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CHARTING THE NEW ELEMENTS

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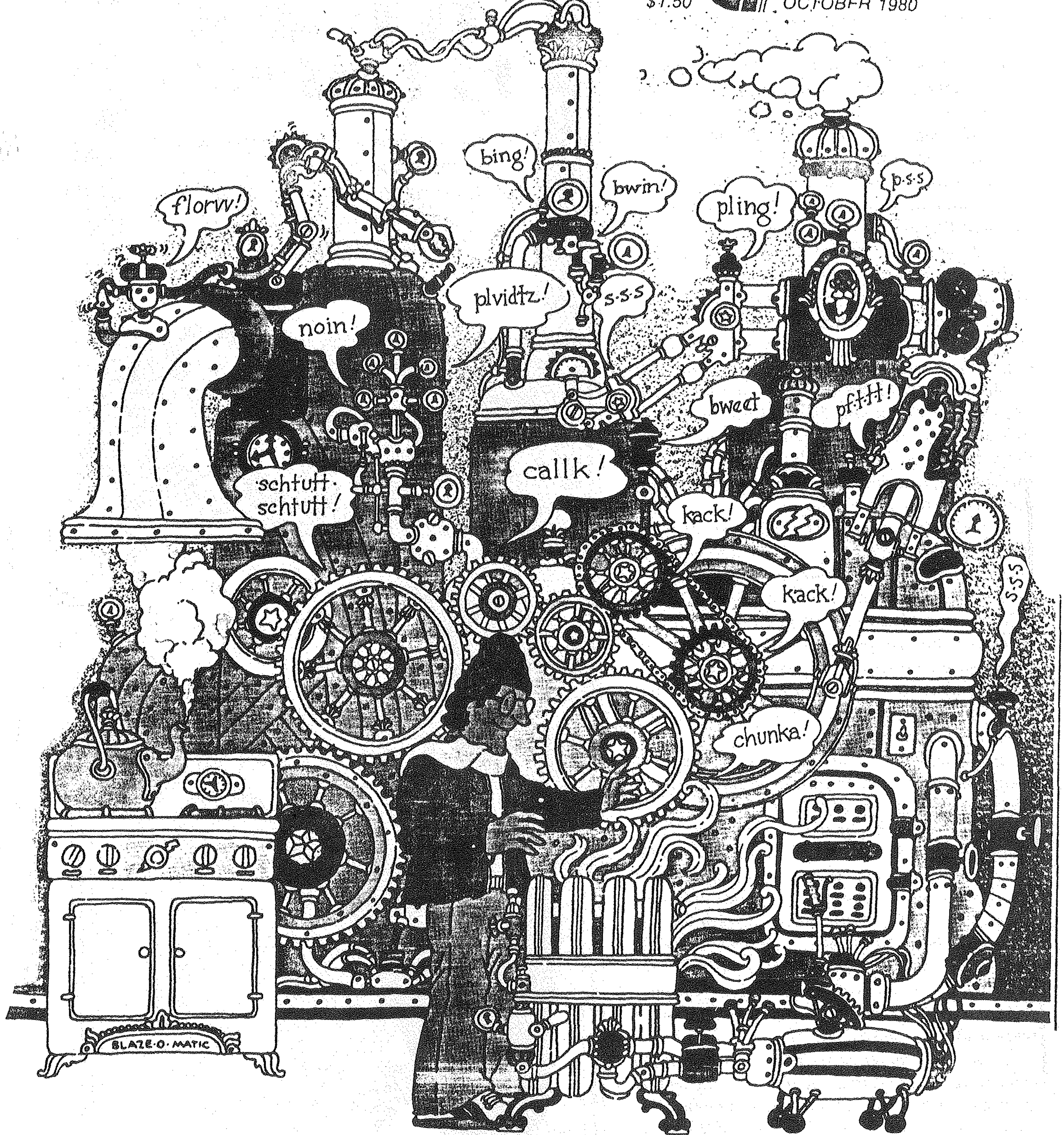


The Energizer

Uncle Sam as the Mother of Invention

"Fission" was the obvious answer to the question of how to produce lightweight elements from heavy ones. Once we settled that—and it took some time—we went on to the new elements, and have been working on them since that time.

Investigation of these new elements beyond the magical element uranium has led to a tremendous expansion of our knowledge of atomic and nuclear structure. The new elements are man-made, created through a variety of transmutation reactions by neutrons or charged particles, including heavy ions.

Our initiation into the realm of the new elements came in the spring of 1940, when Edwin M. McMillan and Philip H. Abelson proved that the radioactive product of their fission experiments was actually a new element—the first identifiable member of the transuranium family. In the 40 years following that discovery, teams of scientists have tried to increase our knowledge of nature by expanding the periodic table of elements. Looking at the events since late 1938 when fission was discovered not only illustrates how much has been learned, it also helps dispel any idea that good scientists—even top scientists working together—don't miss the obvious answer on occasion.

To really appreciate the number of false starts—the erroneous paths we took toward the discovery of the new elements—we need to go back to the beginning. And the beginning was in 1869, when Dmitry Ivanovich Mendeleyev, a Russian chemist, proposed an arrangement of chemical elements that not only took into account similarities among known elements, but which provided the framework for predicting then-unknown entries.

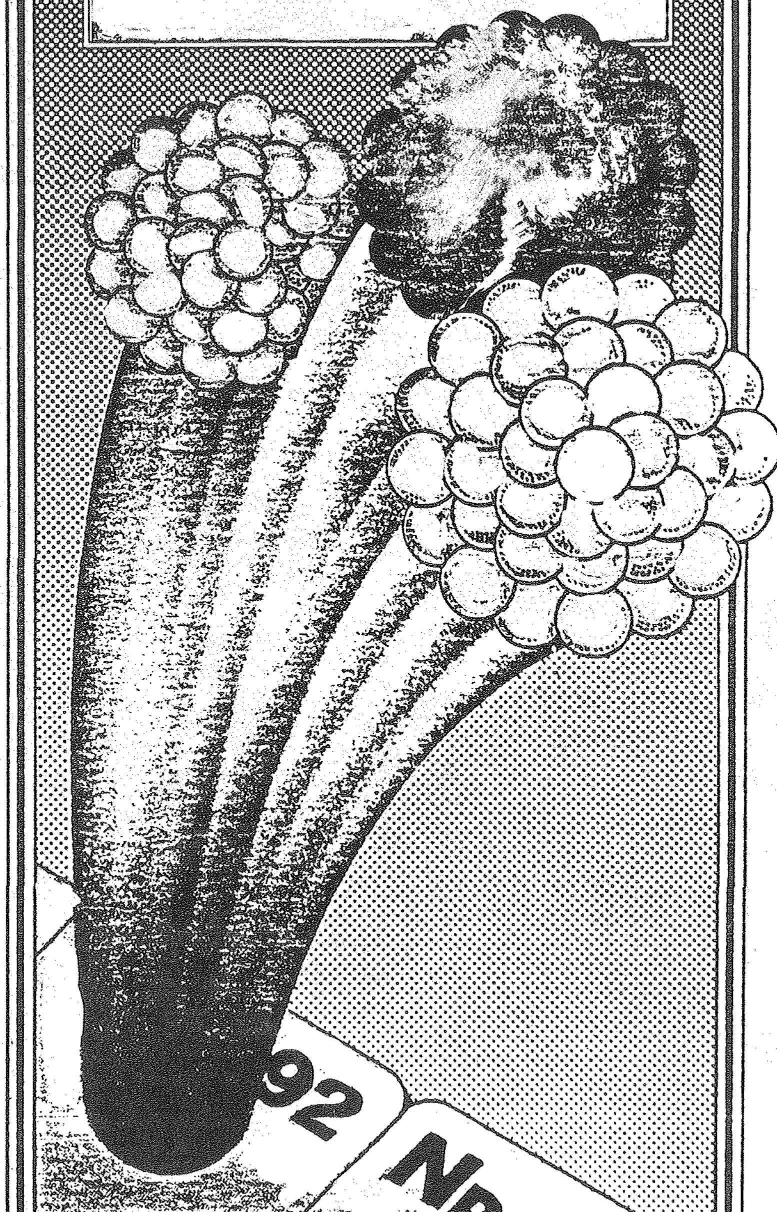
The form of the table was to line up the elements in order of their atomic weights, beginning with hydrogen and then going across to lithium, beryllium, boron, and so on. Then Mendeleyev noticed that if you started over again and went across, starting over once again at a certain point, elements with similar chemical properties fell into rows—the similarities ran vertically in the table. Mendeleyev made his most important contribution by realizing that to be logical he had to skip some places (atomic weights 44, 68 and 72), indicating that these were undiscovered elements.

It was only many years later that scientists came to realize that it is not atomic weights but atomic numbers, the charge in the nucleus, that should determine the construction of the periodic table. But even constructing it with weights, Mendeleyev predicted the existence somewhere on Earth of these three elements,

CHARTING THE NEW ELEMENTS

Scientists predict the undiscovered elements and their properties, but they have yet to find all of them. Fusing the nuclei of known elements may be the key.

by Glenn T. Seaborg



and predicted their chemical properties in some detail.

By the 1930s, the total number of known elements had increased to 88 including a family of so-called noble gases which was fitted into the scheme by the addition of another family group (vertical column), and a series of elements—the rare earths, or lanthanides—located in the place of a single element (lanthanum).

The positioning of the lanthanide series was chiefly the contribution of Niels Bohr, who showed that it should be pulled out of the main periodic table because, in this case, the chemical similarities ran horizontally, not vertically.

The work of Sir Joseph Thomson, Ernest Rutherford, Bohr, H. G. J. Moseley, Werner Heisenberg, Erwin Schrödinger, and others on the structure of the atom and its nucleus provided the final argument to support this 1930s version of the periodic table. They developed the concepts of atomic number and electronic structures to such a degree that these, rather than atomic weight, could be correlated with each chemical element's position in the table.

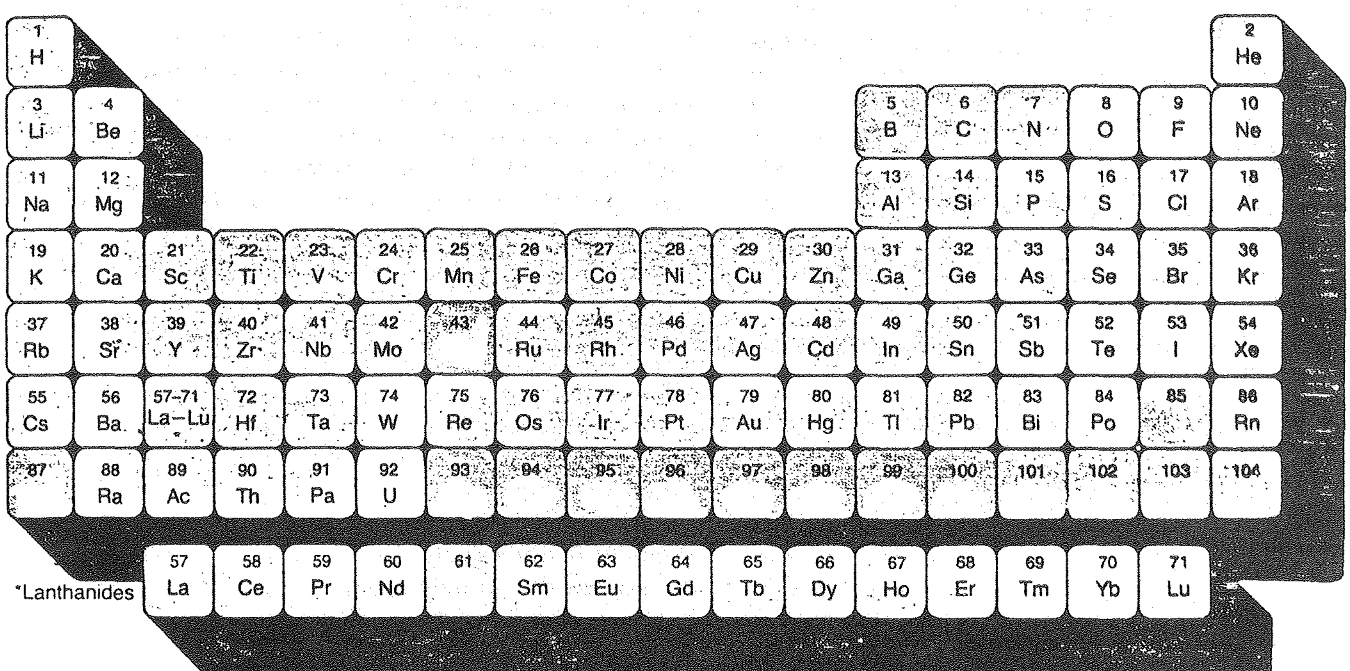
Using this periodic table, Enrico Fermi, the great Italian physicist, thought that if he could operate on uranium some way—transmute it—why couldn't he produce element 93, and maybe element 94? He would start with the heaviest element, actually by bombarding it with neutrons, and then hope that after it captured a neutron it would emit an electron (that is the same thing as increasing its charge by one), losing a negative charge, and that way go up to element 93. So Fermi bombarded uranium with neutrons, forming a number of radioactive isotopes. Of course it was expected that these isotopes would be radioactive because they do not exist on Earth; they had decayed away.

Fermi and his co-workers in 1934 thought that they proved chemically that one of the isotopes, with a half-life of 13 minutes, had chemical properties like those expected for element 93. Fermi thought that he had discovered a new element, and, in fact, when he received the Nobel prize in 1938 he was cited for discovery of the transuranium elements.

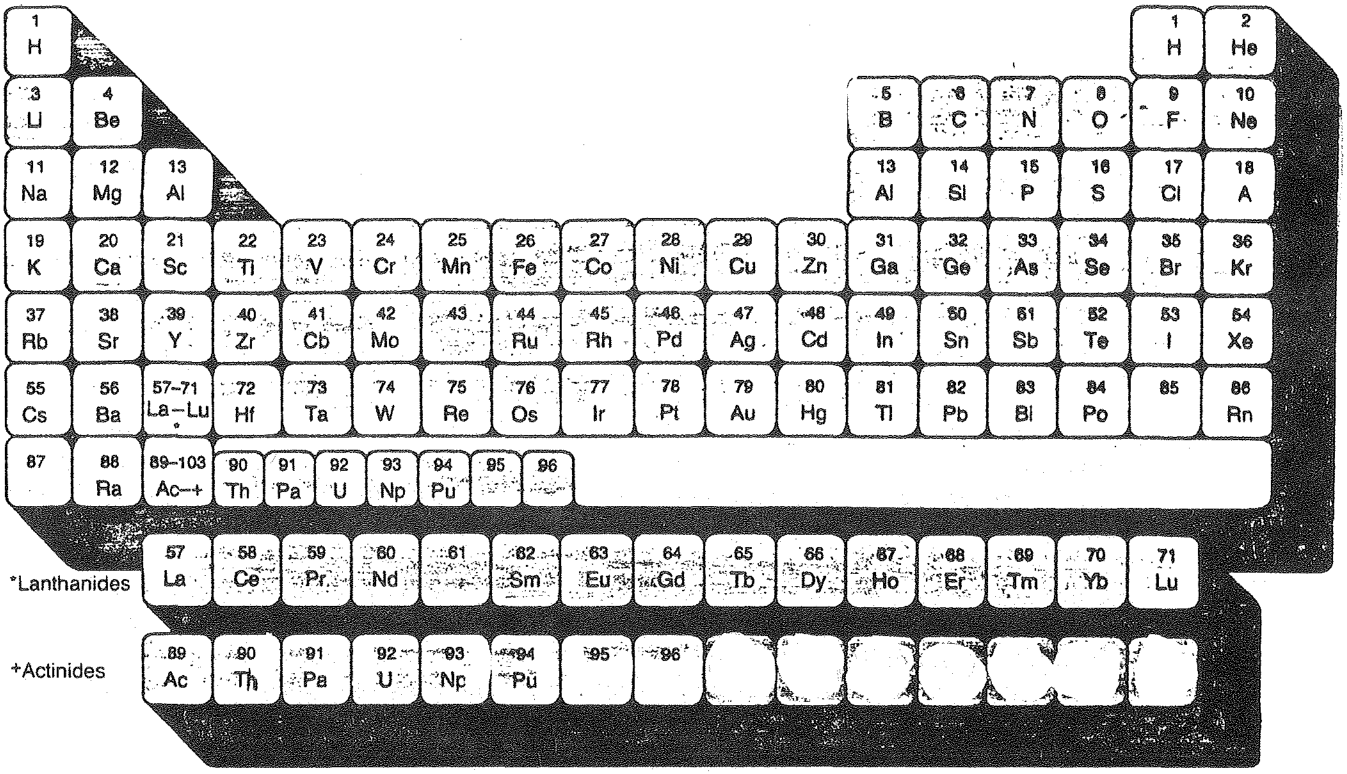
For several years the transuranium elements were the subject of much experimental work and discussion. Experiments by Otto Hahn, Lise Meitner, and F. Strassmann seemed to confirm Fermi's view. A series of papers published between 1935 and 1938 reported not only eka-rhenium—that which resembles rhenium—but eka-osmium, eka-iridium and eka-platinum.

There was only one person who didn't believe that those were transuranium elements—and that was Ida Noddack in Germany. In 1934 she wrote a paper asking why this activity couldn't be due to isotopes in the middle of the periodic table. Fermi had not proved that they were transuranium elements. Even then, we didn't see the light. This paper was in the literature from the beginning, and was ignored.

Early in 1939, Hahn and Strassmann described experiments that confirmed that they had observed radioactive barium isotopes as a result of the bombardment of uranium with neutrons. Subsequent work showed that the radioactivities previously ascribed to transura-



There were 88 known elements in the 1930s periodic table. Atomic numbers of then-undiscovered elements are in the tinted squares.



The periodic table, as it was published in 1945 by Seaborg, shows the heaviest elements as members of an actinide series.

nium elements are actually due to uranium fission products.

Hahn and Strassmann were absolutely nonplussed by their results, and the tone of that 1939 paper was more or less along the lines of: "You're not going to believe this, but this is what we found—actually, when you bombard uranium with neutrons, you get barium."

I remember when this news came to Berkeley. It was reported at what they call the Journal Club in the Physics Department, a meeting that I attended every Monday night. Somebody got up and said this: "You know, all of these transuranium elements that Hahn and Strassmann had been finding were due to the splitting of uranium in half, and fission . . . ." Before they had finished the sentence, I said to myself, "My God, what stupidity!" Obviously, that should be the explanation.

With poetic justice the actual discovery of the first transuranium element resulted from experiments aimed at understanding quite a different sort of process, fission.

During an investigation of the fission process, McMillan discovered a radioactive isotope of 2.3-day half-life. Working at the University of California at Berkeley in the spring of 1939, he was trying to measure the energies of the two main recoiling fragments from the neutron-induced fission of uranium. He found that the isotope with the 2.3-day half-life did not recoil sufficiently to escape.

He thought that could be due to the fact that it wasn't a fission product but rather element 93. McMillan wasn't able to prove that until Phil Abelson came to Berkeley and joined him, and did some chemistry. They found that the isotope could be chemically separated from all the other elements in the periodic table, but it had a different kind of chemistry entirely than had been predicted by Hahn, Strassmann, and the rest. It was chemically like uranium.

Element 93 was given the name neptunium (Np) because it is beyond uranium, just as the planet Neptune is beyond Uranus. Soon after this, a team consisting of McMillan, J. W. Kennedy, A. C. Wahl and myself went ahead and bombarded uranium with deuterons (nuclei of deuterium atoms) and found an isotope of neptunium, which upon decay led to an alpha-particle-emitting isotope, which was chemically like neptunium and uranium, but different. (An alpha particle is positively charged and is identical to the nucleus of the helium atom.) We could separate them and show that it was a new element. The name plutonium (symbol Pu), after the planet Pluto, was suggested for element 94 in a secret report written on March 21, 1942, which was actually published after the war.

At this time we thought that the transuranium elements had the same kind of a relationship as the rare earths—a new group of rare earths—and there should be 14 of them, with uranium as the prototype. This we would call the uranide series, just like the lanthanide series. And on this basis we would predict that element 95 and element 96 would be like plutonium, neptunium and uranium—a little different, but more or less the same. Wrong again! We were just slow learners; we had to proceed by making mistakes. When we tried by transmutation reactions to produce elements 95 and 96 by this method and chemically identify them, we could not do it.

In 1944, I got the idea that maybe these elements were misplaced in the periodic table and that you should start the new heavy rare earth series back at thorium. Actinium is the prototype, so it should be called the actinide series. If you do that, then by the time you get to 95 and 96, they should be like europium and gadolinium. When we did this, we found that it was right. We could identify elements 95 and 96, and a year later I published that rearrangement to the periodic table in *Chemical and Engineering News.* I remember at the time that I showed this table to a number of my friends and said that I contemplated publishing it in *Chemical and Engineering News.* They said, "Don't do it, you'll ruin your scientific reputation." I had a great advantage—I didn't have any scientific reputation at that time, so I went ahead and published it.

This concept had great predictive value, and its success led to acceptance by the scientific community. The modern periodic table contains not only a full lanthanide series, but a full actinide series as well.

The discovery of elements 95 and 96 was announced for the first time on "The Quiz Kids," a radio program. I was a guest on the program on Nov. 11, 1945, Armistice Day, and the moderator turned the format around so the Quiz Kids asked me questions for the last 15 minutes of the show. One of the kids, Richard Williams, asked me, "By the way, have any new elements been discovered during the work at the Metallurgy Laboratory during the war?" Our work had just been declassified so that I could present a paper the next Friday afternoon at an American Chemical Society Symposium at Northwestern University. So I just blurted out, "Yes, elements 95 and 96." This was the first time in the history of the world that the announcement of the discovery of chemical elements was sponsored by Alka Seltzer.

So, now we have the actinide series terminating at element 103, and all the elements be-

	1 H																	2 He
	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
	55 Cs	56 Ba	57–71 La–Lu *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
	87 Fr	88 Ra	89–103 Ac–Lr +	104 Rf	105 Ha	106	107	108	109	110	111	112	113	114	115	116	117	118
	119	120	121–153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
*Lanthanides			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
+Actinides			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	
**Super-actinides				122	123	124	125	126	→								153	

In this concept of the periodic table of the future, the atomic numbers of undiscovered elements appear in the tinted squares.

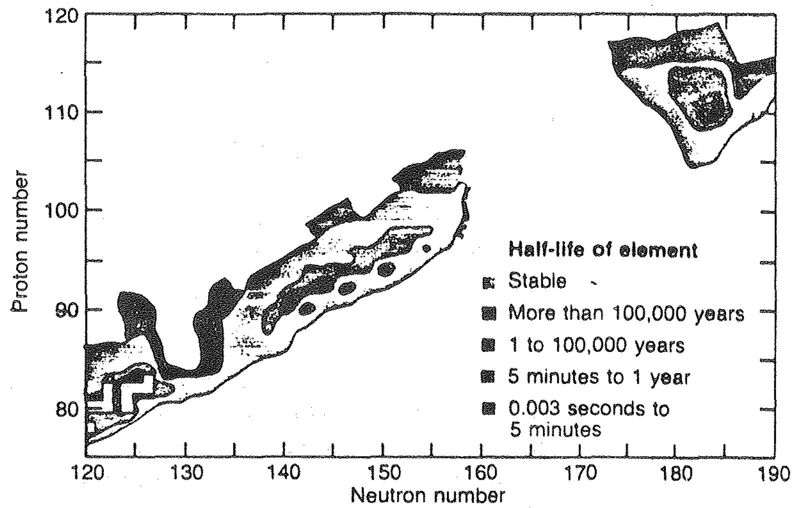
yond element 103 are referred to as transactinide elements. The first three of the transactinide elements—rutherfordium (element 104), hahnium (number 105) and the unnamed element 106—have been synthesized and identified by A. Ghiorso and co-workers at Berkeley. The study of the chemical properties of rutherfordium, which was discovered in 1969, has confirmed that it is indeed similar to hafnium. This similarity is demanded by the element's position in the periodic table.

Today we know of 14 transuranium elements, and we hold out hope for the production and identification of still further elements. But curiously enough, only by jumping up some distance in the periodic table are we likely to find them. Beyond 106, half-lives become short and yields become extremely small (with element 106, the yield is only a few atoms per day . . . at 107 the yield is predicted to be even smaller; at this point, identifications are hard to make). But there are theoretical indications that if you think big, moving into a region where there might be another closed proton or closed neutron shell, the nucleus will become relatively more stable and longer-lived.

Calculations based on modern theories of nuclear structure have shown that in instances where the proton number equals 114 and the neutron number equals 184, the ground states of nuclei should be stabilized against fission. This stabilization is due to the complete filling of major proton and neutron shells, in the same way that the noble gases are rendered stable by the filling of their electron shells. Some predictions of these superheavy elements estimate half-lives as long as 10^8 years—long enough still to exist on Earth even if they had been formed ages past when all the elements were produced by stellar reactions.

The circumstance of the superheavy elements has been optimistically "mapped" as the "island of stability" and separated from the "peninsula" of known nuclei by a "sea" of instability. To approach the island of stability after reaching the end of the known transuranium elements and crossing the sea of instability, large numbers of neutrons, as well as protons, must be added.

We have not yet reached the island of stability for two possible reasons: The reactions we have tried so far just do not produce superheavy elements, and our map of the island of stability may not be correct. For example, one reaction we have tried is fusion—fusing together two nuclei until they add up to the atomic number 114. But nuclei just don't seem to fuse when both components are very heavy. Those that do are so



This "map" of the peninsula of known elements and the island of stability represents the optimistic view of the discovery of superheavy elements.

excited that they undergo fission over 99 percent of the time and leave nothing for us to identify as a superheavy element.

Attempts to synthesize and identify superheavy elements through bombardments of a wide range of heavy nuclides with varieties of heavy ions have not yet been successful. But a great deal of effort has been expended to predict the chemical properties of the superheavies. If and when they are produced by some means, we would like to have a procedure for their chemical identification. And always we are in danger of misinterpreting the periodic table while trying to make our predictions of chemical properties fit into the scheme.

We have accumulated much knowledge since the alchemists succeeded in identifying arsenic, antimony and bismuth between the 12th and 16th centuries, and since most of the remaining elements—about 50 in all—were discovered in the 19th century. But we have not reached the end point or the completion of the periodic table. We continue to search for the undiscovered that we know is there.

Suggested Readings

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