

### Fission of Bismuth, Lead, Thallium, Platinum, and Tantalum with High Energy Particles\*

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THE 184-inch Berkeley frequency-modulated cyclotron produces deuterons, helium ions, and neutrons of energies up to 200, 400, and 100 Mev, respectively. Nuclear fission in elements covering the range of atomic numbers 83 (bismuth) to 73 (tantalum) has been observed with one or more of the above projectiles. Fission was determined by chemical identification of radioactive fission products.

Although a number of the fission products characteristic of slow neutron fission of uranium are found, the fission reaction on these light elements with high energy particles differs in some important respects. There is no evidence for well-defined asymmetric cleavage with a deep valley at the midpoint of the yield curve as is the case with slow neutron fission. Another difference is the appearance in good yield of light isotopes of a given element, and undoubtedly the formation of stable isotopes as primary fission products is not unusual. For example, the shielded isotope  $\text{Br}^{82}$  is formed in comparable yield to  $\text{Br}^{83}$  with 400 Mev helium ions and 200 Mev deuterons on bismuth, while the relative yields are 1 to  $10^4$  for these isotopes in the slow neutron fission<sup>1</sup> of uranium. In the bombardment of bismuth and lead with 400 Mev helium ions, no measurable amount of  $\text{Ba}^{140}$  (formed in highest yield with slow neutrons on uranium) was found, but an activity which is probably<sup>2</sup>  $\text{Ba}^{133}$  was noted. This isotope is not found at all in the fission of uranium with slow neutrons as it falls well down among the lightest stable isotopes of barium.

It has not been possible, thus far, to compare accurately yields from different bombardments because of the inability to determine the beam strength. However, certain trends appear to be definite: The probability of the fission reaction for a given projectile drops off as the target atomic number decreases from bismuth to tantalum. That for a given target element the fission yield decreases as the projectile energy decreases is indicated by the decrease in yield of bromine activities from bismuth fission as the deuteron energy is varied from 200 to 50 Mev. The distribution of fission products changes in varying the projectile energy since the ratio of  $\text{Br}^{83}$  to  $\text{Br}^{82}$  was 2 for 200 Mev deuterons on bismuth and 100 for 50 Mev deuterons on bismuth.

Table I shows fission products found from the reaction of 400 Mev helium ions with bismuth and the relative yields of these isotopes. The radioactive properties checked reasonably well those previously reported for these iso-

TABLE I. Relative yields of fission products from 400 Mev helium ions on bismuth.

Ga <sup>72</sup>	22	Mo <sup>99</sup>	480
Br <sup>82</sup>	150	Ru <sup>106</sup> →Rh <sup>105</sup>	240
Br <sup>83</sup>	390	I <sup>131</sup>	8
Sr <sup>91</sup> →Y <sup>91</sup>	540	Ba <sup>133</sup>	34
Y <sup>90</sup>	1400		

TABLE II. Summary of irradiations in which fission was observed

Target	Projectile	Energy (Mev)
Bi	$\alpha$	400
Bi	$d$	200, 150, 90, 70, 50
Bi	$n$	100
Pb	$\alpha$	400
Pb	$d$	200
Pb	$n$	100
Tl	$\alpha$	400
Tl	$d$	200
Pt	$\alpha$	400
Ta	$\alpha$	400

topes.<sup>1,2</sup> The yields are expressed in arbitrary units. It is of interest that  $\text{Ba}^{140}$  was not present in detectable amount.

The conditions of irradiation that were tried and under which fission was observed in all cases are summarized in Table II.

It is of interest to speculate on the mechanism of the fission in view of the high degree of excitation of the compound nucleus. Since the probability of fission would increase with a greater (charge/mass) ratio, and since it is known<sup>3</sup> that large numbers of neutrons may be ejected from such highly excited nuclei, it seems likely that the actual fission reaction is preceded, on the average, by the boiling-off of a large number of neutrons. Some experimental evidence supporting this view is the appearance of light isotopes for a given element in a few cases and the finding that the most probable fission results in products the sum of whose masses lies well below that of the target mass number. However, the same observations would result if the fission reaction would occur first with the fragments still in highly excited states after dissipation of their kinetic energy.

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<sup>1</sup> Plutonium Project compilation of nuclei formed in fission. J. Am. Chem. Soc. **68**, 2411 (1946).

<sup>2</sup> G. T. Seaborg, "Table of Isotopes," Rev. Mod. Phys. **16**, 1 (1944).

<sup>3</sup> B. B. Cunningham, H. H. Hopkins, M. Lindner, D. R. Miller, P. R. O'Connor, I. Perlman, G. T. Seaborg and R. C. Thompson. Paper to be given before Stanford University meeting of the American Physical Society, July 11-12, 1947.

### The Radiations from 60-Day Ir<sup>192</sup> and 27-Day Pa<sup>233\*</sup>

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THE 180° beta-ray spectrometer which was used in the determination of the maximum energy of the beta-ray spectrum of  $\text{C}^{14}$ , described in a previous letter, has been used to investigate the conversion electron and beta-ray spectrum of 27-day  $\text{Pa}^{233}$ . This spectrometer, and an additional photographically recording spectrograph, were