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 Br^{82} is formed in comparable yield to 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[1] of uranium. In the bombardment of bismuth and lead with 400 Mev helium ions, no measurable amount of Ba^{140} (formed in highest yield with slow neutrons on uranium) was found, but an activity which is probably[2] 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 Br^{83} to 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 isotopes.[1,2] The yields are expressed in arbitrary units. It is of interest that Ba^{140} was not present in detectable amount.

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

Ga^{72}	22	Mo^{99}	480
Br^{82}	150	$Ru^{105}\rightarrow Rh^{105}$	240
Br^{83}	390	I^{131}	8
$Sr^{91}\rightarrow Y^{91}$	540	Ba^{133}	34
Y^{90}	1400		

Table II. Summary of irradiations in which fission was observed

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

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[3] 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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[1] Plutonium Project compilation of nuclei formed in fission. J. Am. Chem. Soc. **68**, 2411 (1946).

[2] G. T. Seaborg, "Table of Isotopes," Rev. Mod. Phys. **16**, 1 (1944).

[3] 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^{192} and 27-Day Pa^{233}*

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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 C^{14}, described in a previous letter, has been used to investigate the conversion electron and beta-ray spectrum of 27-day Pa^{233}. This spectrometer, and an additional photographically recording spectrograph, were

TABLE I. Gamma-rays and conversion lines in $_{91}Pa^{233}$.

Gamma-ray	Conversion lines observed	Energy of conversion lines (Mev)	Energy of gamma-rays (Mev)
1	*K* *L* *M*	0.193 0.289 0.305	0.309 0.310 0.310
2	*K* *L*	0.222 0.318	0.337 0.339
3	*K* *L*	0.183 0.277	0.298 0.298
4	*L* *M*	0.063 0.081	0.084 0.083

employed to analyze the spectrum of the 60-day Ir^{192} activity.

The data on the conversion electrons from Pa^{233} are summarized in Table I. The end point of the continuous spectrum of the Pa^{233} is completely masked by a conversion line, and consequently it is difficult to estimate the maximum energy more accurately than to say that it is approximately 0.2 Mev. These beta- and gamma-ray energies are in substantial agreement with the values reported by Haggstrom,[1] who found conversion lines indicative of only three gamma-rays, but suggests that a fourth might exist.

The beta-ray and conversion electron spectrum of the 60-day Ir^{192} activity consists of a large number of conversion lines superimposed on what appears to be a simple continuous spectrum. The maximum energy of the spectrum, determined from a Kurie plot constructed from data taken with the 180° spectrometer, is 0.67 Mev. This value would be accurate to 2 percent if the presence of the conversion lines near the high energy end of the spectrum did not introduce the possibility of a larger error. Because of these lines the shape of the spectrum is difficult to ascertain. Consequently, one cannot exclude the possibility that the spectrum consists of several components, nor can one use it to make a theoretical analysis based on its shape.

TABLE II. Gamma-rays and conversion lines in $_{77}Ir^{192}$.

Gamma-ray	Conversion lines observed	Estimated intensity of conversion lines	Energy of conversion lines (Mev)	Energy of gamma-rays (Mev)
1	*K*	Very faint	0.121	0.199
2	*K*	Very faint	0.124	0.202
3	*K* *L*	Faint Very faint	0.128 0.193	0.205 0.205
4	*K* *L* *M*	Medium Faint Faint	0.131 0.194 0.202	0.209 0.208 0.205
5	*K* L_{I+II} L_{III} *M*	Strong Medium Faint Faint	0.217 0.281 0.284 0.293	0.295 0.295 0.296 0.296
6	*K* L_{I+II} L_{III}	Strong Medium Faint	0.229 0.295 0.297	0.307 0.308 0.308
7	*K* L_{I+II} L_{III} *M* *N*	Very strong Medium Faint Faint Very faint	0.237 0.303 0.305 0.314 0.316	0.316 0.317 0.316 0.316 0.317
8	*K* L_{I+II} L_{III}	Strong Faint Very faint	0.390 0.456 0.457	0.468 0.469 0.469
9	*K*	Very faint	0.410	0.488
10	*K* *L*	Faint Very faint	0.513 0.580	0.591 0.593
11	*K* *L*	Faint Very faint	0.529 0.595	0.607 0.608
12	*K*	Very faint	0.537	0.615

The conversion lines were studied with the photographic spectrograph, and the results are summarized in Table II. These results are in agreement with, but are more accurate than, those obtained with the 180° counter spectrometer. The accuracy of the gamma-ray energies for both the Pa^{233} and Ir^{192} is approximately 2 percent. The energy differences of the observed lines agree best with the differences between the electronic levels of Pt, and therefore it was assumed that all of the conversions take place in the Pt atom formed by beta-decay.

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* A detailed description of this work and of the spectrometer used is contained in Plutonium Project Report CP-3702 which is to appear in Division IV of the Manhattan Project Technical Series as part of the contribution of Clinton Laboratories. This work was done under the auspices of Manhattan District Contract W 7405-eng 39.

[1] E. Haggstrom, Phys. Rev. **59**, 322 (1941).

On a Connection between the Fountain Effect, Second Sound, and Thermal Conductivity in Liquid Helium II

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UNDER the above title, Lothar Meyer and William Band[1] advanced the assumption that "in the absence of constriction, the internal forces responsible for the fountain effect are still present, and produce an internal momentum density *M*." They conclude that there exists a wave equation for the temperature *T* "similar" to second sound, with the velocity $c_2(T)$ increasing up to the λ-point. Since this is in conflict with experiments according to which $c_2(T)\rightarrow 0$ as $T\rightarrow T_\lambda$, Meyer and Band conclude that the disagreement is due to irreversible effects. Their reason seems to be the resemblance between the curves representing $c_2(T)$ and $\mu(T)$, the latter being the fountain pressure measured in not very thin capillaries where irreversible effects make their appearance.

The following points should be raised in connection with these ideas:

The assumption that the fountain pressure exists in helium II far from solid walls is correct,[2,3] but Eq. (1), which Meyer and Band deduce from this, is not. The correct equation should read in Meyer and Band's notation:

$$\mu\nabla T=\nabla p=-(\rho/\rho)_s d\mathbf{M}/dt. \qquad \text{(1a)}$$

Equation (1a) differs by the factor ρ/ρ_s from Eq. (1) of Meyer and Band. Equation (1a) has been given[2] and derived[3] from the point of view of the theory of the Bose-Einstein liquid. Actually it can be derived also from more general assumptions with quasi-thermodynamical methods.[4] The factor ρ/ρ_s assures that $c_2\rightarrow 0$ for $T\rightarrow T_\lambda$ as required by