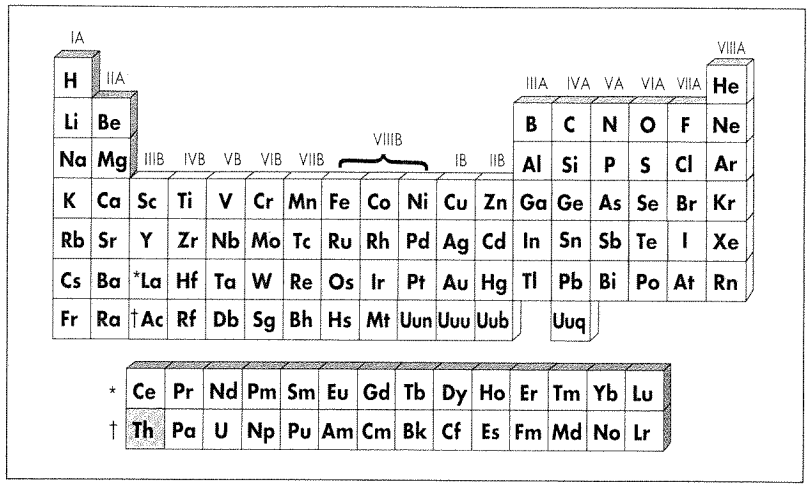
THORIUM



Th

Thorium is a radioactive, silvery-white metal that tarnishes very slowly when exposed to air. After a few months, it reacts with the air to form a black oxide. Pure thorium is very soft and malleable. Its oxide has a melting point of 3,300°C, one of the highest of any oxide, and when finely subdivided, can be ignited to burn in air, producing a brilliant white light.

Thorium was discovered in 1828 by the Swedish chemist Jöns Jakob Berzelius, who named it for Thor, the Scandinavian god of war. He was unaware of its radioactivity because that was not known as a physical process until it was discovered by Henri Becquerel and the Curies in 1897. Thorium-232, the isotope of thorium that occurs naturally, is actually very weakly radioactive. Its half-life is an enormous 14 billion years, so that very little of it decays in a short period. The radiation it emits can nevertheless fog photographic film if left in contact with the film for several hours.

Thorium-containing ores are about as abundant as those of lead in the Earth's crust and about three or four times more abundant than uranium ores. Monazite sand, some of which is found as beach sand in Florida, can contain up to 10 percent thorium, and this sand is used for the commercial preparation of the element.

Thorium shows great promise of becoming an important source of nuclear energy in the future. When thorium-232 is subjected to a beam of neutrons, it undergoes several nuclear transformations to form an isotope of uranium called uranium-233. Uranium-233 can undergo nuclear fission in the same manner as uranium-235, the isotope now used throughout the world as a commercial source of nuclear power. Several experi-

Atomic Number **90**

Chemical Symbol **Th**

Group **IIIB—Transition Element (The Actinides)**

Thorium oxide is used to make the mantles of portable gas lamps.

mental prototype reactors using uranium-233 are currently under construction. Given the large quantities of thorium available on Earth, there are hopes that it will become a major future source of energy.

Thorium has some 25 known isotopes, with half-lives ranging from one-tenth of a millionth of a second to the 14 billion years of thorium-232, the longest-lived isotope of the element. When thorium-232 decays, it transmutes itself into 11 different elements before ending up as lead-208, a stable isotope of lead. This series of transformations is called the thorium decay series.

Despite its radioactivity, thorium metal and its compounds have several commercial applications. The metal serves as an alloying element for magnesium that must be subjected to high temperatures. Thorium also serves as a very efficient emitter of electrons for electronic devices. The brilliant light that thorium oxide emits when burning makes it useful in fabricating certain types of portable gas lamps.

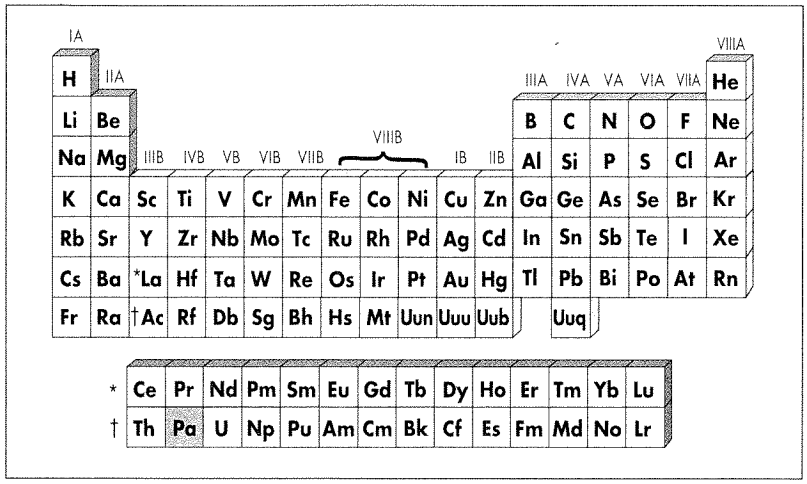
Thorium was discovered in 1828 by the Swedish chemist Jöns Jakob Berzelius, who named it for Thor, the Scandinavian god of war.

PROTACTINIUM

Atomic Number **91**

Chemical Symbol **Pa**

Group **IIIB—Transition Element (The Actinides)**



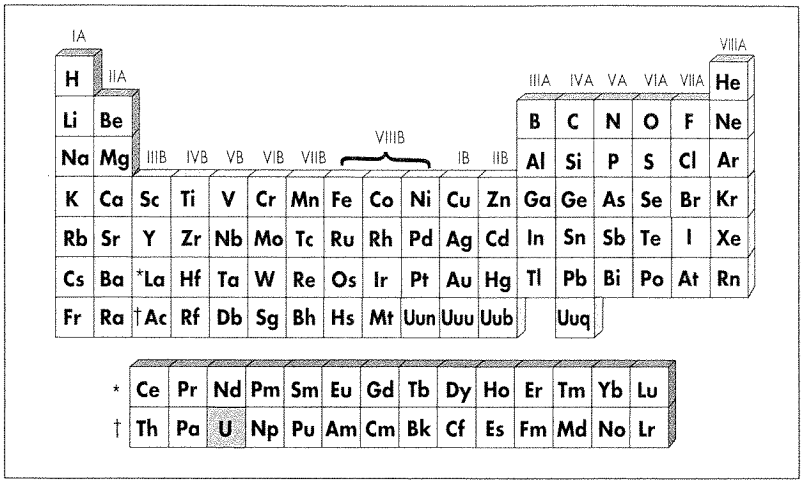
Pa

Protactinium is one of the scarcest and most expensive of the naturally existing elements. It is radioactive and is found in such uranium ores as pitchblende, where it is produced as one of the decay products of uranium.

Only a few hundred grams of protactinium are available for study. This meager amount was largely produced in England some 30 years ago, where it was extracted from 60 tons of ore at a cost of half a million dollars.

Protactinium was discovered by the German physicists Kasimir Fajans and O. H. Gohring in 1913 during an investigation of the elements produced in the decay of uranium. The two scientists actually named their new element brevium, but the name was later changed to protactinium in 1949. Its name is derived from the Greek word *protos,* meaning "first," and *actinium,* because the decay product of protactinium is actinium. There are some 22 known isotopes of protactinium, of which the most important is protactinium-231, with a half-life of 32,500 years.

Not much is known about the chemical and physical properties of protactinium. The pure metal was finally isolated in 1934, and it is a silvery-white metal with a bright luster that it loses very slowly in air, through oxidation. Protactinium is extremely toxic and must be handled with great care.



URANIUM

U

Uranium is the last and heaviest of the natural elements. Most people associate it with nuclear reactors and the atomic bomb as a source of enormous energy. Once considered scarce, it is now found in many minerals, including pitchblende, uranite, "yellowcake," and monazite sands. In the United States, the ownership and sale of uranium are strictly controlled by the U.S. Nuclear Regulatory Commission.

The use of uranium compounds to color glass and ceramic glazes dates back thousands of years. The German chemist Martin Klaproth, in 1789, was the first investigator to realize that pitchblende contained an unknown element. It was not until 1841 that the French chemist Eugène-Melchior Péligot first isolated and identified uranium. It was named for the planet Uranus. In 1896, the French physicist Henri Becquerel discovered that uranium was radioactive. It was the first radioactive element to be discovered.

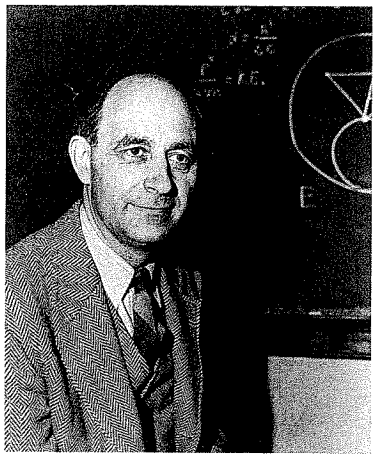
Naturally occurring uranium is a dense, silvery-white metal that quickly acquires a dark oxide coating when exposed to air. A typical sample of uranium essentially consists of two isotopes, uranium-238 (99.2798 percent) and uranium-235 (0.7171 percent), with a trace of a third isotope, uranium-234 (0.0031 percent). It is not surprising that uranium-238 is the dominant isotope of the element; its half-life of 4.6 billion years makes it the longest-lived of the three isotopes. A long half-life means that an isotope is less active, and that fewer of its atomic nuclei disintegrate in any given period. Uranium-235 has a half-life of 700 million years, while uranium-234 has a half-life of only 25 million years.

Given the long half-lives of these three isotopes, uranium itself is only weakly radioactive. But in the process of decaying, uranium does create many new highly radioactive isotopes, such

Atomic Number **92**

Chemical Symbol **U**

Group **IIIB—Transition Element (The Actinides)**



Enrico Fermi's work with uranium led to the first self-sustaining nuclear chain reaction in 1944. Fermi went on to work on the development of the atomic bomb.

Uranium is the last and heaviest of the natural elements.

as those of radon and polonium, before finally reaching a stable state as an isotope of lead. This chain of isotopes is called the uranium decay series.

In the late 1930s two German scientists, Lise Meitner and Otto Hahn, discovered that bombarding uranium with neutrons produced such elements as barium and krypton. The atoms of these elements were approximately half the size of the uranium atom. Where were they coming from? It was Lise Meitner and her nephew, the German physicist Otto R. Frisch, who first visualized the result as a fracture of the uranium nucleus into two fragments of intermediate size. They called the process, initiated by the uranium nucleus observing a neutron, nuclear fission. A large amount of energy was released in the process, as well as several additional neutrons. Subsequent research quickly demonstrated that it was the uranium-235 isotope that was fissioning.

The ability of the neutrons released during the fission of the uranium nucleus to themselves split other uranium nuclei was quickly utilized by scientists to create a self-sustaining chain reaction. When controlled, this reaction produces the energy we obtain from nuclear reactors. When uncontrolled, it can produce an atomic explosion. The first self-sustaining nuclear chain reaction was achieved by the Italian-American scientist Enrico Fermi at the University of Chicago in 1944.

The uranium fuel used for nuclear reactors is often enriched by increasing its percentage of uranium-235. The most common method for doing this uses the diffusion of gaseous uranium hexafluoride through thousands of porous membranes to obtain a fuel with the desired uranium-235 content. In the process of diffusion, which is the name given to the spontaneous movement of gases from regions of higher concentration to those of lower concentration, heavier gases move more slowly than light ones. Because uranium-238 is slightly heavier than uranium-235, it is eventually "left behind" as uranium-235 atoms accumulate at the end of the diffusion process.

When uranium-238 absorbs neutrons, it undergoes a number of reactions that transform it into plutonium-239, an isotope whose ability to fission is similar to uranium-235. This ability to fission is made use of in the so-called breeder reactors where new fuel in the form of plutonium-239 is produced as uranium-235, the original fuel powering the reactor is used up. Plutonium-239 is also used in the manufacture of atomic bombs.

Depleted uranium is uranium from which most of the uranium-235 atoms have decayed or been removed. It is used to produce armor-piercing antitank shells, ballast for missile re-entry

After the creation of the atomic bomb, the public was captivated by the potential of nuclear energy. Here, a woman experiments with her very own sample of uranium.

systems, glazes for ceramics, and shielding against radiation. Great care must be used in handling uranium-containing materials because, in addition to posing a radiation hazard, uranium and its compounds are highly toxic.

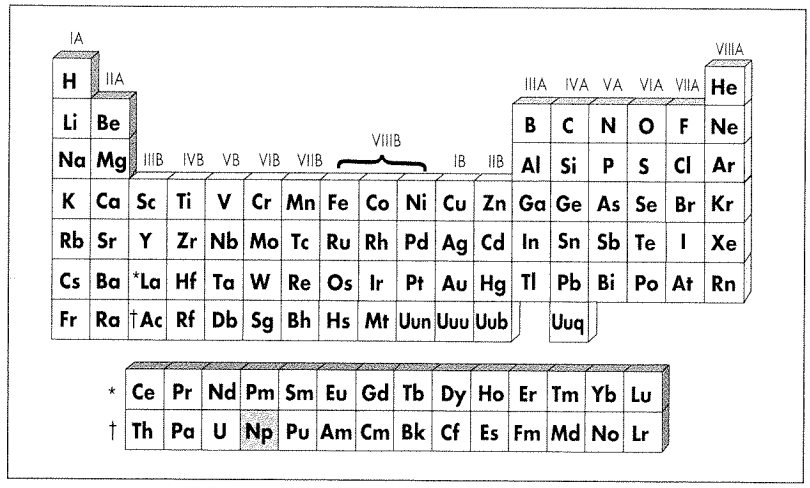
The age of rocks containing uranium can be dated by measuring the ratio of the remaining uranium-238 to the amount of lead-206, the last element in the uranium-238 decay series. This dating method has shown that the oldest rocks found on Earth are approximately 4.5 billion years old.

NEPTUNIUM

Atomic Number **93**

Chemical Symbol **Np**

Group **IIIB—Transition Element (The Actinides)**



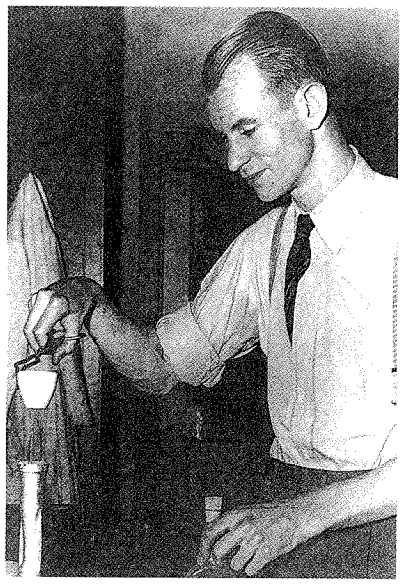
Np

Neptunium was the first artificially produced transuranium element. The prefix *trans* indicates that an element is "beyond" uranium in the periodic table. Neptunium derives its name from the planet Neptune because that is the planet beyond Uranus (the planet that gave its name to uranium) in our solar system.

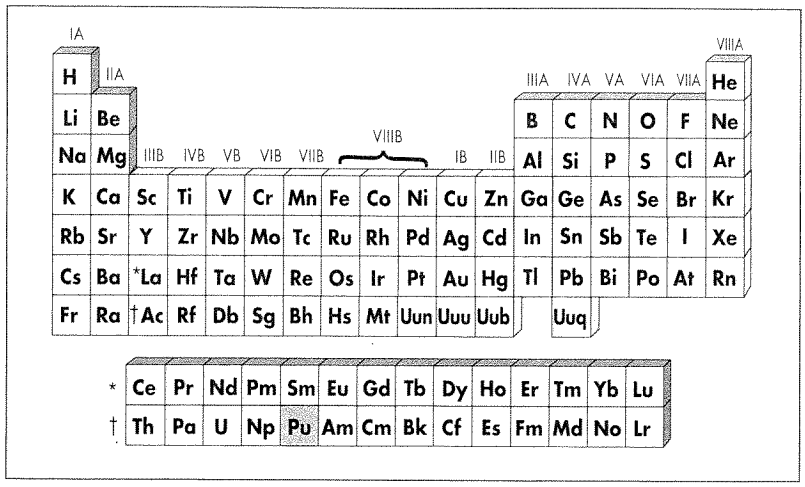
Neptunium was first produced by the American physicists Edwin M. McMillan and Philip H. Abelson in 1940. Working at the cyclotron at the University of California at Berkeley, they produced neptunium by bombarding uranium with neutrons. It is now known that trace quantities of neptunium do actually exist in nature as a result of the action of neutrons present in uranium ore.

Currently, 18 isotopes of neptunium have been produced, all of them radioactive. The most important, and the first to be produced, was neptunium-237, with a half-life of 2.1 million years.

Neptunium is currently being made in nuclear reactors as a by-product of the generation of plutonium. It is a fairly reactive, silvery metal.



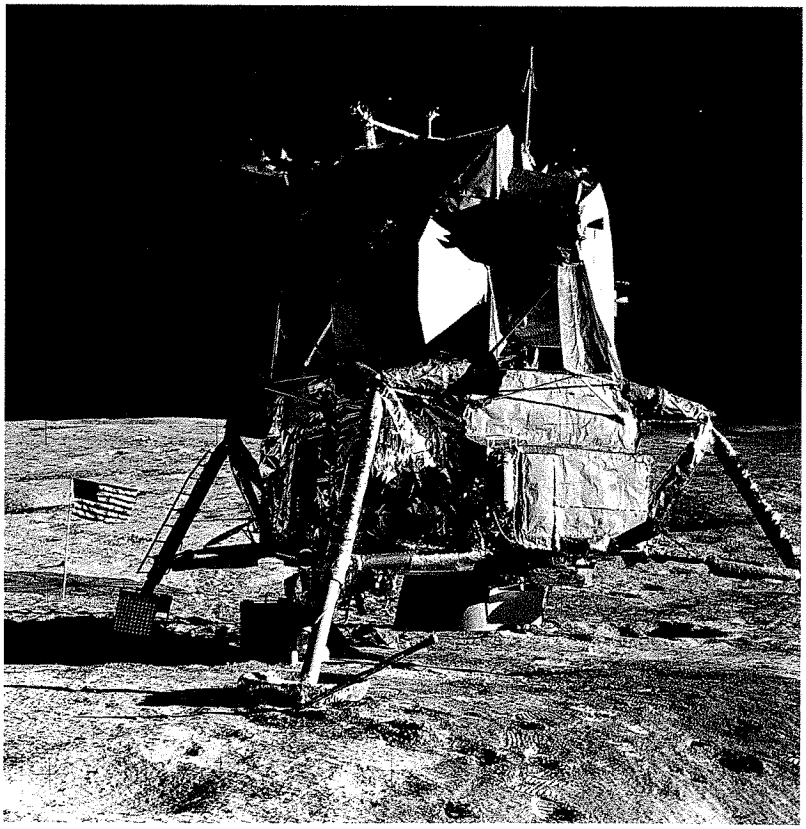
Dr. Edwin McMillan, one of the discoverers of neptunium, at work in his laboratory at the University of California at Berkeley.



Pu

PLUTONIUM

Plutonium is the most important of the transuranium elements, all of which follow uranium in the periodic table and all of which are artificially made. Plutonium was the second transuranium element to be synthesized (neptunium was the first). In 1941, the celebrated American chemist Glenn T. Seaborg used the cyclotron at the University of California at Berkeley to



Plutonium was used to power electronic equipment on this Apollo lunar excursion module (LEM) in 1971.

Atomic Number **94**

Chemical Symbol **Pu**

Group **IIIB—Transition Element (The Actinides)**

In 1941, American chemist Glenn T. Seaborg used the cyclotron at the University of California at Berkeley to discover plutonium.

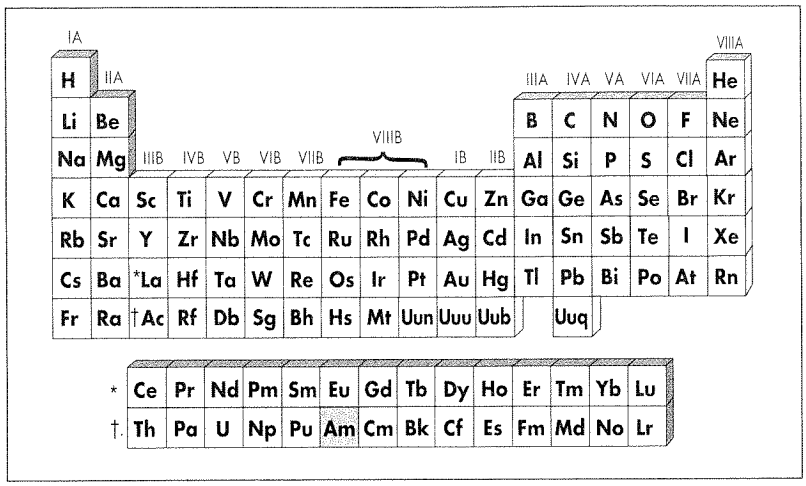
discover plutonium. The element was produced by bombarding uranium with deuterons. Deuterons are the nuclei of the hydrogen isotope deuterium and contain a neutron as well as a proton. Plutonium was named for Pluto, the planet that follows Neptune (which gave its name to neptunium) in our solar system. Because the United States was at war with Germany and Japan during this period, the discovery of plutonium was not announced until 1946 for security reasons.

Plutonium is a fairly active, silvery metal that tarnishes in air to form an oxide with a slightly yellow color. A sample of the metal feels warm to the touch because of the energy released by its own radiation. The element is highly toxic, and special care is required to handle it safely.

Plutonium has 15 known isotopes, and all are radioactive. Plutonium-239, with a half-life of 24,400 years, is the most important because it readily fissions when bombarded by thermal neutrons. Like uranium-235, the nuclei of its atoms split into two intermediate-size nuclei (called fission fragments), releasing large amounts of energy and producing more neutrons to sustain a chain reaction. Mixed with powdered beryllium, it is an effective source of neutrons for scientific work in laboratories and universities. Here the alpha particles emitted by the plutonium interact with beryllium nuclei to produce the neutrons.

Plutonium can be produced in huge quantities of tens of thousands of kilograms per year in nuclear reactors. Special "breeder" reactors have the sole function of producing plutonium, but it is also produced in ordinary nuclear reactors. The plutonium generated in the latter way is fairly easy to remove from the uranium by chemical separation. Huge diffusion plants, like the ones needed to to separate uranium-235 from uranium-238, are not required. The abundance of plutonium has made it the material of choice for nuclear weapons.

Plutonium-238, with a half-life of 87 years, emits only alpha particles (helium nuclei), which are easily stopped by shielding. Although it does not fission, the energy of the alpha particles it gives off can be converted into heat, and this heat can then be converted into electricity by a thermoelectric device. The yield is about one half a watt of power for every gram of plutonium. This has made it useful for power sources that are remote, such as on the Apollo lunar excursion module, or difficult to get at, such as a pacemaker for the heart.



AMERICIUM

Atomic Number **95**

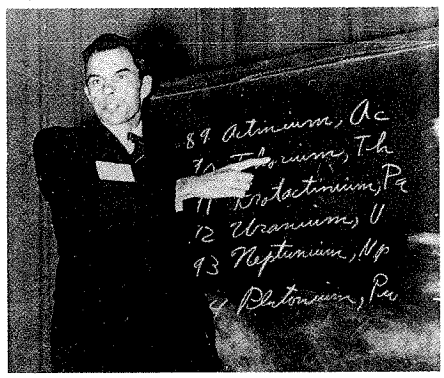
Chemical Symbol **Am**

Group **IIIB—Transition Element (The Actinides)**

Am

Americium is a transuranium element, one of the elements that follows uranium in the periodic table. Like all of the transuranium elements, it is artificially made. It was the fourth transuranium element to be discovered and was named after the place where it was discovered, America.

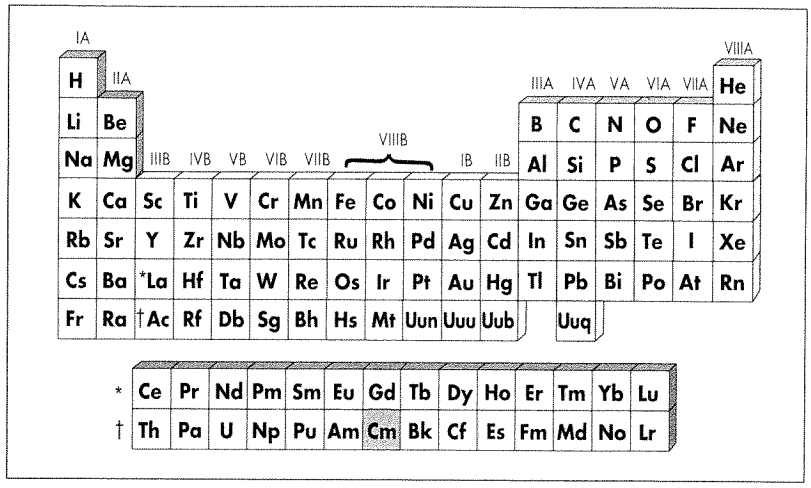
Americium was discovered in 1944 by a team of chemists working under the leadership of the American chemist Glenn T. Seaborg. This took place during World War II, and the work was done at the former Metallurgical Laboratory at the University of Chicago, a laboratory that is today the world-famous Argonne National Laboratory. Seaborg's team produced americium-241, one of the 14 known isotopes of americium, all of which are radioactive, by bombarding plutonium with neutrons. Americium-241 emits both alpha particles (helium nuclei) and gamma rays (radiation similar to X rays) and has a half-life of 470 years.



A team led by American chemist Glenn T. Seaborg discovered americium in 1944.

Americium-241 is made in large quantities in nuclear reactors. The intense gamma radiation it emits has made it useful as a portable source of X rays. It is also used in home smoke detectors, in which alpha particles emitted by this isotope ionize the surrounding air by stripping electrons from gas molecules. Ionized air is a fairly good conductor of electricity; smoke particles in the air reduce its electrical conductivity and generate a signal that triggers the alarm.

CURIUM



Atomic Number **96**

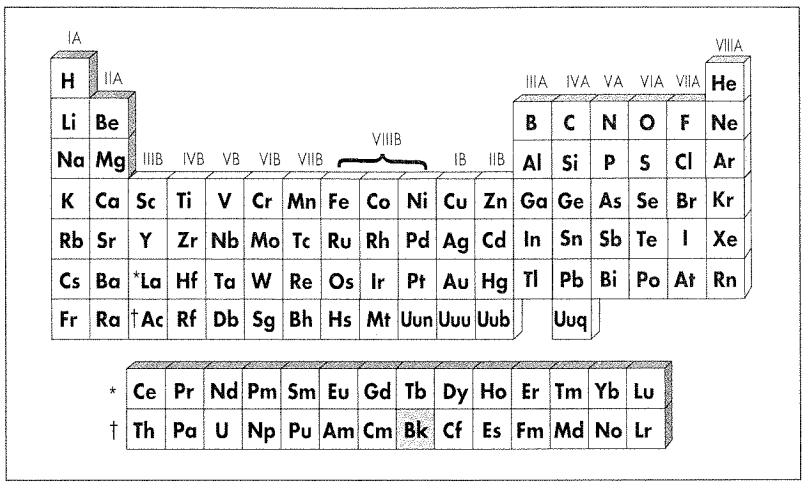
Chemical Symbol **Cm**

Group **IIIB—Transition Element (The Actinides)**

Cm

Curium is a transuranium element, one of the elements that follow uranium in the periodic table. Like all of the transuranium elements, it is artificially made. It was discovered in 1944 by Glenn T. Seaborg, Ralph A. James, and Albert Ghiorso, who produced it by using a cyclotron at the University of California at Berkeley to bombard plutonium-239 with alpha particles (helium nuclei). The chemical identification of curium took place during World War II at the former Metallurgical Laboratory of the University of Chicago, known today as the Argonne National Laboratory. Seaborg, James, and Ghiorso named their new element in honor of Pierre and Marie Curie, the famous couple who discovered radium and polonium.

Curium is a silvery-white metal that is fairly reactive. Oxide and curium fluoride compounds of the element have been prepared and studied. Curium has 14 known isotopes, all of which are radioactive. The first to be discovered, and the third transuranium element to be made, was curium-242, with a half-life of only 163 days. The most stable of the curium isotopes is curium-247 with a half-life of 16 million years. A great deal of interest has been shown in the possibility of using curium-242 and curium-244 as sources of energy in remote areas. Fairly large quantities of curium-244, with a half-life of 18 years, can be made by subjecting plutonium to neutron bombardment in a nuclear reactor. The radiation these isotopes emit can be easily converted into heat and then into electricity by thermoelectric devices. Although it has a relatively short half-life, the power output of curium-242 is an impressive two to three watts per gram. These compact units are useful for pacemakers, remote navigational buoys, and space missions.

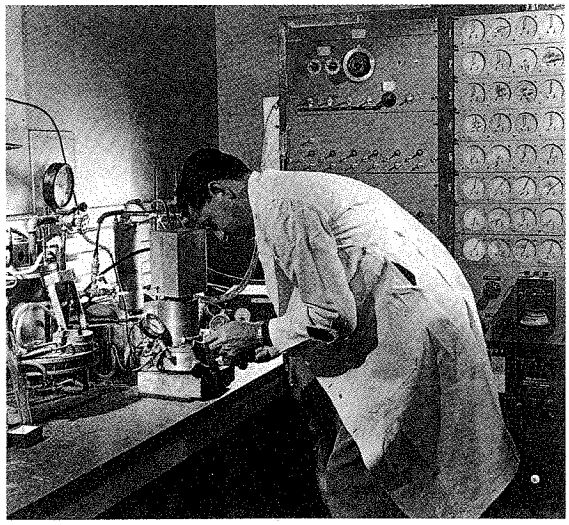


BERKELIUM

Bk

Berkelium, like so many of the actinium transition elements, was discovered in Berkeley, California. The discoverers of the element, the team consisting of Glenn T. Seaborg, Stanley Thompson, and Albert Ghiorso, named it in honor of the city. They synthesized it in 1949 by using a cyclotron to bombard a sample of americium-241 with alpha particles (helium nuclei). Berkelium-243, the isotope they produced, was the fifth actinide to be created in a laboratory. It has a half-life of only 4.6 hours, hardly long enough to study in any detail.

Fourteen more isotopes of berkelium have been synthesized, and all are radioactive. The longest-lived is berkelium-249, with a half-life of 314 days, which was made by subjecting curium-244 to intense neutron irradiation. Using berkelium-249, it was possible in 1962 to produce 3 billionths of a gram of berkelium chloride, but the pure metal has never been isolated. Given its scarcity, it is not surprising that no commercial or scientific applications for berkelium have been developed.



In 1949, Albert Ghiorso (above) and two of his colleagues produced berkelium using the cyclotron at the University of California at Berkeley.

Atomic Number **97**

Chemical Symbol **Bk**

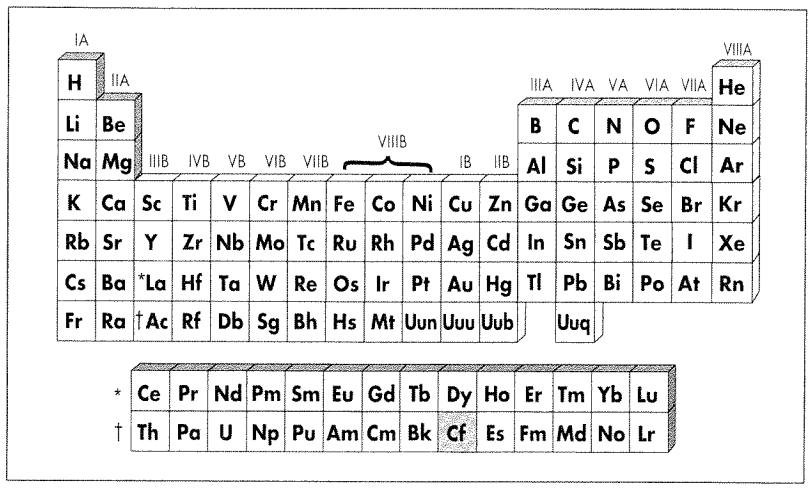
Group **IIIB—Transition Element (The Actinides)**

CALIFORNIUM

Atomic Number **98**

Chemical Symbol **Cf**

Group **IIIB—Transition Element (The Actinides)**



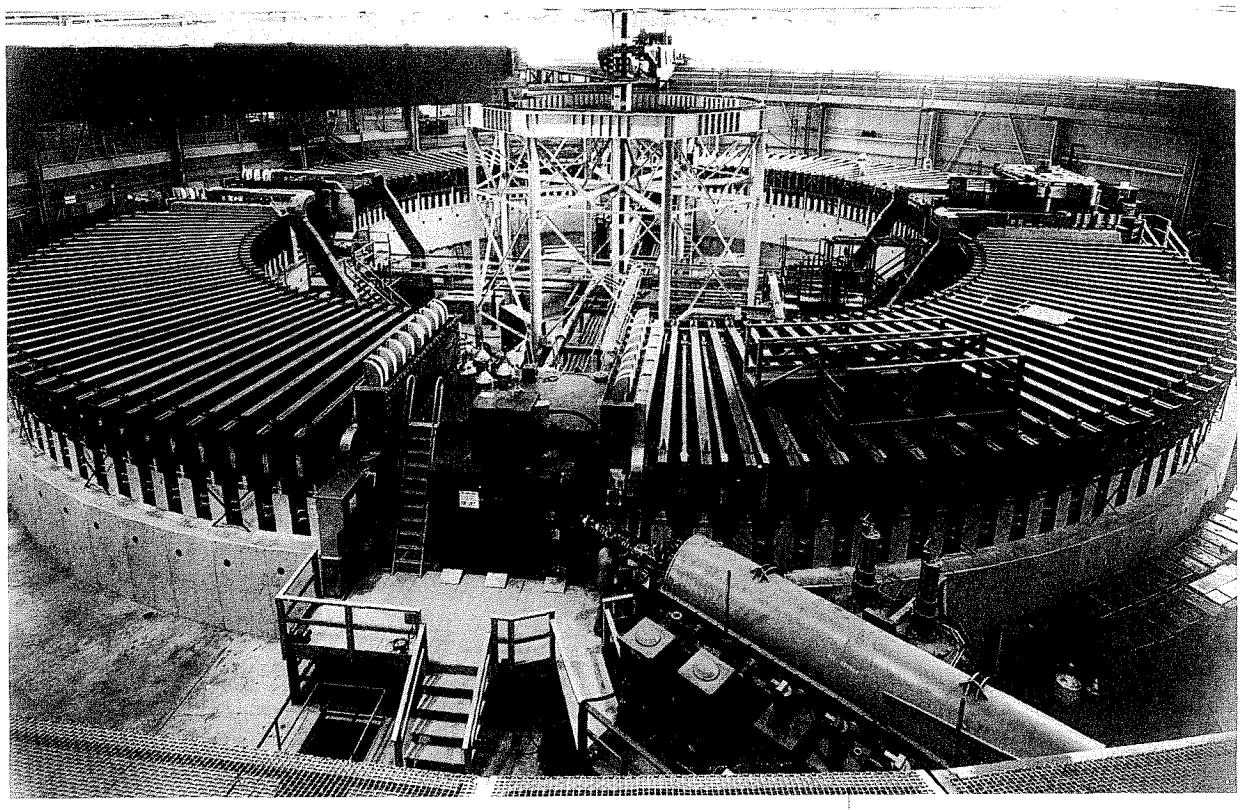
Cf

Californium was discovered in 1950 by the same team that discovered berkelium, but with one new member. In 1950, Stanley Thompson, Kenneth Street, Jr., Albert Ghiorso, and Glenn T. Seaborg synthesized the sixth transuranium element to be made in a laboratory by using the cyclotron at the University of California at Berkeley to bombard curium-242 with alpha particles (helium nuclei). They named the new element after the state of California.

The first isotope of californium to be made was californium-245, with a half-life of only 44 minutes. Some 14 other isotopes of the element have since been made, usually by subjecting berkelium to the intense neutron radiation produced in a nuclear reactor.

The most interesting isotope of californium to date has been californium-252, an isotope that spontaneously emits neutrons. With a half-life of 2.65 years, it is extremely radioactive and must be handled with great care.

Neutron sources are ordinarily hard to come by. Either a nuclear reactor is required to generate neutrons from an element, or some highly radioactive emitter of alpha particles (helium nuclei), such as plutonium, must be mixed with beryllium powder. The discovery of an extremely portable neutron source such as californium-252 suggests many possible applications for it. It can easily be taken into the field for the analysis of oil-bearing layers of earth or for the mining of gold and silver by activation. The activation process occurs because neutrons, having no electrical charge, are easily absorbed by the nuclei of other atoms, rather than being repelled by their electron shells. Once their nuclei have been rendered radioactive in this way, it is often easier to identify



The cyclotron at the University of California at Berkeley's Lawrence Berkeley Laboratory. A cyclotron uses a strong magnetic field and an electric field of alternating polarity to accelerate particles along a spiral path to high velocities.

gold or silver by examining their radiation characteristics than by analyzing them chemically.

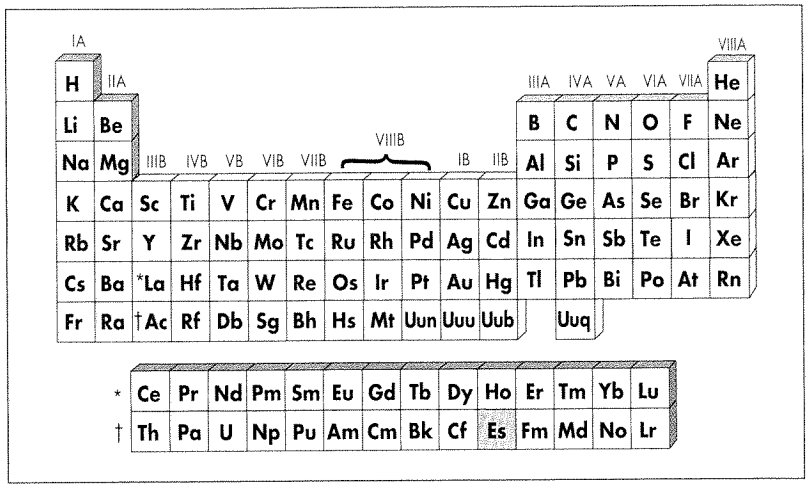
The U.S. Nuclear Regulatory Commission, in an effort to encourage its use, is making californium-252 available at a cost of $10 per millionth of a gram. This seemingly microscopic quantity of the isotope is often sufficient for many applications, particularly for demonstrations of neutron reactions in college and university laboratories.

EINSTEINIUM

Atomic Number **99**

Chemical Symbol **Es**

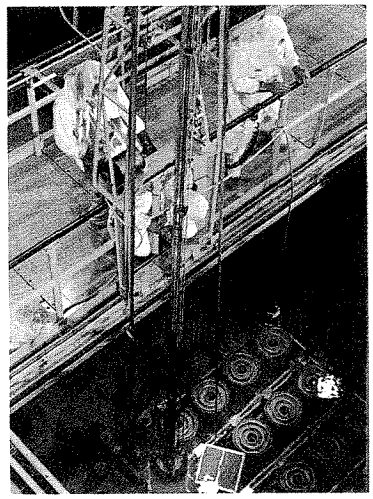
Group **IIIB—Transition Element (The Actinides)**



Es

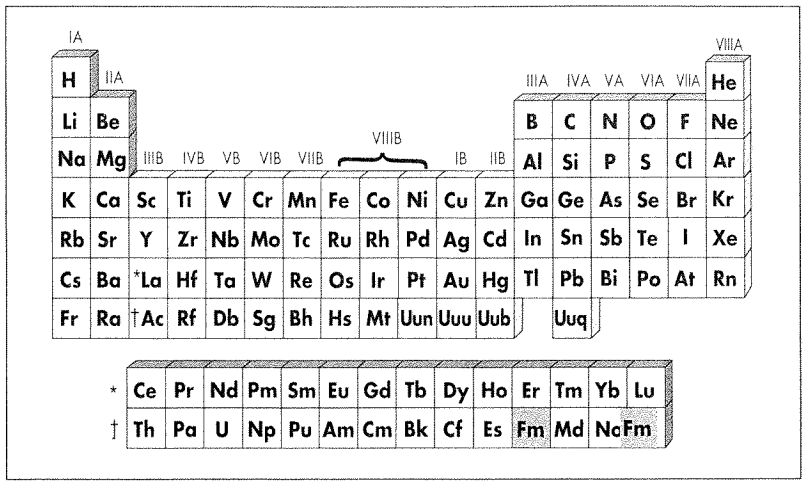
Einsteinium, named for the celebrated physicist Albert Einstein, was discovered by the American physicist Albert Ghiorso and his coworkers in 1952. They found the seventh transuranium element, subsequently called einsteinium-253, while investigating the debris of the first hydrogen bomb explosion in the Pacific Ocean. The sample they recovered weighed only one hundred millionth of a gram, and the isotope had a half-life of 20 days. The discovery was not announced until 1955 because information about atomic testing was restricted by the United States at that time.

Some 16 isotopes of einsteinium are now known. The most stable of these is einsteinium-254, with a half-life of 252 days. Most of the known isotopes of einsteinium have been produced in the High Flux Isotope Reactor at Oak Ridge National Laboratory in Tennessee by irradiating plutonium-239 with intense beams of neutrons. The plutonium samples are often left in the reactor for several months before the chemical separation of einsteinium can be efficiently performed. At Oak Ridge, the reactor used for producing transuranium elements lies beneath a large pool of water. It is possible to stand above it and see the eerie blue light produced by the high energy radiation from these elements.



Workers at Oak Ridge National Laboratory carefully remove plutonium samples from the High Flux Isotope Reactor.

Einsteinium is extremely radioactive, and great care must be taken when handling it.



FERMIUM

Fm

Like einsteinium, the element that precedes it in the periodic table, fermium, the eighth transuranium element, was identified in 1952 by the physicist Albert Ghiorso and his coworkers. As had also been the case with einsteinium, they discovered fermium-252, with a half-life of 20 hours, in the debris formed by the first hydrogen bomb explosion in the Pacific Ocean. They named the element in honor of the celebrated Italian-born physicist Enrico Fermi, who in 1944 had generated the first self-sustaining nuclear reaction in a facility located under the grandstand of the athletic field at the University of Chicago. For security reasons, the discovery of fermium was not announced until 1955.

Eighteen isotopes of fermium are now known to exist, all of which are intensely radioactive. They are usually synthesized by subjecting elements such as uranium and plutonium to intense neutron bombardment. In a neutron-rich environment such as the High Flux Isotope Reactor at Oak Ridge National Laboratory in Tennessee, or in the center of a thermonuclear explosion, an element such as uranium can undergo successive neutron capture, often absorbing as many as 16 or 17 neutrons, to produce the heavy transuranium elements.

The longest-lived of the fermium isotopes is fermium-257, with a half-life of about 82 days. It can be produced in amounts large enough to be studied. No commercial or research applications for fermium have yet been developed.

Atomic Number **100**

Chemical Symbol **Fm**

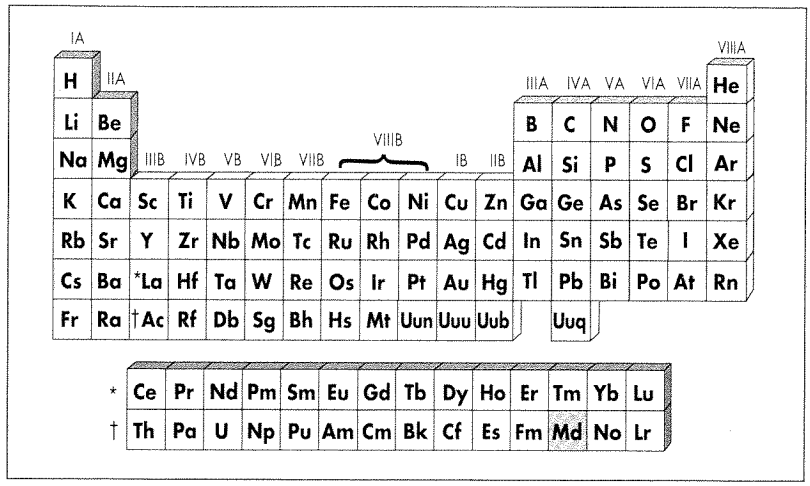
Group **IIIB—Transition Element (The Actinides)**

MENDELEVIUM

Atomic Number **101**

Chemical Symbol **Md**

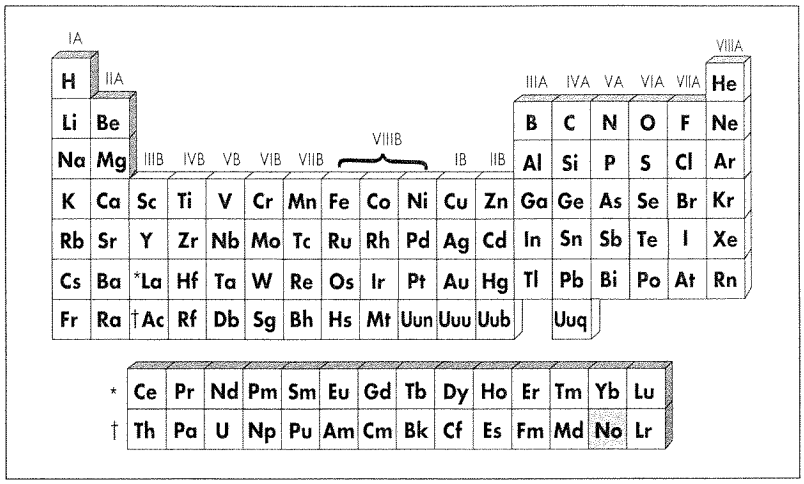
Group **IIIB—Transition Element (The Actinides)**



Md

The ninth artificial transuranium element was discovered in 1955 by a team of scientists led by the physicist Albert Ghiorso at the University of California at Berkeley. Continuing their search for ever heavier elements, they used the cyclotron at Berkeley to bombard einsteinium-253 with alpha particles (helium nuclei), and eventually fabricated mendelevium-256, with a half-life of 77 minutes. The element was named for the Russian chemist Dmitry Mendeleyev, the creator of the periodic table. The small amounts of mendelevium-256 that were originally produced at Berkeley made its identification very difficult. It is often said that this element was synthesized one atom at a time.

Some 13 isotopes of mendelevium are now known. All are radioactive, with the longest-lived being mendelevium-258, which has a half-life of 56 days. Only trace amounts of these isotopes have been made, and little is known of their chemistry. They have no known applications.



NOBELIUM

No

The sequence of events that led to the discovery of the transuranium element nobelium is somewhat confused. The work that led to the first claim of its discovery by a team of scientists working at the Nobel Institute in Stockholm was shown to be faulty. Subsequently, in 1958, the physicist Albert Ghiorso and his colleagues, working at the University of California at Berkeley, unambiguously identified nobelium-254, which has a half-life of 55 seconds.

In creating nobelium-254, the Berkeley group abandoned the cyclotron, the accelerator they had previously used so successfully to manufacture a host of transuranium elements. Instead, they bombarded a sample of curium-244 and curium-246 with carbon-12 ions using the Heavy Ion Linear Accelerator (HILAC) at Berkeley. Their success in synthesizing nobelium-254 was confirmed by a group of Russian physicists working at Dubna, in the Soviet Union. Ghiorso and his coworkers decided to retain the original name of the element, which had been assigned to it by the Stockholm group in honor of Alfred Nobel, the inventor of dynamite.

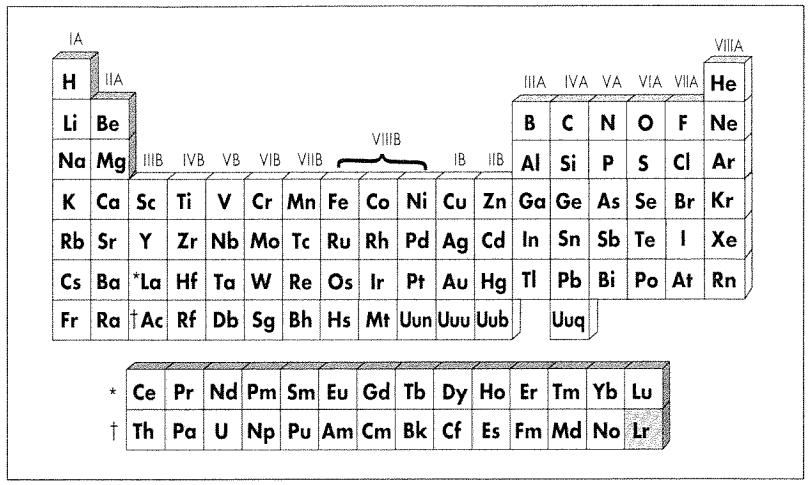
Eleven isotopes of nobelium have so far been synthesized, and all are radioactive. Nobelium-259 is the longest-lived of the isotopes, with a half-life of 57 minutes. Nobelium has not been produced in quantities large enough to permit the study of its chemical and physical properties.

Atomic Number **102**

Chemical Symbol **No**

Group **IIIB—Transition Element (The Actinides)**

LAWRENCIUM



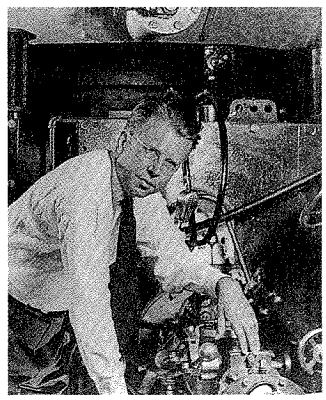
Lr

Continuing their astonishing string of discoveries at Berkeley, a team of scientists led by Albert Ghiorso synthesized and identified lawrencium, a new transuranium element heavier than nobelium, in 1961.

Using the Heavy Ion Linear Accelerator (HILAC) at the University of California, they bombarded a mixture of three isotopes of californium with boron-10 and boron-11 ions. The target weighed only a few millionths of a gram. Careful analysis of the reaction indicated that the Berkeley team had manufactured lawrencium-258, an isotope of lawrencium with a half-life of 4 seconds. It was named in honor of Ernest O. Lawrence, the inventor of the cyclotron and a former professor at the University of California.

Eight isotopes of lawrencium have been synthesized to date, with the longest-lived being lawrencium-256, which has a half-life of about 30 seconds.

Very little is known about the chemical and physical properties of lawrencium, although Ghiorso and his colleagues, working with unbelievably small amounts of lawrencium equivalent to a few atoms managed a very preliminary study of the oxidation behavior of the element. They found that the chemical behavior of lawrencium seemed to resemble that of the lighter actinides.

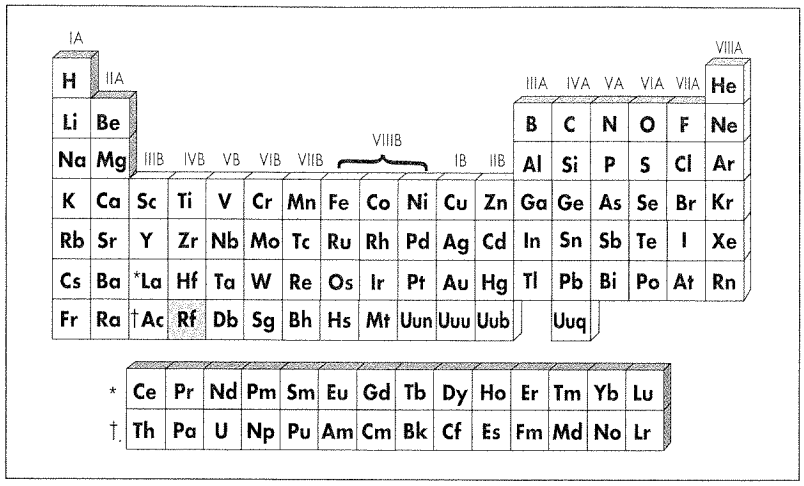


Element 103 was named lawrencium in honor of Ernest O. Lawrence, the inventor of the cyclotron.

Atomic Number **103**

Chemical Symbol **Lr**

Group **IIIB—Transition Element (The Actinides)**



RUTHERFORDIUM

Atomic Number **104**

Chemical Symbol **Rf**

Group **IVB—**
A Transactinide

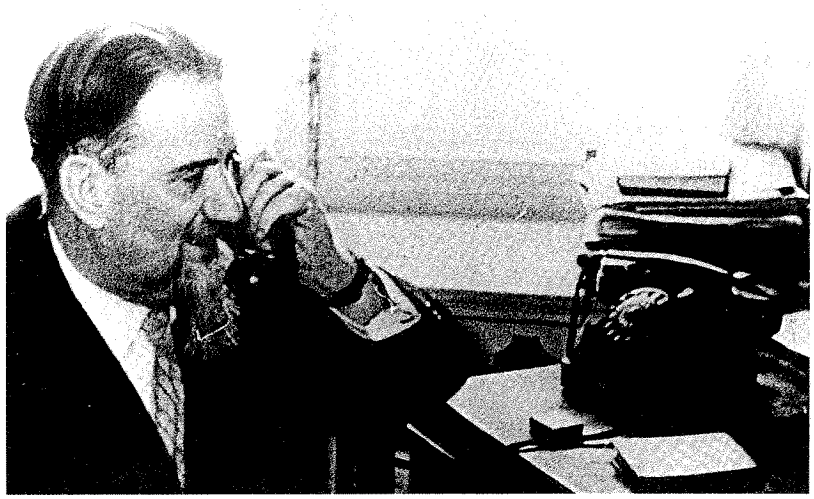
Rf

A history of competing claims confused the naming of element 104, the first of the elements beyond the actinides in the periodic table, which are usually called transactinide elements. The honor of naming a new element usually goes to the discoverer. When the discovery is disputed, a system of nomenclature designed by the International Union of Pure and Applied Chemistry (IUPAC) is used to identify the atomic number of the new element. For this purpose, IUPAC has recommended the use of the following code, which assigns a syllable to each digit in an element's atomic number, with all names ending in *ium*.

0 = nil	5 = pent
1 = un	6 = hex
2 = bi	7 = sept
3 = tri	8 = oct
4 = quad	9 = enn

The dispute over the discovery of element 104 began in 1964, when a team of Russian scientists working at the Joint Institute for Nuclear Research at Dubna, in the Soviet Union, reported that they had created a new element, unnilquadium-260, with a half-life of three-tenths of a second. The original, ungainly name of "un-nil-quad-ium" (1-0-4-ium) was based on the IUPAC system; its chemical symbol was Unq. In their experiments, the Russian scientists bombarded plutonium-242 with neon-22 ions. They subsequently suggested the name kurchatovium for the new element, in honor of the head of Soviet Research, Ivan Kurchatov. The evidence for this discovery, however, was not very convincing to the international community.

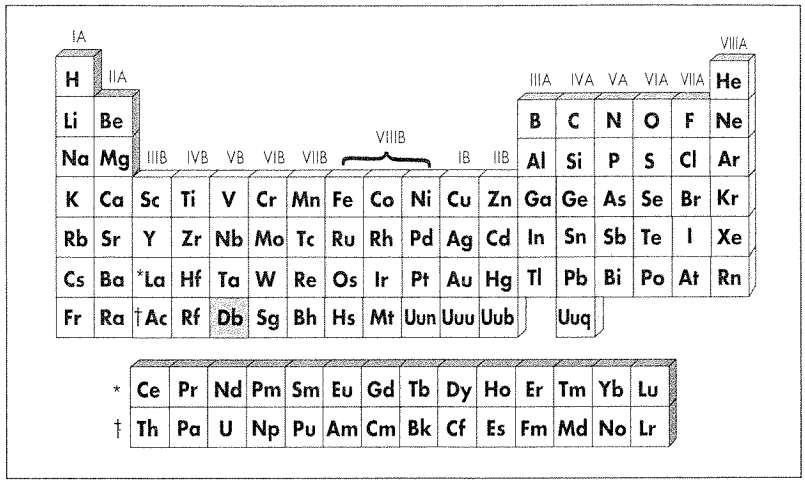
Then, in 1969, a team led by the American physicist Albert Ghiorso bombarded californium-249 with carbon-12 ions using



Soviet scientists claimed credit for discovering both rutherfordium (for which they proposed the name kurchatovium in honor of Soviet chemist Ivan Kurchatov, above) and hahnium, now named dubnium. However, their claims were rejected by the International Union of Pure and Applied Chemistry.

the Heavy Ion Linear Accelerator (HILAC) at the University of California at Berkeley. They reported the positive identification of unnilquadium-257, an isotope with a half-life of four to five seconds. Large amounts of this isotope have subsequently been detected. The Berkeley group proposed naming the element rutherfordium, in honor of the distinguished New Zealand physicist Ernest Rutherford, whose work had been instrumental in the early understanding of the atom. The American claim won the day, and the name rutherfordium is now the name endorsed by the American Chemical Society.

Six isotopes of rutherfordium, all radioactive, have so far been identified. Rutherfordium-261, the longest lived, has a half-life of 62 seconds. Little is known about the chemical or physical properties of the element.



DUBNIUM

Atomic Number **105**

Chemical Symbol **Db**

Group **VB—**
A Transactinide

Db

Disputed claims of its discovery have plagued element 105, previously known as unnilpentium (see the section on rutherfordium for a description of the naming process used for new elements). In 1967, a group of Russian scientists working at the Joint Institute for Nuclear Research at Dubna, in the Soviet Union, bombarded americium-243 with the heavy ions of neon-22. They claimed to have produced a few atoms each of unnilpentium-260 and unnilpentium-261.

In 1970, a team headed by the American physicist Albert Ghiorso bombarded californium-249 with heavy nitrogen-15 ions using the Heavy Ion Linear Accelerator (HILAC) at the University of California at Berkeley and positively identified unnilpentium-260, with a half-life of 1.6 seconds, among the products of the bombardment. Ghiorso and his colleagues attempted to duplicate the Russian experiment, but this proved fruitless. The Berkeley group proposed to name their new element hahnium in honor of Otto Hahn, the German chemist who discovered nuclear fission.

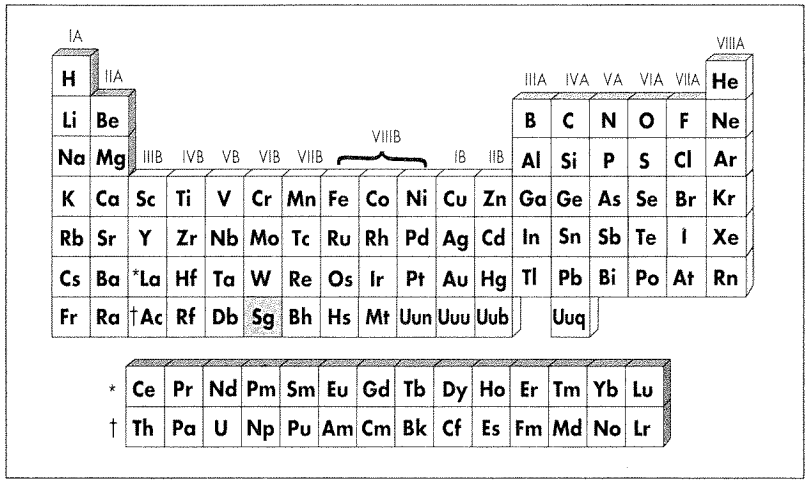
In view of the overwhelming evidence presented by the Berkeley team, the American Chemical Society officially endorsed the name of hahnium for unnilpentium. Ghiorso and his team continued their work with the element and produced two new isotopes in 1971. In 1997 the International Union of Pure and Applied Chemistry decided to change the name of this element to dubnium. There are now five known isotopes of dubnium, and all are radioactive. The longest-lived is dubnium-262, with a half-life of 34 seconds. Its chemical and physical properties are unknown.

SEABORGIUM

Atomic Number **106**

Chemical Symbol **Sg**

Group **VIB**—
A Transactinide



Sg

Like the two preceding elements in the periodic table, the claim of discovery of element 106, along with the right to name it, was a subject of dispute. After a waiting period of some 10 years, an international group of referees finally approved the name unnilhexium for the new element (see the discussion of how new elements are named in the section on rutherfordium). In March 1994, the American Chemical Society announced that the new element was to be named seaborgium in honor of Glenn T. Seaborg, who was a member of the team that discovered this element and who won the 1951 Nobel Prize in chemistry for his work in the discovery of plutonium and nine other artificially created elements.

In June 1974, a team of Russian scientists working at the Joint Institute for Nuclear Research in Dubna, in what was then the Soviet Union, reported that they had produced unnilhexium by bombarding lead-206 with highly energetic heavy chromium-54 ions produced in their cyclotron. Because other experiments failed to confirm this result, their claim of discovery was in doubt.

At about the same time, a team of scientists at the Lawrence Livermore Laboratory and the University of California at Berkeley triumphantly reported the unambiguous discovery of unnilhexium-263, with a half-life of nine-tenths of a second. In generating the element, the California scientists used the Berkeley Heavy Ion Linear Accelerator (HILAC) to bombard californium-249 with oxygen-18. They produced only a tiny amount of element 106, however, so that international regulatory groups delayed in resolving the conflicting claims of prior discovery of the new element.

The technique that was used by the California group to identify the element is quite fascinating. It employed an elaborate apparatus previously used to discover rutherfordium and hahnium, in which jets of air propelled the products of nuclear reactions to the top of a vertical wheel, where they were deposited. As the wheel rotated, detectors wired to computers and mounted around the wheel then identified these products by monitoring the half-lives of the decay products to which they gave rise.

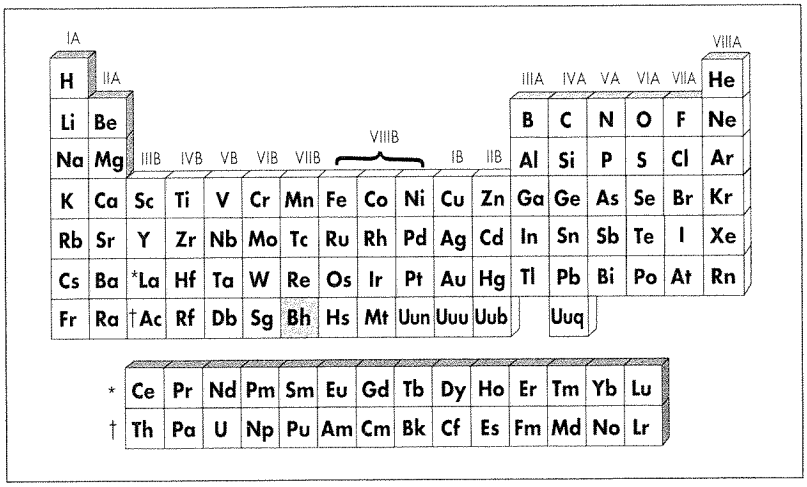
In 1993, scientists at the Lawrence Livermore and Berkeley laboratories repeated their experiment, confirming the original result, and established their claim to the discovery of element 106. Four isotopes of seaborgium have been identified; seaborgium-263 is the one with the longest half-life.

It is interesting to note that the naming of seaborgium by a group at the University of California at Berkeley set off an international disagreement on the naming of many of the recently discovered elements. Although the honor of naming an element had always been granted to its discoverers, an international commission organized by the International Union of Pure and Applied Chemists (IUPAC) voted at the end of August 1994 to disallow the name on the grounds that Glenn T. Seaborg was still alive. The commission went even further and proposed an entirely new list of names for elements 104 to 108.

After three years of meetings and discussions, a compromise was finally agreed to by an international group of chemists during the summer of 1997. The names now accepted by the IUPAC are the ones used in this book.

In July 1997, a consortium of scientists led by Dr. Matthias Schadel at the Heavy Ion Research laboratory (G.S.I.) in Darmstadt, Germany, reported that they had managed to do chemical analysis on seaborgium. This was the first time that any such work had ever been done, and it was done with an incredibly small sample of only seven seaborgium atoms. They found that seaborgium seemed to have chemical properties consistent with its position in the periodic table. That is, it produced reaction products similar to molybdenum and tungsten, the elements just above it in column 6 of the table. This came as a surprise, as elements 104 and 105 do not appear to react in ways consistent with their position in the table. It is as yet not known why seaborgium behaves differently from these two lighter atoms.

BOHRIUM



Bh

In 1976, a team of Russian scientists at the Joint Institute for Nuclear Research at Dubna in the Soviet Union announced that they had synthesized unnilseptium, element number 107. They claimed to have created the new element by bombarding bismuth-204 with heavy ions of chromium-54 that had been accelerated in a cyclotron. Their claim was rejected.

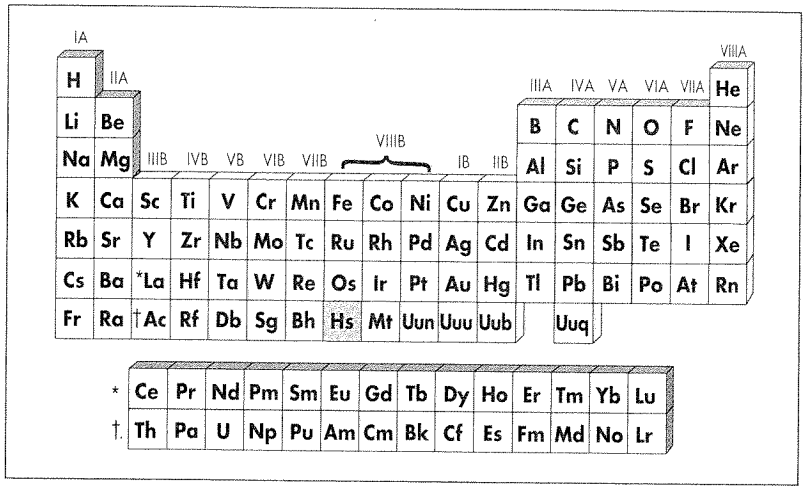
In 1981, physicists Peter Armbruster and Gottfried Munzenberg, working in Darmstadt, Germany, also announced the creation of unnilseptium. They proposed the name *nielsbohrium* for this element, in honor of the great Danish physicist Niels Bohr, whose work led to the modern concept of the atom. Their research claims were confirmed in 1992 by the International Union of Pure and Applied Chemistry, and the American Chemical Society approved the name the German team proposed for the new element. In 1997 the International Union of Pure and Applied Chemistry decided to change the name of this element to bohrium.

The chemical and physical properties of the isotopes of bohrium are unknown.

Atomic Number **107**

Chemical Symbol **Bh**

Group **VIIB—**
A Transactinide



HASSIUM

Hs

In 1984, a team led by physicists Peter Armbruster and Gottfried Munzenberg, working in Darmstadt, Germany, announced the discovery of unniloctium, element 108. This was the same team that had synthesized bohrium.

The name that the discoverers proposed for this new element was hassium, for *hassia,* the Latin name for the German state of Hesse. In 1992, the International Union of Pure and Applied Chemistry confirmed the research claims of the German team and the American Chemical Society endorsed the proposed name. The chemical and physical properties of hassium are unknown.

The German physicists Peter Armbruster (back row, second from right) and Gottfried Munzenberg (front) led the team that discovered elements 107, 108, 109, 110, and 111.

Atomic Number **108**

Chemical Symbol **Hs**

Group **VIIIB—**
A Transactinide