that for $Br^{79} + p \longrightarrow Sc^{44} + P^{34} + 2n$ is about 80 Mev calculated as above. The Sc^{44} was observed with proton energies of 125 and 140 Mev with cross sections of about 10^{-32} cm^2, with the value at the higher energy several times that at the lower energy, and the yield was too small to measure at 70 Mev. Special purity ammonium bromide was synthesized and used in all bombardments.

The comparable reactions for silver, $Ag^{107}(p,p6n10\alpha)Co^{61}$ and $Ag^{107} + p \longrightarrow Co^{61} + Sc^{45} + 2n$, have calculated thresholds of about 210 and 60 Mev, respectively. In this case the fission reaction is exoergic by about 10 Mev. The isotope Co^{61} (1.8 hours) was observed at an energy of 180 Mev with an approximate cross section of 10^{-32} cm^2 based on elemental silver, but the results must be termed borderline due to the difficulty in resolving the Co^{61} due to the silver from that formed by a small amount of copper impurity. Radioactivation methods were used to determine the amount of copper present. Unfortunately, the yield of Co^{61} from the copper impurity was about as much as that from the silver itself.

The formation of gallium isotopes from tin bombardment was also studied, and isolation of the gallium fraction showed the characteristic activities of Ga^{66} (about 9 hours) and Ga^{72} (about 14 hours). The calculated threshold for $Sn^{118}(p,7n10\alpha)Ga^{72}$ is about 230 Mev and that for the reaction $Sn^{118} + p \longrightarrow Ga^{72} + Ca^{45} + 2n$ is about 70 Mev; the fission reaction is exoergic by about 10 Mev. The Ga^{66} and Ga^{72} were observed at energies of 150 and 180 Mev with cross sections based on elemental tin of about 10^{-32} cm^2 and with the values at the higher several times those at the lower energy; the yield at 100 Mev was too small to identify and no yield was detectable at 80 Mev.

Apparently, when the energy threshold requirements are met, large fragments are emitted among the competitive products of nuclear reactions throughout the entire range of atomic numbers of the elements. This is certainly not surprising and the measured yields reported here seem to be quite reasonable. It seems certain that the size of the fragments varies continuously from those (neutrons, protons, deuterons, alpha-particles, etc.) which accompany what we for convenience call spallation reactions, through intermediate sizes (for example,[2,3] Li^8, etc.), and on up to sizes such that the nucleus is split essentially into several pieces of comparable weight. Apparently a number of reactions in which there occurs the latter type of nuclear splitting have been observed in the present investigation and perhaps the term "fission" is as proper a name as any to apply to this process.

It should be emphasized again that the above cross sections are calculated on the basis of the single isotope observed and do not represent the total fission cross sections for the given elements in the sense that this term is ordinarily used. It should also be pointed out that the number of cases in which similar reactions can be studied at present is very limited due to the strict requirements on purity of the bombarded substance, the high factor of radioactive purification necessary, and the sensitivity needed in detecting the product isotope.

The bombardments were carried out on the 184-inch cyclotron, and the required energy was obtained by adjusting the distance of the target from the periphery of the tank. We wish to thank Mr. James T. Vale and the group operating the 184-inch cyclotron for the irradiations performed in the course of these studies. This work was performed under the auspices of the U. S. AEC.

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[1] Perlman, Goeckermann, Templeton, and Howland, Phys. Rev. 72, 352 (1947).

[2] S. Wright, Phys. Rev. 77, 742 (1950)(A).

[3] L. Marquez and I. Perlman, unpublished work (1950).