

sideration and of the ratio of the momentum transfer, the calculation of the decrease of the force is practically impossible. We can compute only whether the measured decrease of the total force *can* be caused by a decrease of the gas pressure.

For this purpose we shall take the forces at 15 amp. measured by Tanberg in vacuum and by Robertson at 1 mm Hg for a copper arc indicated in Fig. 4 of Robertson's paper. We assume that the transfer of the momentum of the stream to the gas diminishes the gas pressure to one-half. The measured forces in vacuum and at 1 mm Hg are 270 dynes and 160 dynes, respectively. The reduction is 110 dynes and the reduced gas pressure must then be effective on 0.168 cm². It naturally must be not larger than the area of the face of the cathode spot but may be larger than the area of the cathode spot. The face of the cathode in the experiments of Robertson had an area of 0.316 cm². The area of the cathode spot is 0.00105 cm² at 15 amperes if we calculate it with the ratio of 0.007 mm² amp. measured in vacuum by Tanberg and Berkey. At 1 mm Hg the current density is rather higher and the area of the cathode spot therefore smaller. We see that the calculated area lies between the two limits. The explanation seems therefore to be possible.

Lamar⁴ also has pointed out that the absence of the force on the cathode in an arc at higher gas pressures may be due to the compensating effect of holding back the gas pressure from the cathode spot. But, according to his opinion this effect occurs as the result of convection currents set up around the cathode if this is of relatively small dimensions and therefore can not occur if the cathode has a large surface area.

Now, if my explanation of the effect is right the compensating effect is not confined to small cathode areas because the reduction of the gas pressure in front of the cathode spot and its near surroundings does not augment the gas pressure on areas of the cathode which lie further away from the cathode spot and because the high velocity stream is only slowed down by the gas and is not reflected back to the cathode. On the contrary for the full development of the compensating effect the area of the cathode must be larger than a certain minimum.

In conclusion I should like to thank Dr. F. Luedi for his suggestion to explain the results obtained by Robertson.

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² Risch, Helv. Phys. Acta **4**, 122 (1931); Risch and Luedi, Zeits. f. Physik **75**, 812 (1932); Mason, Trans. A. I. E. E. p. 245 March, (1933).

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⁴ Compton, Proc. Nat. Acad. Sci. **18**, 711 (1932).

Induced β -Activity of Uranium by Fast Neutrons

In the course of experiments on the fission of uranium by fast neutrons,¹ besides fission products the uranium fraction showed a β -activity with a period 6.5 days.

This activity was induced appreciably only by fast neutrons obtained by bombarding lithium with 3-Mev. deuterons from our cyclotron. The experimental procedure was as follows.

A few grams of uranium oxide, U₃O₈, carefully purified and freed from its disintegration products were exposed to fast neutrons for more than fifty hours. After the exposure, a uranium fraction (U₃O₈) was separated and purified from all possible elements produced by fission as well as from its own disintegration products. The most care was given to the removal of lanthanum from the sample, the procedure taking as long as one day. The activity of the irradiated uranium was compared with that of a nonirradiated sample, in order to subtract the growing β -activity due to disintegration products of uranium. The difference thus obtained shows a 6.5-day period. This activity is probably due to U²³⁷ produced from U²³⁸ through loss of a neutron, as in the case of the production of UY from thorium.² If this is the case, we have here a member of the missing radioactive family $4n+1$.

The sign of the β -rays was shown to be negative and consequently we suspected the production of a radioactive element of atomic number 93, the chemical properties of which are probably homologous to rhenium. From the decay curve it is clear that its period must be very long, if it exists. To search for such an element, the irradiated uranium oxide, which was freed from fission products as well as its own disintegration products as above mentioned, was left for about 7 days, and was then dissolved in nitric acid. The solution, after an addition of perrenic acid, was treated with ammonium sulphide and then acidified with sulphuric acid. The precipitated rhenium sulphide, after the removal of contaminated sulphur by carbon bisulphide, was examined for β - and α -activities. Neither of them could be found within the error of our experiments. We may thus conclude, as in the case of 23-minute uranium,³ that the 6.5-day uranium decays also into a very long-lived 93 element. The detailed accounts of the experiments will be given elsewhere.

The above investigations were carried out as a part of the work of the Atomic Nucleus Sub-Committee of the Japan Society for the Promotion of Scientific Research. We acknowledge the assistances given by our laboratory colleagues in connection with the irradiation of samples and by Messrs. N. Saito and N. Matuura regarding the chemical separations.

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¹ Y. Nishina, T. Yasaki, H. Ezoe, K. Kimura and M. Ikawa, Nature **144**, 547 (1939); Nature, in press (1940).

² Y. Nishina, T. Yasaki, K. Kimura and M. Ikawa, Nature **142**, 874 (1938).

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Anomalous Dispersion and Absorption of Electric Waves in Solutions of Amino-Acids and Dipeptides

The dielectric constants and absorption coefficients of aqueous solutions of several amino-acids and dipeptides, listed in Table I, have been measured for electric waves of $\lambda=25.5$ cm ($\nu=1.18 \times 10^9$ cycles). The method used was a modification of Drude's second method. The waves were generated as described earlier.¹ The table shows the results obtained: $\Delta\epsilon'/c$ is the so-called dielectric increment per mole and $\Delta\epsilon''/c$ is the absorption coefficient increment per mole; ϵ' and ϵ'' being the real and the imaginary parts of the dielectric constant $\epsilon=\epsilon'-i\epsilon''$. The increments $\Delta\epsilon_0/c$ of the static dielectric constant per mole were taken from the literature.^{2,3} The table shows also the relaxation times τ calculated from our data for the dielectric increment by the use of Debye's theory formulae with the Wyman's formula $\tau=a+bp$ in place of the Clausius-Mossotti relation (p —volume polarization; a and b —Wyman's constants). The relaxation times τ_0 calculated for spherical molecules from molecular volumes are given for comparison in the last column.

Attention may be drawn to the following points: (a) the anomalous dispersion and absorption were increasing with increasing molecular size; (b) the dielectric increment was independent of concentration within the limits of error; (c) the absorption coefficient increment tended to increase with the concentration; this could be quantitatively accounted for as being due to the change in relaxation time with the change in viscosity to which ϵ'' is very sensitive when frequency corresponds to the edge of the dispersive region.

As is well known the observed static dielectric increments of simple straight-chain dipolar ions in a polar solvent have been accounted for statistically on the assumption of free rotation about the various single bonds of the chain, irrespective of whether polarization in a static field is accomplished by deformation or by orientation of the entire molecule.^{4,5} At high frequencies, however, the dielectric properties of the solution should depend upon the mechanism of polarization, each mode of deformation or orientation having its own relaxation time. The behavior of the higher peptides of glycine strongly suggests polarization by deformation of a flexible chain, since no anomalous dispersion has been observed at frequencies corresponding to the rotation of the molecules as a whole.³ The present data for the simple dipeptides, on the other hand, suggest orientation of these molecules, and are further consistent with the assumption of an asymmetry factor of about 2. The amino-acids, with the

very doubtful exception of glycine, also give evidence of relaxation times not greatly different from those corresponding to molecular rotation. A fuller discussion of the experiments will be published elsewhere.

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¹ G. Potapenko, Phys. Rev. **39**, 625, 628 (1932).

² J. Wyman and T. L. McMeekin, J. Am. Chem. Soc. **55**, 915 (1933).

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Radioactive Element 93

Last year a nonrecoiling 2.3-day period was discovered¹ in uranium activated with neutrons, and an attempt² was made to identify it chemically, leading to the conclusion that it is a rare earth. Impressed by the difficulties raised by this identification, the authors independently decided that the subject was worth further investigation. In Berkeley it was found that: (1) If a layer of $(\text{NH}_4)_2\text{U}_2\text{O}_7$ with about 0.1 mm air equivalent stopping power, placed in contact with a collodion film of 2 mm air equivalent, is activated by neutrons from the cyclotron, the 2.3-day period appears strongly in the uranium layer, and not at all in the collodion, which shows a decay curve parallel to, and 1/7 as strong as, that of a paper "fission catcher" behind it. One day after bombardment the uranium layer has five times the activity of the fission catcher. This shows that the 2.3-day period has a range of <0.1 mm air and an intensity larger than all the long period fission products together. (2) When a thin layer of uranium is bombarded with and without cadmium around it, the fission product intensity is changed by a large factor, while the 2.3-day period and the 23-minute uranium period are only slightly changed, and their ratio remains constant. Also absorption of resonance neutrons by uranium changes these two periods in the same ratio, suggesting a genetic relation between them, and the consequent identification of the longer period with element 93. In Washington it was found that the 2.3-day period probably does not behave consistently as a rare earth, since attempts to concentrate it chemically with the rare earths from activated uranium failed, although it is known to have an intensity large compared with that of the rare earth fission products.

At this stage of the investigation one of the authors (P.H.A.) came to Berkeley on a visit, and a combined attack was made. With pure 2.3-day substance from thin uranium layers, the chemical properties were investigated, and a very characteristic difference from the rare earths was soon found; namely, the substance does not precipitate with HF in the presence of an oxidizing agent (bromate in strong acid). In the presence of a reducing agent (SO_2) it precipitates quantitatively with HF. Cerium was used as a carrier. This property explains the erratic nature of previous chemical experiments in which the oxidizing power of the solution was not controlled. Further chemical

TABLE I. Dielectric constants, absorption coefficients, and relaxation times.

SUBSTANCE	$\Delta\epsilon_0/c$	CONCENTRATION RANGE	$\Delta\epsilon'/c$	$\Delta\epsilon''/c$	$\tau \times 10^{10}$	$\tau_0 \times 10^{10}$
Glycine	22.8	0.2-2.0	21.3	14.3	2.60	6.61
α -Alanine	23.3	0.4-0.8	17.4	13.8	6.55	8.50
β -Alanine	34.8	0.4-0.8	25.7	19.1	6.72	8.50
Glycylglycine	71.1	0.2-0.4	28.7	41.2	14.94	10.82
Glycylalanine	72.3	0.2-0.4	20.2	39.5	20.28	12.71
Alanylglycine	71.5	0.2	18.9	40.3	21.28	12.71

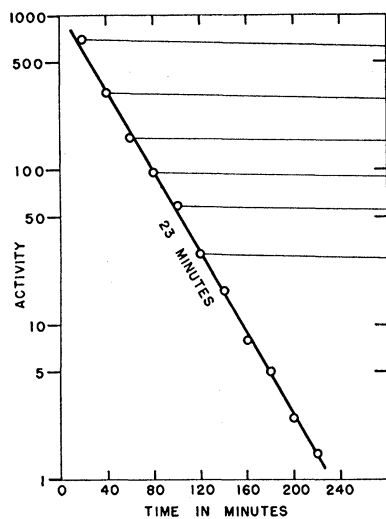


FIG. 1. Growth of 2.3-day 93^{239} from 23-minute U^{239} . The points indicate the activities of successive fluoride extractions, plotted at the times of extraction. Decay measurements were made a day later on the first six fractions, and the resulting slopes are shown on the plot.

experiments showed that in the reduced state with a thorium carrier it precipitates with iodate, and in the oxidized state with uranium as sodium uranyl acetate. It also precipitates with thorium on the addition of H_2O_2 . It precipitates in basic solution if carbonate is carefully excluded. These properties indicate that the two valence states are very similar to those of uranium (U^{++++} and UO_2^{++} or $U_2O_7^{--}$), the chief difference from that element being in the value of the oxidation potential between the two valences, such that the lower state is more stable in the new element. It is interesting to note that the new element has little if any resemblance to its homolog rhenium; for it does not precipitate with H_2S in acid solution, is not reduced to the metal by zinc in acid solution, and does not have an oxide volatile at red heat. This fact, together with the apparent similarity to uranium, suggests that there may be a second "rare earth" group of similar elements starting with uranium.

The final proof that the 2.3-day substance is the daughter of the 23-minute uranium is the demonstration of its growth from the latter. For this experiment activated uranium was purified twice by precipitation as sodium uranyl acetate, which was dissolved in HF and saturated with SO_2 . Then equal quantities of cerium were added at twenty-minute intervals and the precipitates filtered out. The first precipitate, made immediately after purification, carried all the fluoride-precipitable contaminations and was discarded; its weakness indicated a very good purification. The activities of the others are plotted in Fig. 1.

A preliminary study of the radiations from 93^{239} shows that it emits continuous negative beta-particles with an upper limit of 0.47 Mev, and a weak complex spectrum of low energy gamma-rays (<0.3 Mev) and probably x-rays. The question of the behavior of its daughter product 94^{239} immediately arises. Our first thought was that it should go to actinouranium by emitting an alpha-particle.

We sought for these by preparing a strong sample (11 millicuries) of purified 93 and placing it near a linear amplifier in a magnetic field to deflect the beta-particles. From this experiment we conclude that, if alpha-particles are emitted, their half-life must be of the order of a million years or more; the same experiment showed that if spontaneous fission occurs its half-life must be even greater. We wish to express our gratitude to the Rockefeller Foundation and the Research Corporation, whose financial support made this work possible.

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¹ E. McMillan, Phys. Rev. 55, 510 (1939).

² E. Segrè, Phys. Rev. 55, 1104 (1939).

Masses of Stable Nuclei from Ne^{20} to Fe^{57}

The observation of the proton groups in (dp) and (αp) reactions recently made in this laboratory, together with a knowledge of beta-ray maximum energies makes it possible to give reasonably correct values for isotopic masses as far as Fe^{57} with a few exceptions. These values are given in Table I. The values from Ne^{22} to A^{38} are derived entirely from transmutation data, and mass-spectrograph values are given in parentheses for comparison where they are available. Above K^{39} the accuracy is less and reliance has to be placed on mass-spectrograph measurements of Ti^{48} , Fe^{56} ¹ and Cr^{52} ,²

Such mass values are useful in checking theories of nuclear structure and to facilitate a bird's-eye view of the trend of mass values a quantity called here the "mass deviation" is plotted against the mass number. This is simply the deviation from a whole number plotted on a sloping scale which enables the whole range of elements to be plotted in a small space. Precisely defined it is $M_A - A + 0.001(A - 20)$ where M_A is the mass of an element of

TABLE I. Isotopic masses.

Ne^{20}	19.99881 (Bainbridge)	A^{40}	39.97504 (Bainbridge)
Ne^{21}	21.00018 (20.99968)	Ca^{40}	39.9745
Ne^{22}	21.99864 (Bainbridge)	K^{41}	40.9739
Na^{23}	22.99680	Ca^{42}	41.9711
Mg^{24}	23.99189	Ca^{43}	42.9723
Mg^{25}	24.99277	Ca^{44}	
Mg^{26}	25.99062	Sc^{45}	44.9701
Al^{27}	26.98960	Ti^{46}	45.9678
Si^{28}	27.98639 (27.9866)	Ti^{47}	
Si^{29}	28.98685 (28.9866)	Ti^{48}	47.9651 (Dempster)
Si^{30}	29.98294	Ti^{49}	48.9664
P^{31}	30.98437 (30.9843)	Ti^{50}	49.9632 (Dempster)*
S^{32}	31.98306 (31.9823)	V^{51}	50.9587
S^{33}	32.98260	Cr^{52}	51.9575 (Aston)
S^{34}	33.97974	Cr^{53}	52.9572
Cl^{35}	34.98107	Cr^{54}	
Cl^{36}	35.97852	Fe^{54}	53.9601 (Dempster)*
Cl^{37}	36.97829 (36.9779)	Mn^{55}	54.9653
A^{38}	37.97544	Fe^{56}	55.9608 (Dempster)
K^{39}	38.97518	Fe^{57}	56.9609

* Considerably less accurate than the other values given.

The Seven-Day Uranium Activity

The production of radioactive U^{237} by fast neutron irradiation of uranium has been reported recently by Nishina *et al.*¹ The same activity has been observed independently here. It was first found in samples of uranium placed immediately behind a beryllium target bombarded by 16-Mev deuterons. These showed an activity of half-life 7.0 ± 0.2 days which could not be separated chemically from uranium. If the purification was done immediately after activation, the 23-minute uranium and its 2.3-day daughter² also appeared, but if the purification was done after a few hours, only the 7-day period was seen. The ratio after a short bombardment of the initial intensities of the 7-day activity to the 2.3-day activity was about $\frac{1}{3}$.

Since the 7-day period was not seen in earlier experiments of the author in which uranium layers thin enough to allow the fission products to recoil out were exposed to neutrons from a beryllium target bombarded by 8-Mev deuterons, it seemed likely that it is produced by a fast neutron reaction. In confirmation of this it was found that the intensity (with 16-Mev H^2 on Be) is greatly reduced if the sample is surrounded with paraffin during bombardment and is not affected by cadmium shields. It was also found possible to observe the 7-day period in a thin uranium layer placed immediately behind the target, and an analysis of the resulting decay curve gave the same ratio of intensities (7-day to 2.3-day) as the chemically separated fractions from a bulk sample.

The 7-day beta-particles have an absorption curve characteristic of a simple continuous distribution with an end point at 0.26 Mev. There are also soft gamma-rays with at least two components, but no annihilation radiation, in agreement with the observation of Nishina *et al.*¹ that the electrons are negative. Dr. A. C. Helmholz, using a magnetic spectrograph, could find no internal conversion lines. Since this excludes the possibility of K capture, the daughter product must be element 93. An attempt to find such an activity was made. An 80-microcurie sample of 7-day uranium was allowed to decay for 26 days, and then element 93 was extracted from it, by the method of fluoride precipitation in reducing and oxidizing media,² with cerium carrier. The resulting product showed no measurable activity of either beta- or alpha-rays, so the period of this substance must be very long. (It can hardly be very short, since the active uranium has no high energy beta-particles and no alpha-particles of range greater than those from U_{II} .)

I wish to express my gratitude to the Rockefeller Foundation and the Research Corporation, whose financial support made this work possible.

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¹ Y. Nishina, T. Yasaki, H. Ezoe, K. Kimura and M. Ikawa, *Phys. Rev.* **57**, 1182 (1940).

² E. McMillan and P. H. Abelson, *Phys. Rev.* **57**, 1185 (1940).

The Energy Released in the Reaction $Li^6(p,\alpha)He^3$ and the Mass of He^3

Two groups of workers in this laboratory have completed determinations of the energy released in the reaction $Li^6(p,\alpha)He^3$ using different variable-pressure absorption cells calibrated in different ways. The variable-pressure cells used were constructed with two compartments, the forward one for retarding the alpha-particles, and the rear one for collecting the ionization produced by them at the end of their range. A linear amplifier was used to detect the ionization pulses. The region from which ions were collected was defined by a perforated screen transverse to the axis of the cell, but the ionization compartment was always at the same pressure as the retarding compartment. This introduces no complications into the interpretation of the results provided that the alpha-particles, at all pressures used, come to the end of their range in the gas of the ionization compartment. Thus there was only one window for the particles to traverse, placed over a perforated screen at the entrance to the retarding compartment.

In one experiment, such a cell was placed to collect particles from thin targets of lithium and beryllium, bombarded with 370-kev protons. The range difference between the alpha-particles from $Be^9(p,\alpha)Li^6$ and $Li^6(p,\alpha)He^3$ was found to be 1.83 mm. Using the precisely known energy of the beryllium particles, from our electrostatic analyzer measurements, and the slope of the Cornell (1938) range-energy curve in this region, we find that Q for $Li^6(p,\alpha)He^3$ is 3.95 ± 0.06 Mev.

The other determination was an outgrowth of experiments on the range-energy curve of alpha-particles in the energy region 0.8–2.0 Mev. A strong source of polonium was placed near the entrance of our electrostatic analyzer, and absorption screens introduced between it and the analyzer to absorb all but the last 0.5–1.0 cm of range. A small fraction of the resulting particles, homogeneous in energy, was deflected through the electrostatic analyzer and allowed to enter an absorption cell of the previously described type. By varying the deflecting voltage, the cut-off pressures of the cell for alpha-particles from 1.09 to 1.73 Mev have been determined. This same cell, with all its auxiliary apparatus, was then placed opposite a thin lithium target and the cut-off for the alpha-particles from $Li^6(p,\alpha)He^3$ determined. The result indicated an energy release of 3.94 ± 0.05 Mev.

We have used our previous values for reaction energies in computing the mass of He^3 which is included in the following list, based on 1.00813 ± 0.00002 , 2.01473 ± 2 , and 4.00386 ± 7 for the masses of H, D, and He^4 , respectively.

He^3	3.01685 ± 10	Be^8	8.00765 ± 15
Li^6	6.01684 ± 11	Be^9	9.01484 ± 13
Li^7	7.01814 ± 11		

The previously accepted value for the energy release in the reaction $Li^6(p,\alpha)He^3$ was 3.72 ± 0.08 Mev.

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Nuclear Properties of 93^{237} *

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The isotope Np^{237} , produced as the decay product of the previously known 6.8-day U^{237} , has been isolated with carrier material and some of its nuclear properties measured. The U^{237} was formed by means of the reaction $\text{U}^{238}(n, 2n)\text{U}^{237}$. Np^{237} decays with the emission of alpha-particles with a half-life of about 3×10^6 years. It has been shown that the upper limit for the cross section for the fission of Np^{237} with slow neutrons is less than 1 percent of that of U^{238} .

THE bombardment of uranium with fast neutrons produces^{1, 2} the beta-emitting 6.8-day U^{237} , formed in the reaction $\text{U}^{238}(n, 2n)\text{U}^{237}$. We have investigated 93^{237} , the daughter of U^{237} , the primary purpose of our investigation being to measure the fission properties of this isotope. Our measurements, performed upon a sample weighing about 0.6 microgram, show that 93^{237} does not undergo appreciable fission with slow neutrons. The experiments also show that 93^{237} is an alpha-emitting isotope with a half-life of about 3×10^6 years.

For the preparation of the sample of 93^{237} about 1200 grams of uranyl nitrate hexahydrate, $\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, were placed directly behind the beryllium target of the 60-inch Berkeley cyclotron and exposed to the fast neutrons produced in a 15,000-microampere hour bombardment of the beryllium with deuterons. After the lapse of several months, so that substantially all of the U^{237} had decayed to 93^{237} , a chemical separation was performed on this bombarded uranyl nitrate in order to isolate the 93^{237} into a thin rare earth fluoride precipitate (approximately 0.3 mg/cm²), special care being exercised to remove all of the 94, uranium, protactinium, and thorium. This procedure has been described in principle in another report.³

* This article was mailed, as a secret report, from Berkeley, California to the Uranium Committee in Washington, D. C. on April 14, 1942. The experimental work was done during 1941 and the early part of 1942. The original article is published here essentially without change. The abstract was written at the time of publication since the original report contained no summary.

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¹ E. M. McMillan, *Phys. Rev.* **58**, 178 (1940).

² Y. Nishina, T. Yasaki, H. Ezoe, K. Kimura, and M. Ikawa, *Phys. Rev.* **57**, 1182 (1940).

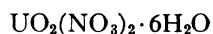
³ G. T. Seaborg and A. C. Wahl, *J. Am. Chem. Soc.* (March, 1948).

The chemical procedure, in outline, is as follows. The uranyl nitrate hexahydrate is subjected to an ether extraction process in order to remove the bulk of the uranium, and rare earth fluoride is precipitated from the water phase. This rare earth fluoride contains the 94, 93, and thorium, the uranium and the protactinium (when zirconium carrier is present) remaining in solution. This rare earth fluoride is dissolved in sulfuric acid, and from a cold potassium bromate (KBrO_3) solution the rare earth fluoride is again precipitated. In this step the 94, in its reduced form, and the thorium and the rare earth fission products are precipitated as insoluble fluorides, and the 93 remains in solution in its oxidized form. After reduction with sulfur dioxide, the 93 in the solution is precipitated with a small amount of rare earth fluoride. Of course, it is necessary that a number of cycles be performed in order to remove completely from the final sample the 94, uranium, protactinium, and thorium, and in our procedure there were three separations from 94, six separations from uranium, five separations from protactinium, and five separations from thorium. The last 94-containing rare earth precipitate was mounted for alpha-counting and was found to contain practically no 94 (<30 counts per minute) while the final sample containing the 93^{237} had a counting rate of about 300 alphas per minute. In order to keep track of the yield of 93 through this rather lengthy chemical procedure there was added at the beginning some 2.3-day 93^{239} as tracer for the 93, and it was found that the yield of 93 in the final sample amounted to about 50 percent of that originally added to the bombarded uranium nitrate.

In order to prove that in this chemical pro-

cedure no uranium, protactinium, or thorium remained in the final sample, a chemical separation, of a similar type, was performed on non-irradiated uranyl nitrate using U^{233} as tracer for uranium, Pa^{233} as tracer for protactinium, and UX_I as tracer for thorium. This "blank experiment" proved that in our chemical procedure there remains in the final sample much less than a microgram of each of these elements.

In order to know how much 93^{237} was formed in the bombardment described above, it was necessary, of course, to determine the yield of U^{237} in the bombardment of uranyl nitrate hexahydrate under similar conditions. A sample of 700 grams of $UO_2(NO_3)_2 \cdot 6H_2O$ was placed directly behind the beryllium target and subjected to a 500-microampere hour bombardment. This sample was carefully purified from all of the fission products and from element 93 by the ether extraction method; the ether phase, containing the bulk of the uranyl nitrate and the U^{237} , was washed 8 or 10 times with water in order to insure a very thorough purification. Aliquot amounts, determined by weighing the uranyl nitrate containing the 6.8-day U^{237} , were taken from the ether phase and the intensity of the activities was measured with a Lauritsen quartz fiber electroscope calibrated in an absolute manner for the radiation from the 6.8-day U^{237} . This calibration was accomplished by preparing thin electrolytically deposited aliquots of the uranium and counting the beta-particles from the 6.8-day U^{237} with a thin-window Geiger-Müller counter of calibrated efficiency; the weight of uranium in these small aliquots was determined by counting its natural alpha-particles with an ionization chamber of calibrated efficiency. (Correction for the self-absorption in the samples and absorption in the Geiger-Müller counter window of the 6.8-day U^{237} beta-particles was made by using the value for the half thickness of the absorption of these beta-particles, which we have determined as 6 mg Al/cm².) From the measurements on the calibrated Lauritsen electroscope of the chemically purified aliquots from the 500-microampere hour bombardment, we found that the yield of 6.8-day U^{237} was 0.0054 microcurie per gram of



per microampere hour of deuterons on beryllium.

From this yield it follows that there was formed in the 15,000-microampere hour bombardment of 1200 grams of $UO_2(NO_3)_2 \cdot 6H_2O$ about 97 millicuries of U^{237} , which corresponds to about 1.2 microgram. Since substantially all of this decayed to 93^{237} before the chemical separation was performed and since the yield in the chemical procedure for the isolation of 93 was about 50 percent, as mentioned above, this means that there was present in our final sample about 0.6 microgram of 93^{237} . We consider this estimate of the amount to be accurate to within a factor of about 2. The alpha-counting rate of this sample, as mentioned above, was about 300 counts per minute, and, from this value, together with the calibrated efficiency (45 percent) of the ionization chamber, it is calculated that the half-life of alpha-emitting 93^{237} is about 3×10^6 years.

This sample was placed on one electrode of an ionization chamber connected to a linear amplifier and recording system which was adjusted so as to record the pulses due to fissions. As a neutron source we used 300 milligrams of radium mixed with beryllium powder. The ionization chamber and the 300-mg radium-beryllium neutron source were completely surrounded by paraffin. Under these conditions the 0.6 microgram 93^{237} sample gave four fission counts in about 56 hours of counting time. When the ionization chamber was surrounded by cadmium, there were recorded two counts in 56 hours of counting time. Thus, the counting rate due to slow neutrons was two counts in 56 hours or 0.035 fission counts per hour. For a calibration experiment the 0.6-microgram sample of 93^{237} was replaced by 200 micrograms of electrolytically deposited uranium, whose weight was determined by counting its alpha-particles with an ionization chamber of calibrated efficiency. The easily measurable fission rate of this uranium sample, containing 1.4 micrograms of U^{235} , when compared to that for 93^{237} showed that the slow neutron fission cross section of 93^{237} is less than one percent⁴ of that for U^{235} .

⁴ Note added at time of publication. More recent work by A. Ghiorso, D. W. Osborne, and L. B. Magnusson has demonstrated that Np^{237} undergoes slow neutron fission with a cross section a few thousandths of a percent of that of U^{235} . (Science 104, 386 (1946).)