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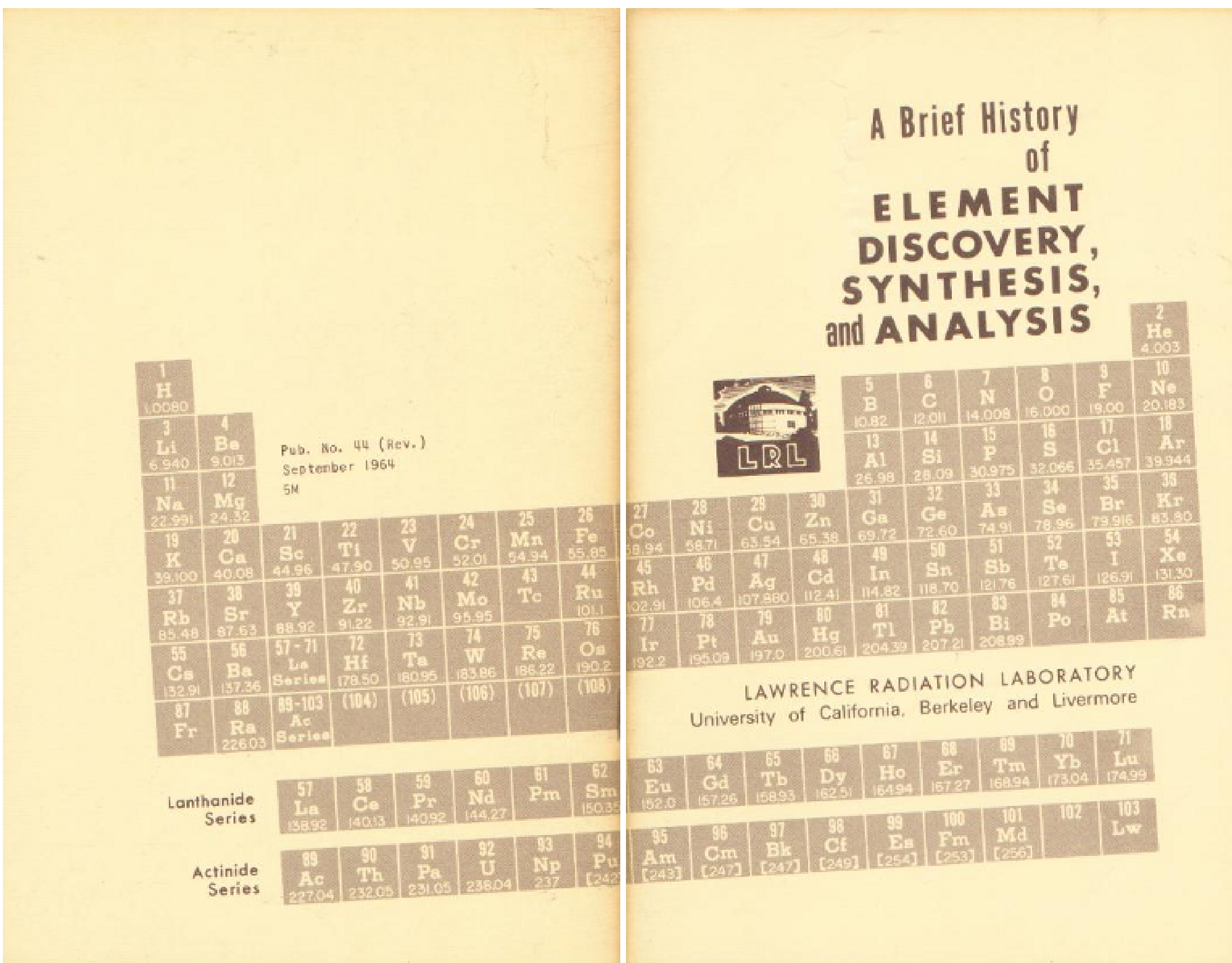


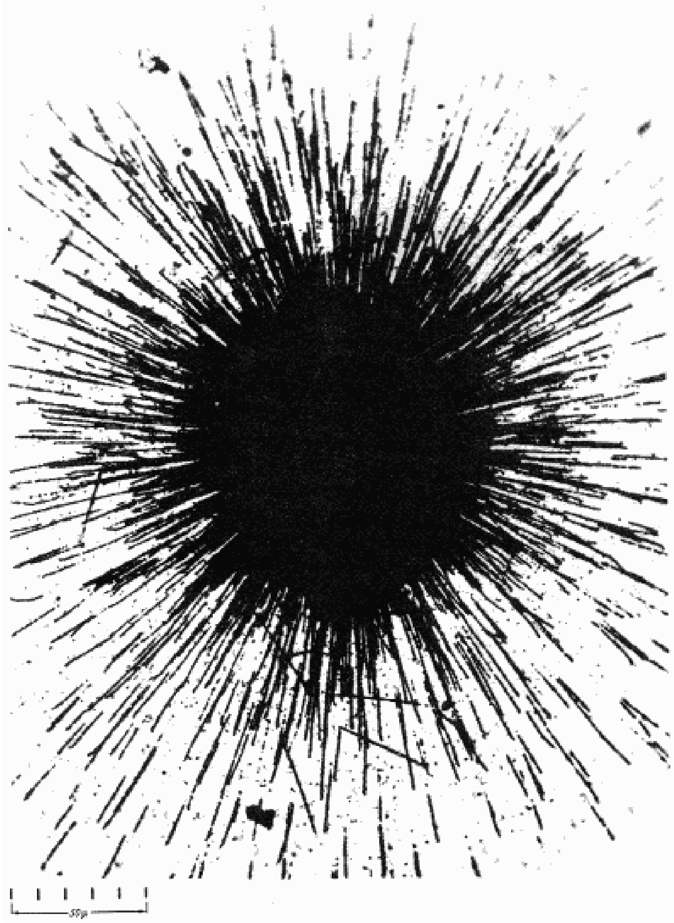
A Brief History of ELEMENT DISCOVERY, SYNTHESIS, and ANALYSIS

Glen W. Watson

September 1963

LAWRENCE RADIATION LABORATORY
University of California
Berkeley and Livermore

Operating under contract with the
United States Atomic Energy Commission



Radioactive elements: alpha particles from a speck of radium leave tracks on a photographic emulsion. (Occhialini and Powell, 1947)

[Pg 1]

A BRIEF HISTORY OF ELEMENT DISCOVERY, SYNTHESIS, AND ANALYSIS

It is well known that the number of elements has grown from four in the days of the Greeks to 103 at present, but the change in methods needed for their discovery is not so well known. Up until 1939, only 88 naturally occurring elements had been discovered. It took a dramatic modern technique (based on Ernest O. Lawrence's Nobel-prize-winning atom smasher, the cyclotron) to synthesize the most recently discovered elements. Most of these recent discoveries are directly attributed to scientists working under the Atomic Energy Commission at the University of California's Radiation Laboratory at Berkeley.

But it is apparent that our present knowledge of the elements stretches back into history: back to England's Ernest Rutherford, who in 1919 proved that, occasionally, when an alpha particle from radium strikes a nitrogen atom, either a proton or a hydrogen nucleus is ejected; to the Dane Niels Bohr and his 1913 idea of electron orbits; to a once unknown Swiss patent clerk, Albert Einstein, and his now famous theories; to Poland's Marie Curie who, in 1898, with her French husband Pierre laboriously isolated polonium and radium; back to the French scientist H. A. Becquerel, who first discovered something he called a "spontaneous emission of penetrating rays from certain salts of uranium"; to the German physicist W. K. Roentgen and his discovery of x rays in 1895; and back still further.

During this passage of scientific history, the very idea of "element" has undergone several great changes.

The early Greeks suggested earth, air, fire, and water as being the essential material from which all others were made. Aristotle considered these as being combinations of four properties: hot, cold, dry, and moist (see Fig. 1). [Pg 2]

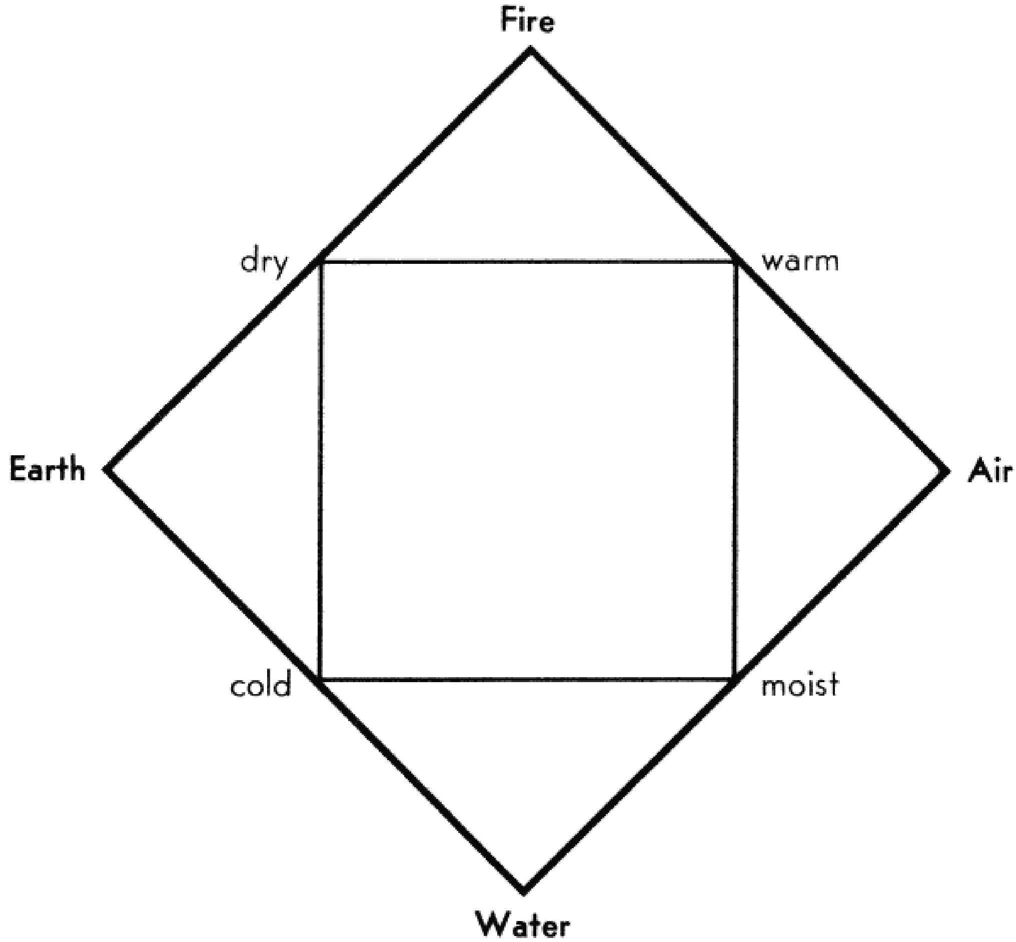


Fig. 1. The elements as proposed by the early Greeks.

Later, a fifth "essence," ether, the building material of the heavenly bodies was added.

Paracelsus (1493-1541) introduced the three alchemical symbols salt, sulfur, and mercury. Sulfur was the principle of combustability, salt the fixed part left after burning (calcination), and mercury the essential part of all metals. For example, gold and silver were supposedly different combinations of sulfur and mercury.

Robert Boyle in his "Sceptical Chymist" (1661) first defined the word element in the sense which it retained until the discovery of radioactivity (1896), namely, a form of matter that could not be split into simpler forms. [Pg 3]

The first discovery of a true element in historical time was that of phosphorus by Dr. Brand of Hamburg, in 1669. Brand kept his process secret, but, as in modern times, knowledge of the element's existence was sufficient to let others, like Kunkel and Boyle in England, succeed independently in isolating it shortly afterward.

As in our atomic age, a delicate balance was made between the "light-giving" (desirable) and "heat-giving" (feared) powers of a discovery. An early experimenter was at first "delighted with the white, waxy substance that glowed so charmingly in the dark of his laboratory," but later wrote, "I am not making it any more for much harm may come of it."

Robert Boyle wrote in 1680 of phosphorus, "It shone so briskly and lookt so oddly that the sight was extreamly pleasing, having in it a mixture of strangeness, beauty and frightfulness."

These words describe almost exactly the impressions of eye witnesses of the first atom bomb test at Alamagordo, New Mexico, July 16, 1945.

For the next two and three-quarters centuries the chemists had much fun and some fame discovering new elements. Frequently there was a long interval between discovery and recognition. Thus Scheele made chlorine in 1774 by the action of "black manganese" (manganese dioxide) on concentrated muriatic acid (hydrochloric acid), but it was not recognized as an element till the work of Davy in 1810.

Occasionally the development of a new technique would lead to the "easy" discovery of a whole group of new elements. Thus Davy, starting in 1807, applied the method of electrolysis, using a development of

Volta's pile as a source of current; in a short time he discovered aluminum, barium, boron, calcium, magnesium, potassium, sodium, and strontium.

The invention of the spectroscope by Bunsen and Kirchhoff in 1859 provided a new tool which could establish the purity of substances already known and lead to the discovery of others. Thus, helium was discovered in the sun's spectrum by Jansen and isolated from uranite by Ramsay in 1895. [Pg 4]

The discovery of radioactivity by Becquerel in 1896 (touched off by Roentgen's discovery of x rays the year before) gave an even more sensitive method of detecting the presence or absence of certain kinds of matter. It is well known that Pierre and Marie Curie used this new-found radioactivity to identify the new elements polonium and radium. Compounds of these new elements were obtained by patient fractional recrystallization of their salts.

The "explanation" of radioactivity led to the discovery of isotopes by Rutherford and Soddy in 1914, and with this discovery a revision of our idea of elements became necessary. Since Boyle, it had been assumed that all atoms of the individual elements were identical and unlike any others, and could not be changed into anything simpler. Now it became evident that the atoms of radioactive elements were constantly changing into other elements, thereby releasing very large amounts of energy, and that many different forms of the same element (lead was the first studied) were possible. We now think of an element as a form of matter in which all atoms have the same nuclear charge.

The human mind has always sought order and simplification of the external world; in chemistry the fruitful classifications were Dobereiner's Triads (1829), Newland's law of octaves (1865), and Mendeleev's periodic law (1869). The chart expressing this periodic law seemed to indicate the maximum extent of the elements and gave good hints "where to look for" and "the probable properties of" the remaining ones (see Fig. 2).

By 1925, all but four of the slots in the 92-place file had been filled. The vacancies were at 43, 61, 85, and 87.

[Pg 5]

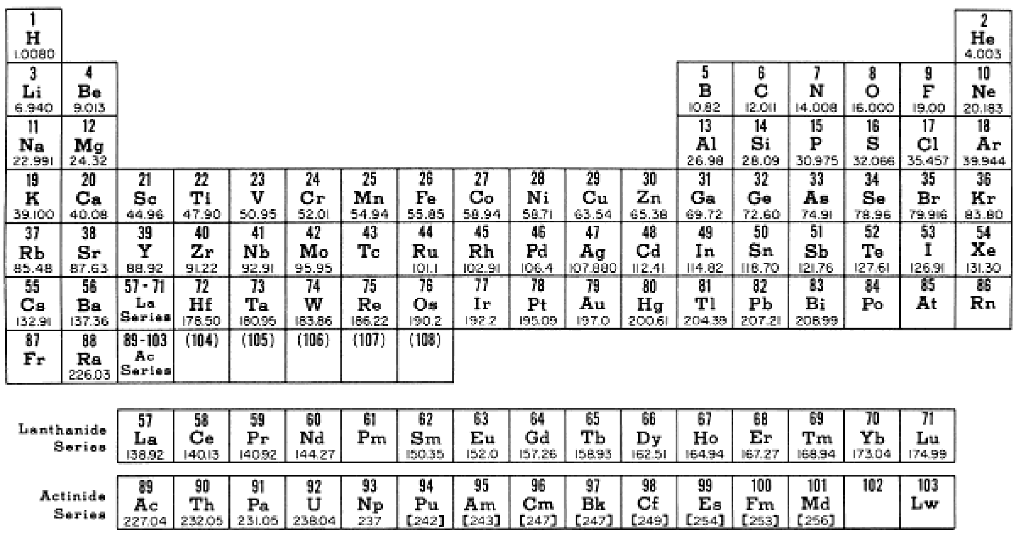


Fig. 2. Periodic chart of the elements (1963)

Workers using traditional analytical techniques continued to search for these elements, but their efforts were foredoomed to failure. None of the nuclei of the isotopes of elements 43, 61, 85, and 87 are stable; hence weighable quantities of them do not exist in nature, and new techniques had to be developed before we could really say we had "discovered" them. [Pg 6]

In 1919, Rutherford accomplished scientifically what medieval alchemists had failed to do with "magic" experiments and other less sophisticated techniques. It wasn't gold (the goal of the alchemists) he found but something more valuable with even greater potential for good and evil: a method of transmuting one element into another. By bombarding nitrogen nuclei with alpha particles from radium, he found that nitrogen was changed into oxygen.

The process for radioactive transmutation is somewhat like a common chemical reaction. An alpha particle, which has the same charge (+2) and atomic mass (4) as a helium nucleus, penetrates the repulsive forces of the nitrogen nucleus and deposits one proton and one neutron; this changes the nitrogen atom into an oxygen atom. The reaction is written

$$_{7}N^{14} + {}_{2}He^{4} \rightarrow {}_{1}H^{1} + {}_{8}O^{17}.$$

The number at the lower left of each element symbol in the above reaction is the proton number. This number determines the basic chemical identity of an atom, and it is this number scientists must change before one element can be transformed into another. The common way to accomplish this artificially is by bombarding nuclei with nuclear projectiles.

Rutherford used naturally occurring alpha particles from radium as his projectiles because they were the most effective he could then find. But these natural alpha particles have several drawbacks: they are positively charged, like the nucleus itself, and are therefore more or less repulsed depending on the proton number of the element being bombarded; they do not move fast enough to penetrate the nuclei of heavier elements (those with many protons); and, for various other reasons (some of them unexplained), are inefficient in breaking up the nucleus. It is estimated that only 1 out of 300,000 of these alpha particles will react with nitrogen.

Physicists immediately began the search for artificial means to accelerate a wider variety of nuclear particles to high energies. [Pg 7]

Protons, because they have a +1 charge rather than the +2 charge of the alpha particles, are repulsed less strongly by the positive charge on the nucleus, and are therefore more useful as bombarding projectiles. In 1929, E. T. S. Walton and J. D. Cockcroft passed an electric discharge through hydrogen gas, thereby removing electrons from the hydrogen atom; this left a beam of protons (i. e., hydrogen ions), which was then accelerated by high voltages. This Cockcroft-Walton voltage multiplier accelerated the protons to fairly high energies (about 800,000 electron volts), but the protons still had a plus charge and their energies were still not high enough to overcome the repulsive forces (Coulombic repulsion) of the heavier nuclei.

A later development, the Van de Graaff electrostatic generator, produced a beam of hydrogen ions and other positively charged ions, and electrons at even higher energies. An early model of the linear accelerator also gave a beam of heavy positive ions at high energies. These were the next two instruments devised in the search for efficient bombarding projectiles. However, the impasse continued: neither instrument allowed scientists to crack the nuclei of the heavier elements.

Ernest O. Lawrence's cyclotron, built in 1931, was the first device capable of accelerating positive ions to the very high energies needed. Its basic principle of operation is not difficult to understand. A charged particle accelerated in a cyclotron is analogous to a ball being whirled on a string fastened to the top of a pole. A negative electric field attracts the positively charged particle (ball) towards it and then switches off until the particle swings halfway around; the field then becomes negative in front of the particle again, and again attracts it. As the particle moves faster and faster it spirals outward in an ever increasing circle, something like a tether ball unwinding from a pole. The energies achieved would have seemed fantastic to earlier scientists. The Bevatron, a modern offspring of the first cyclotron, accelerates protons to 99.13% the speed of light, thereby giving them 6.2 billion electron volts (BeV).

Another instrument, the heavy-ion linear accelerator (Hilac), accelerates ions as heavy as neon to about 15% the speed of light. It is called a linear accelerator because it accelerates particles in a straight line. Stanford University is currently (1963) in the process of building a linear accelerator approximately two miles long which will accelerate charged particles to 99.9% the speed of light. [Pg 8]

But highly accelerated charged particles did not solve all of science's questions about the inner workings of the nucleus.

In 1932, during the early search for more efficient ways to bombard nuclei, James Chadwick discovered the neutron. This particle, which is neutral in charge and is approximately the same mass as a proton, has the remarkable quality of efficiently producing nuclear reactions even at very low energies. No one exactly knowns why. At low energies, protons, alpha particles, or other charged particles do not interact with nuclei because they cannot penetrate the electrostatic energy barriers. For example, slow positive particles pick up electrons, become neutral, and lose their ability to cause nuclear transformations. Slow neutrons, on the other hand, can enter nearly all atomic nuclei and induce fission of certain of the heavier ones. It is, in fact, these properties of the neutron which have made possible the utilization of atomic energy.

With these tools, researchers were not long in accurately identifying the missing elements 43, 61, 85, and 87 and more—indeed, the list of new elements, isotopes, and particles now seems endless.

Element 43 was "made" for the first time as a result of bombarding molybdenum with deuterons in the Berkeley cyclotron. The chemical work of identifying the element was done by Emilio Segrè and others then working at Palermo, Sicily, and they chose to call it technetium, because it was the element first made by artificial technical methods.

Element 61 was made for the first time from the fission disintegration products of uranium in the Clinton (Oak Ridge) reactor. Marinsky and Glendenin, who did the chemical work of identification, chose to call it [Pg 9] promethium because they wished to point out that just as Prometheus stole fire (a great force for good or evil) from the hidden storehouse of the gods and presented it to man, so their newly assembled reactor delivered to mankind an even greater force, nuclear energy.

Element 85 is called astatine, from the Greek astatos, meaning "unstable," because astatine *is* unstable (of course all other elements having a nuclear charge number greater than 84 are unstable, too). Astatine was first made at Berkeley by bombarding bismuth with alpha particles, which produced astatine and released two neutrons. The element has since been found in nature as a small constituent of the natural decay of actinium.

The last of the original 92 elements to be discovered was element 87, francium. It was identified in 1939 by French scientist Marguerite Perey.

Children have a game in which they pile blocks up to see how high they can go before they topple over. In medieval times, petty rulers in their Italian states vied with one another to see who could build the tallest tower. Some beautiful results of this game still remain in Florence, Siena, and other Italian hill cities. Currently, Americans vie in a similar way with the wheelbase and overall length of their cars. After 1934, the game among scientists took the form of seeing who could extend the length of the periodic system of the elements; as with medieval towers, it was Italy that again began with the most enthusiasm and activity under the leadership of Enrico Fermi.

Merely adding neutrons would not be enough; that would make only a heavier isotope of the already known heaviest elements, uranium. However, if the incoming neutron caused some rearrangement within the nucleus and if it were accompanied by expulsion of electrons, that *would* make a new element. Trials by Fermi and his co-workers with various elements led to unmistakeable evidence of the expulsion of electrons (beta activity) with at least four different rates of decay (half-lives). Claims were advanced for the creation [Pg 10] of elements 93 and 94 and possibly further (the transuranium elements, Table I). Much difficulty was experienced, however, in proving that the activity really was due to the formation of elements 93 and 94. As more people became interested and extended the scope of the experiments, the picture became more confused rather than clarified. Careful studies soon showed that the activities did *not* decay logarithmically—which means that they were caused by mixtures, not individual pure substances—and the original four activities reported by Fermi grew to at least nine.

As a matter of fact, the way out of the difficulty had been indicated soon after Fermi's original announcement. Dr. Ida Noddack pointed out that no one had searched among the products of Fermi's experiment for elements *lighter* than lead, but no one paid any attention to her suggestion at the time. The matter was finally cleared up by Dr. Otto Hahn and F. Strassmann. They were able to show that instead of uranium having small pieces like helium nuclei, fast electrons, and super-hard x-rays, knocked off as expected, the atom had split into two roughly equal pieces, together with some excess neutrons. This process is called nuclear fission. The two large pieces were unstable and decayed further with the loss of electrons, hence the β activity. This process is so complicated that there are not, as originally reported, only four half-lives, but at least 200 different varieties of at least 35 different elements. The discovery of fission attended by the release of enormous amounts of energy led to feverish activity on the part of physicists and chemists everywhere in the world. In June 1940, McMillan and Abelson presented definite proof that element 93 had been found in uranium penetrated by neutrons during deuteron bombardment in the cyclotron at the University of California Radiation Laboratory.

The California scientists called the newly discovered element neptunium, because it lies beyond the element uranium just as the planet Neptune lies beyond Uranus. The particular isotope formed in those first experiments was ${}_{93}Np^{239}$; this is read neptunium having a nuclear charge of 93 and an atomic mass number [Pg 11] of 239. It has a half-life of 2.3 days, during which it gives up another electron (β particle) and becomes element 94, or plutonium (so called after Pluto, the next planet beyond Neptune). This particular form of plutonium (${}_{94}Pu^{239}$) has such a long half-life (24,000 years) that it could not be detected. The first isotope of element 94 to be discovered was Pu^{238}, made by direct deuteron bombardment in the Berkeley 60-inch cyclotron by Radiation Laboratory scientists Seaborg, McMillan, Kennedy, and Wahl; it had an α-decay half-life of 86.4 years, which gave it sufficient radioactivity so that its chemistry could be studied.

Having found these chemical properties in Pu^{238}, experimenters knew ${}_{94}Pu^{239}$ would behave similarly. It was soon shown that the nucleus of ${}_{94}Pu^{239}$ would undergo fission in the same way as ${}_{92}U^{235}$ when bombarded with slow neutrons and that it could be produced in the newly assembled atomic pile. Researchers wished to learn as much as possible about its chemistry; therefore, during the summer of 1942 two large cyclotrons at St. Louis and Berkeley bombarded hundreds of pounds of uranium almost continuously. This resulted in the formation of 200 micrograms of plutonium. From this small amount, enough of the chemical properties of the element were learned to permit correct design of the huge plutonium-recovery plant at Hanford, Washington. In the course of these investigations, balances that would weigh up to 10.5 mg with a sensitivity of 0.02 microgram were developed. The "test tubes" and "beakers" used had internal diameters of 0.1 to 1 mm and could measure volumes of 1/10 to 1/10,000 ml with an accuracy of 1%. The fact that there was no intermediate stage of experimentation, but a direct scale-up at Hanford of ten billion times, required truly heroic skill and courage.

By 1944 sufficient plutonium was available from uranium piles (reactors) so that it was available as target material for cyclotrons. At Berkeley it was bombarded with 32-MeV doubly charged helium ions, and the following reactions took place:

$${}_{94}\mathrm{Pu}^{239}\ (\alpha, \mathrm{n})\ {}_{96}\mathrm{Cm}^{242}\ \frac{\alpha}{150\ \mathrm{days}}\ \rightarrow\ {}_{94}\mathrm{Pu}^{238}$$

[Pg 14]

This is to be read: plutonium having an atomic number of 94 (94 positively charged protons in the nucleus) and a mass number of 239 (the whole atom weighs approximately 239 times as much as a proton), when bombarded with alpha particles (positively charged helium nuclei) reacts to give off a neutron and a new element, curium, that has atomic number 96 and mass number 242. This gives off alpha particles at such a rate that half of it has decomposed in 150 days, leaving plutonium with atomic number 94 and mass number 238. The radiochemical work leading to the isolation and identification of the atoms of element 96 was done at the metallurgical laboratory of the University of Chicago.

The intense neutron flux available in modern reactors led to a new element, americium (Am), as follows:

$${}_{94}\mathrm{Pu}^{239}\ (\mathrm{n}, \gamma)\ {}_{94}\mathrm{Pu}^{240}\ (\mathrm{n}, \gamma)\ {}_{94}\mathrm{Pu}^{241}\ \beta\ \rightarrow\ {}_{95}\mathrm{Am}^{241}.$$

The notation (n, γ) means that the plutonium absorbs a neutron and gives off some energy in the form of gamma rays (very hard x rays); it first forms ${}_{94}\mathrm{Pu}^{240}$ and then ${}_{94}\mathrm{Pu}^{241}$, which is unstable and gives off fast electrons (β), leaving ${}_{95}\mathrm{Am}^{241}$.

Berkelium and californium, elements 97 and 98, were produced at the University of California by methods analogous to that used for curium, as shown in the following equations:

$${}_{95}\mathrm{Am}^{240}\ +\ \alpha\ \rightarrow\ {}_{97}\mathrm{Bk}^{243}\ +\ {}_{0}\mathrm{n}^{1},$$

and

$${}_{96}\mathrm{Cm}^{241}\ +\ \alpha\ \rightarrow\ {}_{98}\mathrm{Cf}^{244}\ +\ {}_{0}\mathrm{n}^{1}.$$

The next two elements, einsteinium (${}_{99}\mathrm{Es}$) and fermium (${}_{100}\mathrm{Fm}$), were originally found in the debris from the thermonuclear device "Mike," which was detonated on Eniwetok atoll November 1952. (This method of creating new substances is somewhat more extravagant than the mythical Chinese method of burning down a building to get a roast pig.)

These elements have since been made in nuclear reactors and by bombardment. This time the "bullet" was N^{14} stripped of electrons till it had a charge of +6, and the target was plutonium.

[Pg 15]

Researchers at the University of California used new techniques in forming and identifying element 101, mendelevium. A very thin layer of ${}_{99}\mathrm{Es}^{253}$ was electroplated onto a thin gold foil and was then bombarded, from behind the layer, with 41-MeV α particles. Unchanged ${}_{99}\mathrm{Es}^{253}$ stayed on the gold, but those atoms hit by α particles were knocked off and deposited on a "catcher" gold foil, which was then dissolved and analyzed (Fig. 3). This freed the new element from most of the very reactive parent substances, so that analysis was easier. Even so, the radioactivity was so weak that the new element was identified "one atom at a time"; this is possible because its daughter element, fermium, spontaneously fissions and releases energy in greater bursts than any possible contaminant.

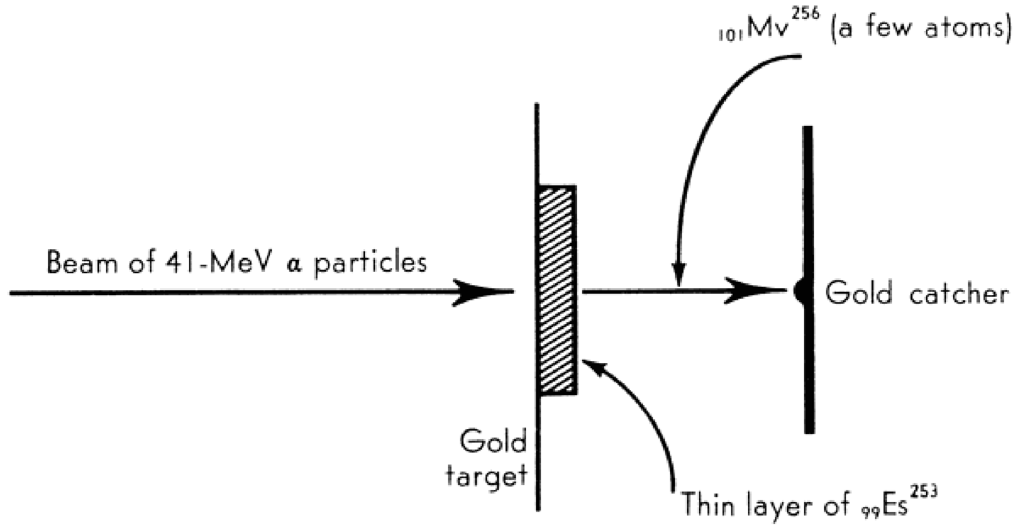


Fig. 3. The production of mendelevium.

In 1957, in Stockholm, element 102 was reported found by an international team of scientists (who called it nobelium), but diligent and extensive research failed to duplicate the Stockholm findings. However, a still newer technique developed at Berkeley showed the footprints—if not the living presence—of 102 (see Fig. 4). The rare isotope curium-246 is coated on a small piece of nickel foil, enclosed in a helium-filled container, and placed in the heavy-ion linear accelerator (Hilac) beam. Positively charged atoms of element [Pg 16] 102 are knocked off the foil by the beam, which is of carbon-12 or carbon-13 nuclei, and are deposited on a negatively charged conveyor apron. But element 102 doesn't live long enough to be actually measured. As it decays, its daughter product, $_{100}Fm^{250}$, is attracted onto a charged aluminum foil where it can be analyzed. The researchers have decided that the hen really did come first: they have the egg; therefore the hen must have existed. By measuring the time distance between target and daughter product, they figure that the hen-mother (element 102) must have a half-life of three seconds.

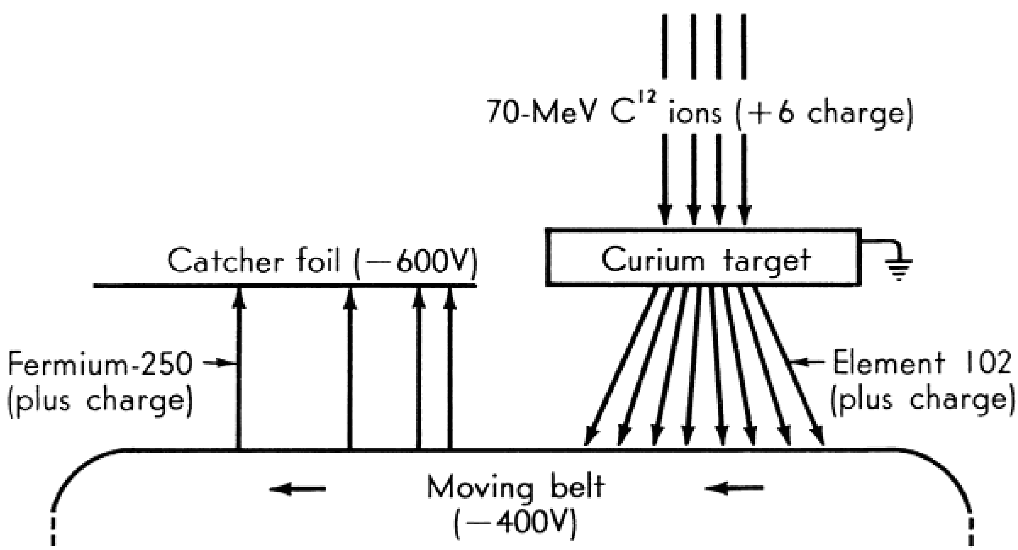


Fig. 4. The experimental arrangement used in the discovery of element 102.

In an experiment completed in 1961, researchers at the University of California at Berkeley unearthed similar "footprints" belonging to element 103 (named lawrencium in honor of Nobel prizewinner Ernest O. Lawrence). They found that the bombardment of californium with boron ions released α particles which had an energy of 8.6 MeV and decayed with a half-life of 8 ± 2 seconds. These particles can only be produced by element 103, which, according to one scientific theory, is a type of "dinosaur" of matter that died out a few weeks after creation of the universe.

The half-life of lawrencium (Lw) is about 8 seconds, and its mass number is thought to be 257, although [Pg 17] further research is required to establish this conclusively.

Research on lawrencium is complicated. Its total α activity amounts to barely a few counts per hour. And, since scientists had the α-particle "footprints" only and not the beast itself, the complications increased.

Therefore no direct chemical techniques could be used, and element 103 was the first to be discovered solely by nuclear methods.[A]

For many years the periodic system was considered closed at 92. It has now been extended by at least eleven places (Table I), and one of the extensions (plutonium) has been made in truckload lots. Its production and use affect the life of everyone in the United States and most of the world.

Surely the end is again in sight, at least for ordinary matter, although persistent scientists may shift their search to the other-world "anti" particles. These, too, will call for very special techniques for detection of their fleeting presence.

Early enthusiastic researchers complained that a man's life was not long enough to let him do all the work he would like on an element. The situation has now reached a state of equilibrium; neither man nor element lives long enough to permit all the desired work.

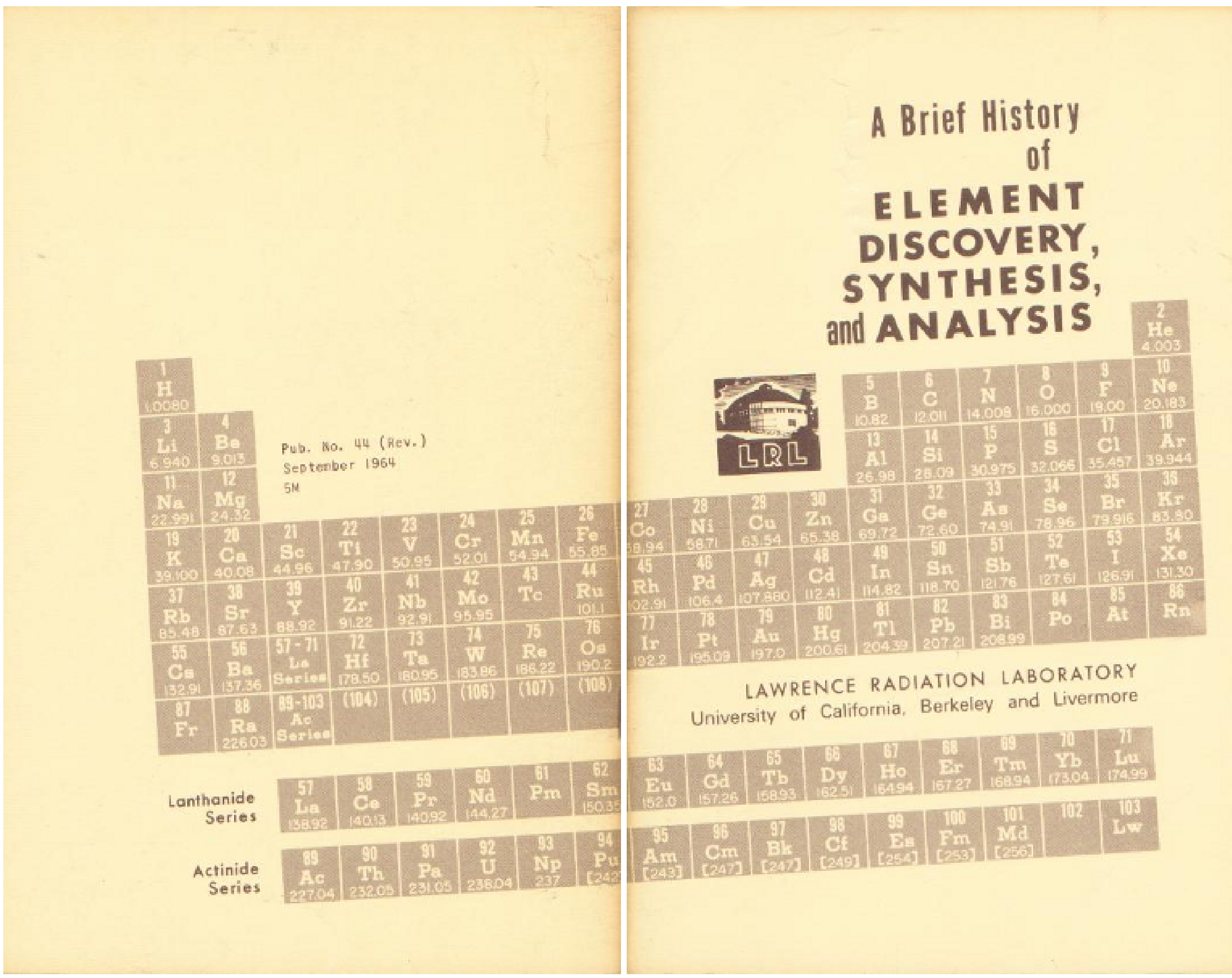
[A] In August 1964 Russian scientists claimed that they created element 104 with a half-life of about 0.3 seconds by bombarding plutomium with accelerated neon-22 ions.

Table I. THE TRANSURANIUM ELEMENTS [Pg 12]

Element	Name (Symbol)	Mass Number	Year Discovered; by whom; where; how
93	Neptunium (Np)	238	1940; E. M. McMillan, P. H. Abelson; University of California at Berkeley; slow-neutron bombardment of U^{238} in the 60-inch cyclotron.
94	Plutonium (Pu)	238	1941; J. W. Kennedy, E. M.McMillan, G. T. Seaborg, and A. C. Wahl; University of California at Berkeley; 16-MeV deuteron bombardment of U^{238} in the 60-inch cyclotron.
	(Pu)	239	Pu^{239}; the fissionable isotope of plutonium, was also discovered in 1941 by J. W. Kennedy, G. T. Seaborg, E. Segrè and A. C. Wahl; University of California at Berkeley; slow-neutron bombardment of U^{238} in the 60-inch cyclotron.
95	Americium (Am)	241	1944-45; Berkeley scientists A. Ghiorso, R. A. James, L. O. Morgan, and G. T. Seaborg at the University of Chicago; intense neutron bombardment of plutonium in nuclear reactors.
96	Curium (Cm)	242	1945; Berkeley scientists A. Ghiorso, R. A. James, and G. T. Seaborg at the University of Chicago; bombardment of Pu^{239} by 32-MeV helium ions from the 60-inch cyclotron.
97	Berkelium (Bk)	243	1949; S. G. Thompson, A. Ghiorso, and G. T. Seaborg; University of California at Berkeley; 35-MeV helium-ion bombardment of Am^{241}.
98	Californium (Cf)	245	1950; S. G. Thompson, K. Street, A. Ghiorso, G. T. Seaborg; University of California at Berkeley; 35-MeV helium-ion bombardment of Cm^{242}.
99 100	Einsteinium (Es) Fermium (Fm)	253 255	1952-53; A. Ghiorso, S. G. Thompson, G. H. Higgins, G. T. Seaborg, M. H. Studier, P. R. Fields, S. M. Fried, H. Diamond, J. F. Mech, G. L. Pyle, J. R. Huizenga, A. Hirsch, W. M. Manning, C. I. Browne, H. L. Smith, R. W. Spence; "Mike" explosion in South Pacific; work done at University of California at Berkeley, Los Alamos Scientific Laboratory, and Argonne National Laboratory; both elements created by multiple capture of neutrons in uranium of first detonation of a thermonuclear device. The elements were chemically isolated from the debris of the explosion. [Pg 13]
101	Mendelevium (Md)	256	1955; A. Ghiorso, B. G. Harvey, G. R. Choppin, S.

			G. Thompson, G. T. Seaborg; University of California at Berkeley; 41-MeV helium-ion bombardment of Es^{253} in 60-inch cyclotron.
102	Unnamed[B]	254	1958; A. Ghiorso, T. Sikkeland, A. E. Larsh, R. M. Latimer; University of California, Lawrence Radiation Laboratory, Berkeley; 68-MeV carbon-ion bombardment of Cm^{246} in heavy-ion linear accelerator (Hilac).
103	Lawrencium	257	1961; A. Ghiorso, T. Sikkeland, A. E. Larsh, R. M. Latimer; University of California, Lawrence Radiation Laboratory, Berkeley; 70-MeV boron-ion bombardment of Cf^{250}, Cf^{251}, and Cf^{252} in Hilac.

[B] A 1957 claim for the synthesis and identification of element 102 was accepted at that time by the International Union of Pure and Applied Chemistry, and the name nobelium (symbol No) was adopted. The University of California scientists, A. Ghiorso et al., cited here believe they have disproved the earlier claim and have the right to suggest a different name for the element.



Transcriber's Note

Table I (The Transuranium Elements) was originally located in the middle of the text on pages 12-13. To improve readability of the e-book text, it has been relocated to the end of the text.

The following errors are noted, but left as printed:

Page 8: "knowns" should be "knows"
Page 17, footnote B: "plutomium" should be "plutonium"
A more accurate rendering of the equation on page 11 would be
$${}_{94}\mathrm{Pu}^{239}\ (\alpha, \mathrm{n})\ {}_{96}\mathrm{Cm}^{242} \xrightarrow[\text{150 days}]{\alpha} {}_{94}\mathrm{Pu}^{238}$$