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NEWS ON ELEMENTS NO. 102

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A little more than a year ago, on July 9, 1957, the news was first published that an international group of scholars from Swedish, American, and English laboratories had succeeded in synthesizing a tenth transuranic element, No. 102. They proposed the name "nobelium," with the symbol No. 102

It was explained that the element in the form of the isotope 102^{253} (or 102^{251}) was obtained by bombarding curium Cm^{244} with carbon ions C^{13}, and that the newly discovered isotope has a half-life of about 10 minutes during which alpha-particles are emitted at 8.5 Mev.

The news of the discovery of the new element was also published in a number of Soviet scientific journals including Usp. Fiz. Nauk (U.S.S.R.) in December 1957, p. 825. It turned out later however, that the story of the discovery of element 102 had by no means been completed, but had barely begun in the summer of 1957. Further work on the synthesis of element 102 was required not by the necessity of establishing new criteria to confirm and prove the nature of the synthesized elements, new experimental methods which would be less and less limited by the life time of the synthesized isotopes. The identification of all newly discovered transuranic elements up to mendelevium (No. 101) was based on the chemical method of separating them in ion exchange columns.

However, despite all the "speed" of ion exchange in comparison with classical chemical procedures, we must not rely upon its applicability to isotopes whose life time is counted in seconds or fractions thereof.

But, from the systematics of the entire aggregation of data on the lifetimes and modes of decay of about 100 transuranic isotopes now known, we can conclude that as the atomic number becomes higher, the instability to alpha decay and spontaneous fission also grows. Therefore, the region of "minute" isotopes ends somewhere around $Z = 102$, and already at $Z = 106 - 108$ the lifetime of even the most "stable" isotopes will evidently be counted in franctions of a microsecond. Therefore, even before the search for element 102 began, it was clear that the limit of applicability of any chemical methods of identifying new elements was already near, and that new methods must be found.

A substantially new solution appeared in the work of A. Ghiorso, B. Harvey, J. Choppin, S. Thompson, and G. Seaborg in 1955 in the synthesis of element 101 — mendelevium. To separate the counted Mv^{256} atoms from the hundreds of millions of atoms of the irradiated einsteinium target, these authors used the method of nuclear recoil. The alpha-particles bombarding einsteinium which make the "successful" hits necessary for their absorption and the formation of mendelevium, transmit to the nuclei of the target a large impulse and knock them out of the target to a special receiver, for instance, a gold foil. The ratio of the number of atoms formed during the bombarding of an element to the number of the atoms of the target element in the receiver, which had similar chemical characteristics, was considerably greater than in the target itself. This considerably facilitates further procedures of chemical separation.

The gathering, in a special receiver, of the product of bombarding curium with ions of carbon preceeded the ion exchange separation of elements in the efforts to synthesize element 102 in the Stockholm cyclotron.

However, both in these experiments and in the experiment for obtaining mendelevium, the method of atomic recoil played an auxiliary, secondary role, and the conclusion that element 102 was discovered, was made by the participants of the Stockholm international group essentially on the basis of the location of the fraction emitting 8.5-Mev alpha particles when it was washed from the ion exchange column.

The announcement of the discovery of element 102 contained many ambiguities mentioned by the very participants in the Stockholm group at the time of its first scientific publication.[1] First of all, there was an obvious contradiction between the values of the decay half-life (10 minutes) and the energy of the alpha-particles (8.5 Mev). There is a definite connection between these two measurements; according to the systematics of alpha decay of heavy nuclei, alpha-particles of an energy of 9.5 Mev have to correspond to a half-life period of about 10 seconds for element 102. And to a certain degree, the experiments were hard to reproduce. Of the six curium targets used, in only

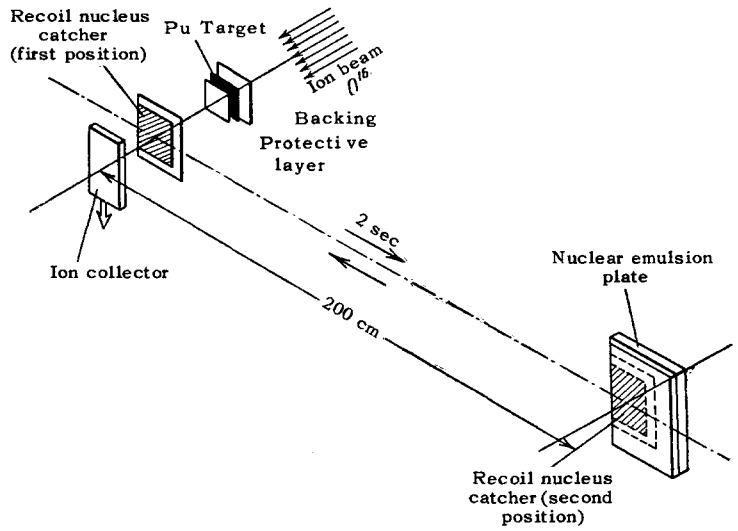

FIG. 1

three did irradiation lead to an alpha activity ascribed to element 102. In addition, for these three targets, positive results were observed only in the first two weeks after their preparation and then only in half the cases.

The contradiction between the life time and the energy of the alpha-particles could, it is true, be explained by the fact that the alpha activity is caused not by element 102 itself but by its short-period daughter product formed in the decay by K-capture of the recoil isotope. The inability to reproduce the experiment was interpreted as a result of possible contaminations of the target during its preparation or during the course of irradiation.

Therefore, new investigations can shed light on the problem of the characteristics of the various isotopes of element 102. These investigations were carried on during the last year in the U.S.S.R. and the USA. They not only led to new interesting results but also laid the basis for a new methodology in identifying isotopes based on a change in the ion exchange methods for studying those isotopes whose life time does not exceed a second or a fraction of a second.

Soviet work on the synthesis of element 102 was begun on the 150-centimeter cyclotron of the Institute of Atomic Energy of the U.S.S.R. Academy of Sciences in the fall of 1957. G. N. Flerov, corresponding member of the U.S.S.R. Academy of Sciences, directed this work. He was assisted by a large group of chemists and physicists: S. M. Polikanov, A. S. Karamyan, A. S. Pasyuk, D. M. Parfanovich, N. I. Tarantin, V. A. Karnaukhov, V. A. Druin, V. V. Volkov, A. M. Semchinova, Yu. Ts. Oganesyan, V. I. Khalizev, and G. I. Khlebnikov.[2]

To obtain the new element, Soviet scientists bombarded isotopes of plutonium Pu^{239} and Pu^{241} with ions of oxygen with an energy of about 100 Mev. Since the lifetime of isotopes of element 102 expected among the products of the bombardment can be counted in seconds, a new method was used that represents a great improvement on the recoil method and that also allows the establishment of the energy of alpha particles emitted by the forming isotopes.

The experimental set-up of the Moscow group is shown in Fig. 1. A beam of oxygen ions (whose current is recorded with the help of an ion collector and a current integrator) falls on a layer of plutonium several hundreds of micrograms/cm^2 thick deposited on a one and one-half micron nickel backing. In absorbing oxygen, the target nuclei acquire a big impulse, are knocked out of the target through a protective layer of sputtered copper, and fall onto a special thin aluminum catcher. From time to time that catcher is quickly moved (in 2 or 3 seconds) two meters to a nuclear emulsion plate which registers alpha-particles emitted by nuclei which have fallen onto the catcher. A group of alpha-particles with an energy of 8.8 ± 0.5 Mev were noted in the spectrum of alpha-particles along with groups that had been produced by earlier-known isotopes of fermium and californium. To the end of August, 87 cases of the emission of such particles were noted. The character of the alpha-particle spectrum observed in the experiments of the Moscow group is shown in Fig. 2.

As is clear from the systematics of alpha decay of heavy nuclei, of all the transuranic elements only isotopes of element 102 could emit 8.8-Mev alpha particles. Among the elements nearer to plutonium only the lightest isotopes can emit

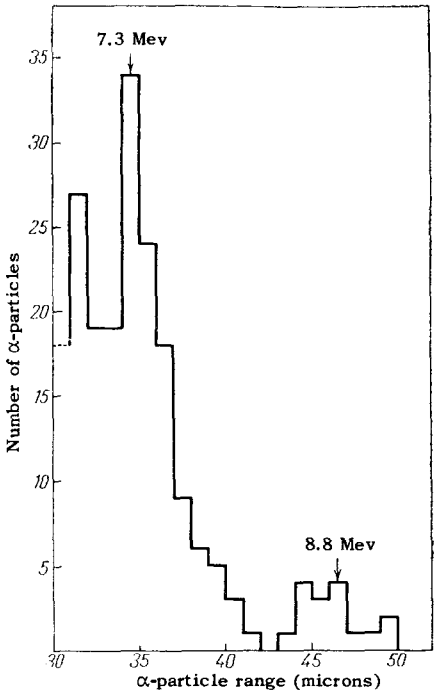

FIG. 2

alpha particles of such an energy. The formation of those isotopes by oxygen ions with an energy of 100 Mev is impossible.

Although the energy of alpha particles emitted by element 102 in the experiments on the cyclotron of the Institute of Atomic Energy of the U.S.S.R. Academy of Sciences agrees with that of the Stockholm group, this still does not signify a confirmation of the Stockholm data, where, as we have stated, the energy of the alpha-particles does not correspond to the half-life period.

The experiments of the Moscow group, in which the speed of moving the catcher of recoil nuclei to the photoplate was changed, showed that the half-life of the newly discovered isotope is in any case less than 30 seconds.

The first report on the Moscow work was made in February 1958 by S. M. Polikanov at a symposium in Copenhagen, and then sent to press.[2] At that time they had not yet settled the problem of whether or not the high energy alpha particles were the result of background contamination. Such background ingredients as cosmic rays, traces of ThC′, and the contribution of (n, α) reactions in the emission of alpha-particles do not depend on the speed of changing the receiver from the beam to the photoplate, and therefore these background sources are insignificant. A considerably greater danger could be hidden in the insignificant admixtures of bismuth, lead, thallium and mercury in the irradiated plutonium target inasmuch as during the bombarding of the elements with oxygen ions, unknown isotopes arise which emit 8 to 9 Mev alpha particles. From April to August 1958, the possible role of these admixtures was studied in detail. A sensitive method of activation analysis was worked out which permitted the reliable determination of fractions of one hundred millionth of a gram of the aforementioned admixtures. As a result it was shown that the observed alpha activity cannot be accounted for by the admixtures alone and the conclusion made at the end of 1957 was confirmed: during the bombardment of plutonium by 100 Mev oxygen ions, the alpha active isotope of element 102 is formed with alpha-particles at 8.8 ± 0.5 Mev. The upper limit of the formation cross section of the new element is estimated at 2×10^{-32} cm^2.

Work on the synthesis of element 102 has begun at the heavy ion accelerator at the Radiation Laboratory of the University of California at Berkeley.

The California group under the direction of G. Seaborg and A. Ghiorso first of all tried to reproduce the results of the Stockholm group. However, in spite of a large number of carefully executed experiments carried on over a long period of time, and even with the use of different methods, they did not succeed in confirming the Stockholm results. Finally, the California group changed to a radical new method which allowed A. Ghiorso, T. Sikkeland, J. Walton, and G. Seaborg to identify in April 1958 the isotope 102^{254} formed in the bombardment of curium Cm^{246} with ions of C^{12}.[3]

The new method worked out at Berkeley is also based on the nuclear-recoil method. The basic idea for identifying isotope 102^{254} was to trap, without interruption, atoms of the new element which formed by alpha decay the daughter isotope fermium Fm^{250}, for which the half-life period (30 minutes) and the energy of emitted alpha-particles (7.43 Mev) had already been established. The method of nuclear recoil was used by the California group in two stages. First, in the bombardment of a curium target containing 5% of the isotope Cm^{246} (and 95% of the isotope Cm^{244}) with carbon ions with an energy of 60 to 100 Mev, atoms of element 102 fly out of the target because of recoil, are slowed down in a helium atmosphere, and are attracted by a negatively charged metallic conveyor belt moving directly under the target (see Fig. 3).

Then atoms of the new element underwent alpha decay during the transfer on the conveyor belt. Daughter atoms of fermium formed during the alpha decay again received recoil energy during which about half of these atoms flew out of the conveyor belt and were attracted by a receiver, a foil charged negatively relative to the belt and

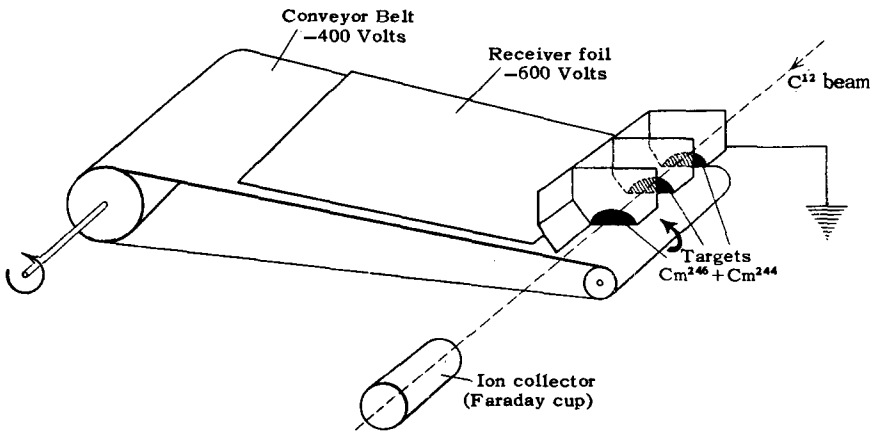

FIG. 3

located over the belt. As a result, in the receiver, which was not subjected to the direct action of bombarding carbon ions, in each trial there appeared up to forty atoms of an isotope identified by the usual ion exchange methods as Fm^{250}. To determine the half-life of the mother isotope 102^{254}, the foil receiver was cut perpendicular to the length of the belt into five parts, and the activity of all five parts was simultaneously registered on an alpha-pulse amplitude analyzer. Knowing the time of transfer of the conveyor belt to a distance from the beginning to the end of the receiver, and comparing the activity of the various portions of the foil receiver, they succeeded in establishing that the half-life of 102^{254} was close to 3 seconds. The cross section for formation of this isotope by the nuclear reaction $Cm^{246}(C^{12}, 4n)102^{254}$, with carbon ion energy 60 to 100 Mev, is calculated to be in microbarns (10^{-30} cm^2), and goes through a sharp maximum at an energy of 70 to 75 Mev, which corresponds, from the calculated maximum probability, to the emission of four neutrons.

It should be mentioned here that the discovery of Fm^{250} atoms in the receiver foil in the aforementioned experiments is not, strictly speaking, 100 percent proof that these atoms have appeared specifically during the alpha decay of 102^{254}. It is possible (though not probable) that atoms of Fm^{250} fell onto the receiver as a result of recoil in the isomeric decay of the hypothetical isomer Fm^{250*} or during the K capture of an electron by a nucleus of a yet unknown isotope of mendelevium Mv^{250}. Then the three-second half-life relates to the isomeric transition or the K capture of parent atoms of fermium or mendelevium and not to alpha decay of isotope 102^{254}.

As an example of the "isomeric variant" of the origin of Fm^{250}, one can name the possible reaction $Cm^{244}(C^{12}, \alpha 2n)Fm^{250}$ on the isotope Cm^{244} which makes up about 95 percent of the curium target. The reaction cross section for the type $(C^{12}, \alpha 2n)$ in a definite carbon ion energy interval can turn out to be 2 or 3 orders of magnitude more than for the reaction $(C^{12}, 4n)$, so that the probability of the formation of the isomer Fm^{250*}, if it exists, cannot be ignored.

One possible way of strictly proving alpha decay from Fm^{250} nuclei in the conditions of the California experiments could be a demonstration of the fact that the recoil energy of these nuclei is not electron volts but tens of kiloelectron volts (for instance, that these nuclei go through the receiver and through thin screens which cut out recoil nuclei of a very low energy).

The position of the maximum emission of Fm^{250} with the energy of C^{12} ions at 70 to 75 Mev, that has already been mentioned above, is only an indirect additional argument in favor of the formation of 102^{254}, and it would be very desirable to have a direct definition of the energy of the alpha-particles emitted by this isotope. On the other hand, to interpret the Moscow results only on the basis of the systematics of alpha decay and therefore without sufficient conclusiveness and authenticity, it would be very important to establish the mass number and lifetime of the isotope. Experiments going on in various countries at this time on the synthesis of element 102 will undoubtedly clear up the problems of how to obtain it and of the characteristics of its isotopes.

[1] Fields, Friedman, Milsted, Atterling, Forsling, Holm, and Astrom, Phys. Rev. **107**, 1460 (1957).

[2] Flerov, Polikanov, Karamyan, Pasyuk, Parfanovich, Tarantin, Karnaukhov, Druin, Volkov, Semchinova, Oganesyan, Khalizev, and Khlebnikov, Dokl. Akad. Nauk SSSR **120**, 73 (1958), Soviet Phys. "Doklady" **3**, 546 (1958).

[3] Ghiorso, Sikkeland, Walton, and Seaborg, Phys. Rev. Lett. **1**, 18 (1958).

Translated by Genevra Gerhart