21. S. Claesson, "Sbornik Khromatografiya" (Symposium, "Chromatography") (Translated into Russian), Inostr. Lit., 1949, p. 53.
22. P. Harteck and K. Suhr, Angew. Chem., 56, 120 (1943).
23. R. S. Alm, R. J. P. Williams, and A. Tiselius, Acta Chem. Scand., 6, 826 (1952).
24. R. S. Alm, Acta Chem. Scand., 6, 1186 (1952).
25. A. A. Zhukhovitskii *et al.*, Dokl. Akad. Nauk SSSR, 77, 435 (1951); 88, 859 (1953); 92, 987 (1953); 94, 77 (1954).
26. R. J. P. Williams, Analyst, 77, 905 (1952).
27. D. W. Bannister, C. S. G. Phillips, and R. J. P. Williams, Analyt. Chem., 26, 1451 (1954).
28. D. L. Mould and R. L. M. Synge, Analyst, 77, 964 (1952).
29. T. B. Gapon and E. N. Gapon, Dokl. Akad. Nauk SSSR, 60, 401 (1948).
30. C. A. Baker and R. J. P. Williams, J. Chem. Soc., 2352 (1956).
31. S. R. Caplan, J. Polymer Sci., 35, 409 (1959).
32. N. Schneider, L. Holmes, C. Mijal, and J. Loconti, J. Polymer Sci., 37, 551 (1959).
33. N. Schneider and L. Holmes, J. Polymer Sci., 38, 552 (1959).
34. H. Deuel, J. Solms, and L. Auyas-Weisz, Helv. Chim. Acta, 33, 2171 (1950).
35. N. Hartler, Acta Chem. Scand., 11, 1162 (1957).
36. R. M. Wheaton and W. C. Bauman, "Ion-Exchange Resins in Medicine and Biology" (Translated into Russian), 1956, p. 130.
37. N. Hartler, Acta Chem. Scand., 11, 1169 (1957).
38. C. A. Zittle, Adv. Enzymol., 14, 319 (1953).
39. S. Moore and N. H. Stein, Adv. Protein Chem., 11, 191 (1956).
40. H. A. Sober and E. A. Peterson, in "Ion Exchange in Organic and Biochemistry" (Edited by C. Calmon and T. R. E. Kressman), New York, 1957, p. 318.
41. G. V. Samsonov and M. D. Faddeeva, Biokhimiya, 21, 403 (1956).
42. K. Narita, S. Fujiwara, and S. Murasawa, Bull. Chem. Soc. Japan, 31, 38 (1958).
43. G. V. Samsonov and R. B. Ponomareva, Biokhimiya, 24, 63 (1959).
44. G. V. Samsonov and I. P. Kuznetsova, Dokl. Akad. Nauk SSSR, 115, 351 (1957).
45. G. V. Samsonov, Yu. B. Boltaks, N. P. Kuznetsova, A. P. Bashkovich, and R. B. Ponomareva, Kolloid. Zhur., 21, 471 (1959).
46. G. V. Samsonov, V. V. Vedeneeva, and A. A. Selezneva, Dokl. Akad. Nauk SSSR, 125, 591 (1959).

Institute of Macromolecular Compounds,
Academy of Sciences of the USSR

THE DISCOVERY OF ELEMENT 103

S. S. Rodin

In April 1961, as the result of numerous experiments, a team from California University Radiation Laboratory consisting of A. Ghiorso, T. Sikkeland, A. Larsh, and R. Latimer obtained evidence of a new artificial synthetic element of atomic number 103.[1,2] In honour of the founder of their laboratory, Nobel prizewinner E. O. Lawrence, they proposed to name this new element lawrencium (symbol Lw).

Element 103 was obtained by the bombardment of californium with boron ions accelerated to 70 MeV energy by the linear accelerator HILAC. An alpha-activity was observed to result from this irradiation which could only be explained by the disintegration of a new element with atomic number 103. However, this activity is so small that it amounts to no more than several alpha-particles an hour. For this reason it is not yet possible to observe the mendelium disintegration products, which would confirm the atomic number of the element responsible for the new activity. Nonetheless, on the basis of nuclear data this activity can be positively ascribed to the element with atomic number 103. The method used by the team to obtain and identify the radiations is shown schematically in Fig. 1. In principle, the method is based on the approach used in the preparation of element 102. The californium target weighed 3 μg and had the following isotopic composition:

^{249}Cf — 3.3%, ^{250}Cf — 32.8%, ^{251}Cf — 12.3% and ^{252}Cf — 50.8%.

The californium was deposited on a nickel foil 0.0015 mm thick in the form of a circle 2.5 mm in diameter. The success of the experiment was strongly dependent on the purity of the target; the purification consisted of meticulous use of ion-exchange columns and specially pure reagents. The last stage in the purification of the target from undesirable traces of lead and bismuth was accomplished by heating the target *in vacuo* by electron bombardment. Traces of lead and bismuth must be reduced to the minimum, since when these elements are irradiated by heavy ions they give a large yield of elements disintegrating with a half-life of 25 sec and emitting alpha-particles of energy 8.8 MeV. This activity can completely obscure the alpha-activity of element 103.

The current of ^{10}B or ^{11}B ions passing through the very thin target was not allowed to exceed 0.5 μA, to avoid melting the target. The atoms formed in the bombardment were ejected from the target into the surrounding

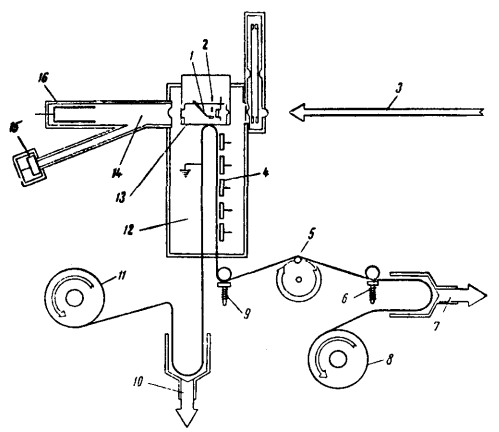


Fig. 1. Diagram of the apparatus for obtaining element 103: 1) target (-400 V); 2) collimator; 3) beam of heavy ions; 4) silicon alpha-particle counters; 5) motor; 6) brake; 7) suction; 8) take-up spool; 9) brake; 10) suction; 11) feed spool; 12) helium; 13) casing (-150 V); 14) vacuum; 15) silicon counter for measuring ion beam energy; 16) Faraday cylinder.

space, which was filled with helium. A slow flow of gaseous helium carried the electrically charged products towards a thin copper conveyor belt. This belt was intermittently drawn along through a short distance in such a way that the atoms collected on it were presented to each of five silicon counters†. The pulses generated by the alpha-particles were passed to preamplifiers within the shielded area. They were then further amplified and analysed by two separate electronic systems. One system consisted of five separate 100-channel pulse analysers, while the other was a complex assembly using a memory device comprising five paper tapes on which the necessary marks were made by punching. With the second of these devices it was possible to determine the time at which each pulse was registered from the conveyor belt.

The crystalline silicon counters played a very important part in these experiments, and were developed by S.Borkowski and D.Blankenship of the Oak Ridge National Laboratory, who helped to make the silicon counters needed for this work. These counters were made from silicon plates 6×10 mm in size, fixed in a mounting and covered by a gold layer of thickness about 20 $\mu g\, cm^{-2}$. At first the counters were very unstable in operation, since they were in a helium atmosphere and subjected to very intensive beta-radiation fields. The use of charge-sensitive preamplifiers reduced these effects, but it was found during the experiments that the silicon crystal counters periodically had to be replaced by new ones.

The energy of the boron ions was also determined by means of a silicon counter, calibrated against nuclear photographic plates.

The whole system was calibrated and checked in the absence of a current of accelerated ions either by means of recoil nuclei from ^{233}U‡ collected on the conveyor belt, or by means of the alpha-particles formed in the disintegration of ^{212}Po. For this purpose the samples mentioned were placed in front of the counter installation. A preliminary study of reactions with the accelerated heavy ions was made by bombarding ^{147}Sm, which formed short-lived emitters. Lead and bismuth were also used in test bombardments, and produced various alpha-emitters with energies from 7 to 9 MeV.

When californium was bombarded with boron ions, the disintegration of element 103 was observed with half-life 8 ± 2 sec and emission of alpha-particles of 8.6 MeV energy. In these experiments alpha-particles with energies 8.4 and 8.2 MeV and half-life 15 sec, probably due to element 102, were also observed. Fig. 2 shows the spectrum of alpha-particles registered by the first counter during the last series of experiments. These activities were observed over many weeks, when bombarding a californium target with ^{10}B or ^{11}B ions. When Pb, Bi, ^{240}Pu, and ^{241}Am are bombarded under similar conditions, the new activities are not formed. The scientists who obtained the isotope of element 103 assume for several reasons that its mass number is 257. Thus, in bombarding ^{250}Cf, ^{251}Cf, and ^{252}Cf with ^{11}B ions the isotope $^{257}103$ is formed after the emission of 4, 5, and 6 neutrons, while in bombarding with ^{10}B ions the same results are obtained with the emission of 3,4, and 5 neutrons.

† Solid state Au–Si surface barrier detectors (Ed. of Translation).

‡ Reference 2 quotes ^{230}U here (Ed. of Translation).

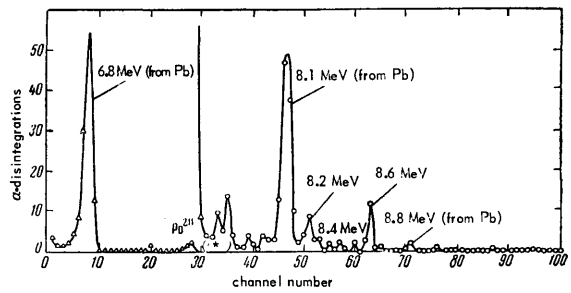


Fig. 2. Alpha-spectrum from the first counter. *(From Pb)

The nuclear reactions taking place can be represented as:

$$^{250}Cf + {}^{11}B \rightarrow {}^{257}103 + 4n$$
$$^{251}Cf + {}^{11}B \rightarrow {}^{257}103 + 5n$$
$$^{252}Cf + {}^{11}B \rightarrow {}^{257}103 + 6n$$
$$^{250}Cf + {}^{10}B \rightarrow {}^{257}103 + 3n$$
$$^{251}Cf + {}^{10}B \rightarrow {}^{257}103 + 4n$$
$$^{252}Cf + {}^{10}B \rightarrow {}^{257}103 + 5n$$

Furthermore, it is known from other experiments that in the nuclear interaction of boron with transuranic elements the most probable reactions are those with neutron emission. The excitation functions of ^{11}B and ^{10}B ions for the formation of alpha-activity with energy 8.6 MeV are consistent with the above conclusion. The form of these functions is such that the observed activity could not positively exclude reactions of the type (B, $p \times n$), leading to the formation of light isotopes of element 102. The final proof of the existence of an isotope of element 103 was then obtained when element 102 was formed by bombarding a californium target with ^{12}C ions, when it was observed that the activity with energy 8.6 MeV decreased by a factor of two, while the 8.2 MeV activity (which basically belongs to isotope $^{255}102$) increased by nearly 20 times. On the other hand, experiments with ^{240}Pu have shown that the cross-section of (^{12}C, $\alpha \times n$) reactions is greater, and that of (^{12}C, $p \times n$) reactions less, than the cross-section of similar reactions in the bombardment of californium by boron ions.

The formation of light isotopes of mendelevium, which could emit alpha-particles with energies in the range 8.2–8.6 MeV was excluded in the experiments on the bombardment of ^{243}Am by ^{12}C ions.

Rather more than twenty years have passed since the discovery of the first transuranic elements neptunium and plutonium, and in this time eleven new transuranic elements have been prepared artifically.

The discovery of each transuranic element has been attended by enormous difficulties. All these elements are radioactive, and they have been discovered by means of various methods in nuclear chemistry, a very new science. Physicists have made important contributions to the discovery of these elements by helping to predict the basic properties of as yet undiscovered elements and to obtain various "atomic missiles", without which the synthesis of new isotopes of transuranic elements would have been impossible. For example, in the discovery of element 103

it was necessary to obtain, from the artificial element plutonium, adequate quantities of the transuranic element californium of great purity and of known isotopic composition. The californium so obtained was used as a target, and work with it was made extremely difficult by its high neutron activity.

The description of the experiments leading to the discovery of element 103 shows that a method of elimination was used. The use of this indirect method of proof calls for a colossal amount of work, since it was necessary to subject a very large number of different targets to irradiation by various ions.

It is interesting to note that the method described had previously been used, in the early days of the discovery of transuranic elements, by the Soviet scientists G. N. Flerov and K. A. Petrzhak, to demonstrate the spontaneous fission of uranium. More recently, the same method was used by G. N. Flerov and his colleagues in the discovery of element 102.

The discovery of an element with atomic number 103 is a significant event, since this element is the last member of an actinide group in the Periodic Table.

The next new chemical element that may be artificially obtained by man in the laboratory is that with atomic number 104. This element will have properties completely different from those of the other artificial elements produced already with atomic numbers from 93 to 103. Element 104 will be similar in its physical and chemical properties to hafnium and zirconium, since it occupies a position in the Periodic Table immediately below them. Various compounds of this new element will be relatively easy to separate from compounds of the actinide elements, by reason of the large difference in properties. A comparatively simple method of extraction can be employed for this separation in place of the complex and laborious method of ion exchange chromatography.

The series of elements beginning with element 104 will be the fourth so-called series of transition metals. If these elements can be prepared, they will have atomic numbers from 104 to 112. The elements from 112 to 118 complete the seventh row of the Periodic Table; they will also have different properties. But it must be pointed out here that steadily increasing difficulties will be met in the discovery of heavier elements. If the half-life of element 103 is 8 sec, then the predicted half-life for element 110 comes to 0.01 sec. Such short half-lives will very seriously limit the possibility of discovering new isotopes of heavy elements.

1. Science News Letter, 79, 259 (1961).
2. Phys. Rev. Letters, in the press. [See Phys. Rev. Letters, 6, 473 (1961) (Ed. of Translation)]

Vernadskii Institute of Geochemistry
and Analytical Chemistry, Academy
of Sciences of the USSR